Abstract

Combat sport athletes typically engage in a process called making-weight, characterised by rapid weight loss (RWL) and subsequent rapid weight gain (RWG) in the days preceding competition. These practices differ across each sport, but no systematic comparison of the size of the changes in body mass exists. The aim was to determine the magnitude of RWL and RWG in combat sport athletes preparing for competition. The review protocol was preregistered with PROSPERO [CRD42017055279]. In eligible studies, athletes prepared habitually with a RWL period ≤7 days preceding competition. An electronic search of EBSCOhost (CINAHL Plus, MEDLINE, SPORTDiscus) and PubMed Central was performed to July 2018. Sixteen full-text studies (total 4432 participants, 156 female, 4276 male) were included, providing data from five combat sports (boxing, judo, mixed martial arts (MMA), taekwondo and wrestling). Three studies reported RWL and fourteen studies reported RWG. Duration permitted for RWG ranged 3–32 hours. The largest changes in body mass occurred in two separate MMA cohorts (RWL 7.4 ± 1.1kg [~10%], RWG 7.4 ± 2.8kg [11.7 ± 4.7%]). The magnitude of RWG appears to be influenced by the type of sport, competition structure, and recovery duration permitted. A cause for concern is the lack of objective data quantifying the magnitude of RWL. There is insufficient evidence to substantiate the use of RWG as a proxy for RWL, and little data are available in females. By engaging in RWG, athletes are able to exploit rules to compete up to three weight categories higher than at the official weigh-in.

Key Words/Phrases

Weight Cycling
Weight Cutting
Making Weight

Manuscript Contents

1 Introduction

Across combat sports, athletes compete in predetermined weight categories to be matched with an opponent of equal body mass, body size, strength, and power (Franchini et al., 2012). However, for competition, athletes typically engage in a process called making-weight, characterised by rapid weight loss (RWL) and subsequent rapid weight gain (RWG) in the days preceding the event. Making-weight has been documented in mixed martial arts (MMA), boxing, judo, Brazilian jiu-jitsu (BJJ), karate, Muay Thai, taekwondo, and wrestling (Artioli et al., 2010a; Brito et al., 2012; Matthews & Nicholas, 2017; Reale et al., 2018). It enables athletes to compete in weight categories that are typically incompatible with their "walk-around" body mass (Smith et al., 2001). As such many athletes undergo cyclical phases of dieting, from periods of negative energy balance (pre-competition) to positive energy balance (post-competition) (Mendes et al., 2013). The duration of each cycle is dependent on the type of combat sport and competition format. For example, MMA athletes typically compete in single-bout events and may undergo RWL and RWG two to four times per year (Andreato et al., 2014). Whereas in judo, multiple-bout tournaments are held frequently which results in the need to make weight on a fortnightly or monthly basis (Artioli et al., 2010a). This presents different patterns of weight management behaviours which may influence RWL and RWG.

The acute effects of RWL alone reduce physical performance in combat sport athletes, likely due to hypohydration from voluntary perspiration and fluid restriction (Filaire et al., 2001; Smith et al., 2001). However, studies allowing athletes to refeed and rehydrate *ad libitum* following RWL have shown no physical performance deficits in modality-specific tests (Artioli et al., 2010c; Fogelholm et al., 1993). It is possible that RWL and subsequent RWG could lead to performance enhancement, through a size and strength advantage over a lighter opponent. There is empirical research to suggest that athletes who undergo greater RWG are more successful in wrestling and judo competition (Alderman et al., 2004; Reale et al., 2016a; Wroble & Moxley, 1998). However the evidence base is equivocal, with studies in wrestling (Horswill et al., 1994; Utter & Kang, 1998) and boxing (Daniele et al., 2016; Reale et al., 2016b) reporting no effect. The disparity may reflect technical differences between grappling and striking-based sports and the level of competition (Reale et al., 2016b). It is noteworthy that no data show lighter competitors to have greater success in competition.

The practice of making-weight has resulted in several fatalities. The 1997 events in which three collegiate wrestlers lost their lives have been well documented, whilst preparing for competition the athletes experienced cardiorespiratory and thermoregulatory complications, secondary to RWL (CDC, 1998). In 2013 and 2016, two MMA athletes lost their lives in the same manner, one of whom was found collapsed in a sauna after suffering a fatal cerebrovascular event (Crighton et al., 2015). More recently, a young British athlete died while training in a heavy tracksuit in Thailand. He had been reportedly making-weight for a Muay Thai bout later that evening (Tangprasert & Marukatat, 2017).

In the US, sporting bodies have issued position papers (Case et al., 2016; Turocy et al., 2011) and weight-management programs

(Oppliger et al., 2006) to regulate the practice of making-weight in wrestling. Elsewhere, case studies and commentary papers have provided guidance on how to make weight whilst avoiding the negative health effects associated with traditional RWL strategies (Langan-Evans et al., 2011; Morton et al., 2010; Reale et al., 2017). Despite these recommendations, athletes continue to engage in potentially harmful RWL practices.

Several narrative reviews have discussed the prevalence and effects of making-weight (Franchini et al., 2012; Gann et al., 2015; Khodaee et al., 2015), but it remains unknown whether RWL and RWG practices are comparable across combat sports and what influences the magnitude of body mass manipulation. Knowledge of these factors will provide key information to help implement rule changes to ensure the health, safety, and wellbeing of competitors. Therefore, the aim of the study was to determine the magnitude of RWL and RWG in combat sport athletes preparing for competition.

2 Methods

2.1 Protocol

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were followed (Moher et al., 2009). A Peer Review of Electronic Search Strategies (PRESS) was carried out to enhance internal validity of the methods (McGowan et al., 2016). The study protocol was preregistered on the PROSPERO International Prospective Register of Systematic Reviews [CRD42017055279].

2.2 Eligibility Criteria

Inclusion criteria were limited to combat sport athletes preparing for a competitive event. The magnitude of RWL or RWG must have been reported as an outcome measure using an official competition body mass measurement or, in the case of self-report data, based on the athletes reported competition body mass. Eligible study designs were observational, uncontrolled and non-randomised by nature. Trials with an intervention where the data from the control arm could be extracted were suitable for inclusion, providing the control athletes had prepared habitually for competition. Studies were excluded if (1) RWL was quantified over a period >7 days; (2) reported RWL or RWG was not based on an official competition body mass, and (3) if preparation was not habitual e.g. RWL targets were imposed by the researchers. Non-English language papers were initially shortlisted for full-text screening, however, if the full-text was not available in English the study was excluded from the qualitative synthesis. No restrictions on date, age, sex, or country were applied.

2.3 Definitions of Terminology

The time permitted for RWL was any change in body mass in the ≤7 days preceding competition. Consensus in the literature is that this period captures the greatest degree of RWL (Artioli et al., 2010a; Khodaee et al., 2015; Matthews & Nicholas, 2017). The term "recovery duration" was used to describe the time from the official weigh-in to commencing competition i.e. the time permitted for RWG to occur. Some studies have used the terms "acute weight loss", "acute weight gain" and "body mass regain" to describe changes in body mass. However, for consistency "RWL" and "RWG" have been used throughout this manuscript.

2.4 Information Sources and Search Strategy

A systematic electronic search of EBSCOhost (CINAHL Plus, MEDLINE, SPORTDiscus) and PubMed Central was performed from the earliest record to July 20, 2018. Searches were limited to peer-reviewed articles only. A standardised search strategy based on a word string using Boolean operators was used (table 1). Reference lists and citations of included studies were searched for additional eligible publications.

[INSERT TABLE 1 HERE]

2.5 Study Selection and Data Extraction

Following removal of duplicates, titles and abstracts of the identified articles were reviewed (JJM) for potential eligibility. The full texts of potentially eligible articles were examined independently by two authors (JJM and ENS) based on the inclusion and exclusion criteria. Strong agreement was found for initial study selection between authors (Cohen's kappa coefficient, κ = 0.702, 85% agreement). Disagreements (n = 6) were resolved via consensus-based discussion between the two reviewers, remaining disagreements (n = 2) were referred to a third reviewer (MSG). Data were extracted (JJM) using a standardised form based on guidelines from the Centre for Reviews and Dissemination (CRD, 2009). The authors of each included study were not contacted for further information.

2.6 Data Items and Summary Measures

Data extracted from studies included: (1) sample size and participant characteristics (age, height, body mass, training/competitive experience, weight category, level and location of competition); (2) the magnitude of RWL or RWG; and (3) the duration permitted for RWL or RWG. For continuous outcomes (RWL and RWG) all studies used the same measurement scale (body mass in kilograms or pounds) and mean difference values were reported.

2.7 Assessment of Risk of Bias in Individual Studies

A modified version of the Downs and Black (1998) checklist was used to assess the risk of bias within included studies. The checklist was reduced to suit the study designs included: non-randomised, uncontrolled, and with no intervention. Questions assessing grouping, randomisation, blinding, and aspects of an intervention were deemed not applicable, remaining items were marked as yes (= 1), no or unable to determine (= 0). From the original 27 items 16 were not applicable, and 11 items were used from the following sub-groups: reporting (items 1, 2, 3, 6, 7, and 10), external validity (items 11 and 12), and internal validity bias (items 16, 18, and 20) (table 2). The qualitative approach was taken to give an appraisal of each study without compromising the validity and reliability of the checklist by using a non-validated scoring system. Two authors (JJM and ENS) independently assessed the risk of bias for each study, showing strong agreement between raters (Cohen's kappa coefficient, $\kappa = 0.807$, 92% agreement). Disagreements (n = 13 of 176 criteria) were resolved by consensus-based discussion between the two reviewers, remaining disagreements (n = 1 of 176 criteria) were referred to a third reviewer (MSG).

2.8 Qualitative Data Synthesis

Statistical pooling of the data was not undertaken due to the nature of the research question and the heterogeneity of the available studies. Instead, findings have been synthesised as a narrative summary using tables of evidence.

3 Results

3.1 Study Selection

The search strategy and study selection process resulted in 16 full-text studies for inclusion in the review (figure 1).

[INSERT FIGURE 1 HERE]

3.2 Study and Participant Characteristics

The included studies were published between 1994 and 2017 (table 3). Five combat sports were represented (wrestling n = 8, boxing n = 2, judo n = 1, MMA n = 3, taekwondo n = 1, and combined sports n =1) encompassing data from a total of 4432 participants (156 females, 4276 males). Five studies did not describe participant characteristics (Alderman et al., 2004; Kordi et al., 2012; Scott et al., 1994; Utter & Kang, 1998; Wroble & Moxley, 1998). Two studies reported baseline body mass only, with no further characterisation of the participants (Reale et al., 2016a, 2016b). In the remaining nine studies, the mean age of participants ranged from 13 ± 2 years to 28.5 ± 5.1 years.

Four studies observed single bout events (Coswig et al., 2015; Daniele et al., 2016; Jetton et al., 2013; Matthews & Nicholas, 2017). All remaining studies (n = 12) recorded data from national and international tournaments. Most were held over multiple days (n = 7), it was not possible to determine the tournament format (i.e. days) in the remaining studies (n = 5) (table 3).

Six studies excluded heavyweight athletes, owing to the evidence that athletes in the heavyweight categories typically do not engage in RWL or are not required to make weight (Daniele et al., 2016; Kordi et al., 2012; Pettersson & Berg, 2014; Reale et al., 2016a, 2016b; Wroble & Moxley, 1998). Scott et al. (1994) included heavyweight athletes but presented data with and without their inclusion.

3.3 Risk of Bias in Individual Studies

All included studies were appraised using the Downs and Black (1998) risk of bias tool (table 2).

[INSERT TABLE 2 HERE]

3.4 Results of Individual Studies

3.4.1 Rapid Weight Loss

Three studies reported the magnitude of RWL (table 3). Matthews & Nicholas (2017) objectively quantified RWL in MMA. Whereas, Coswig et al. (2015) and Irfan (2015) relied on self-report RWL data from athletes. Both MMA samples showed similar relative (10% vs. 8%, mean difference 2% body mass) and absolute (7.4kg vs. 5.6kg, mean difference 1.8kg) RWL. However, RWL was lower in wrestlers (3.8 ± 1.9kg) with the shortest measurement period. Only one study quantified the subsequent RWG after the official weigh-in (Matthews & Nicholas, 2017). As such, it was not possible to examine the direct relationship between the magnitude of RWL and RWG.

3.4.2 Rapid Weight Gain

Fourteen studies recorded the magnitude of RWG (table 3). Thirteen objectively measured body mass, whereas Daniele et al. (2016) sourced historical records from IBF-sanctioned bouts to perform a retrospective analysis.

Relative RWG across studies (figure 2) was largest in a single-event MMA competition (11.7 ± 4.7%) (Matthews & Nicholas, 2017). This was somewhat an outlier as the second-largest relative RWG was found in teenage female wrestlers (mean difference between studies 5.4%) (Viveiros et al., 2015). US-based samples in wrestling and MMA displayed homogenous RWG (mean difference 0.3kg) (Alderman et al., 2004; Jetton et al., 2013; Scott et al., 1994; Utter &

Kang, 1998). However, US high-school wrestlers had markedly smaller RWG of 1.2 ± 1.1kg (Wroble & Moxley, 1998). This was similar to RWG in adolescent taekwondo (1kg [1.6%] and 1.2kg [2.2%]), Iranian wrestlers (1.3kg [2.2%]) and Australian judokas (1.7kg [2.6%]), whereas Estonian wrestlers were higher (2.5kg [3.5%]) all of whom competed in tournament format events (Kazemi et al., 2011; Kordi et al., 2012; Ööpik et al., 2013; Reale et al., 2016a).

Scott et al. (1994) analysed the difference in RWG between competitive levels (Divisions I, II and III). Wrestlers in Division I experienced a small, but significant increase in RWG over wrestlers in Division II (mean difference 0.4kg, $p<0.05$). No differences were found between other divisions. In the largest study sample, juniors (17-18 yrs) exhibited significantly more RWG than cadets (15-16 yrs) (3.6kg vs. 2.9kg, mean difference 0.7kg, $p<0.001$) (Alderman et al., 2004). Professional boxers competing in a single-event (Daniele et al. 2016) exhibited greater RWG than elite amateur boxers (Reale et al., 2016b) in a multiple-day tournament (mean difference 1.3kg [1.9%]).

Differences in RWG between weight categories were heterogeneous and poorly defined. Kazemi et al. (2011) found, in males, the largest RWG in the light heavyweight (78kg upper limit (UL)) and featherweight (55kg UL) categories, 1.9 ± 1kg and 1.6 ± 0.7kg, respectively. In females, RWG peaked and was comparable across the middle five weight categories from bantamweight (46kg UL) to light middleweight (U59kg UL). In wrestling, light heavyweights (80.4-86.4 kg) experienced significantly ($p<0.05$) less RWG than the 57.3kg UL, 64.5kg UL, and 68.2kg UL (Scott et al., 1994). The difference in absolute RWG was comparable between all remaining weight categories. The largest relative RWG was found in the 53.6kg UL, 57.3kg UL, and 60.9kg UL divisions (all >6% mean RWG. In another sample, US middleweight wrestlers (cadets 47-76 kg, juniors 52-87 kg) gained more body mass than wrestlers in the lower (cadets 38-43 kg, juniors 44.5-48 kg) or higher categories (cadets 83-110 kg, juniors 100-125 kg) (Alderman et al., 2004). Alderman et al. (2004) and Scott et al. (1994) did not report specific values for RWG within and between weight categories. None of the three studies reported specific values for relative RWG across weight categories.

3.4.3 Duration Permitted for RWG

Four studies reported a range for the recovery duration (Alderman et al., 2004; Kazemi et al., 2011; Reale et al., 2016b, 2016a). Utter & Kang (1998) sampled the same group of wrestlers across tournaments with different recovery durations (6h and 24h). Pettersson & Berg (2014) split Olympic athletes into those with an evening before weigh-in (taekwondo and wrestling) and those with a morning weigh-in (judo and boxing). The proximity of the pre-competition weigh-in to the start of the bout was consistent across studies and ranged from matside (0 h) to one hour, excluding Jetton et al. (2013) (~2 h) and Daniele et al. (2016) (~12 h). In studies with tournaments spanning multiple days (n = 7) and with unspecified tournament formats (n = 5) RWG was taken from the official weigh-in up until first-round matches only. As a result, these studies did not account for any changes in body mass for subsequent days or bouts.

[INSERT TABLE 3 HERE]

4 Discussion

This systematic review investigated the magnitude of RWL and RWG in combat sport athletes preparing for competition. Based on the results from 14 studies, we found evidence that athletes across five combat sports engage in RWG. The magnitude of RWG may be influenced by the type of sport, the competition structure (single event bout vs. multiple-day tournament), and the recovery duration permitted. Three studies quantified RWL, although these findings were limited to small samples across two combat sports. Overall, there were a lack of studies directly measuring RWL in combat sport athletes, and a paucity of research in female athletes.

4.1 Risk of Bias of the Included Studies

No studies achieved all quality criteria (table 2). Risk of bias was found in reporting (item 3) and for external validity (items 11 and 12). Other than Reale et al. (2016b), no study recruited all participants from an event or a truly random sample. Therefore, the possibility of selection bias cannot be ruled out. Athletes engaging in different patterns of RWL and RWG may not be present in the existing literature. This limits the generalisability of the findings, particularly in studies with small sample sizes.

4.2 Rapid Weight Loss

The available evidence suggests that MMA athletes undergo greater RWL than wrestlers. Coswig et al. (2015) and Matthews & Nicholas

(2017) showed similar relative RWL, consistent with larger studies that have utilised the Rapid Weight Loss Questionnaire (RWLQ) to quantify weight management behaviours in MMA (Andreato et al., 2014; Barley et al., 2017). Barley et al. (2017) found MMA athletes report significantly greater weight lost for a competition compared with BJJ, judo, wrestling, taekwondo, boxing, and Muay Thai/kickboxing. Similarly, we found smaller RWL in wrestlers when compared to MMA athletes (mean difference 3.6 kg) (Coswig et al., 2015; İrfan, 2015). Due to the lack of data, it was not possible to compare the magnitude of RWL across other combat sports. Several RWLQ studies were identified, but did not meet the RWL duration (i.e. ≤7 days) inclusion criteria (Andreato et al., 2014; Artioli et al., 2010a). Our restriction of the RWL period was to ensure that body mass changes from acute diet and body fluid manipulation were the focus, as these pose the greatest risk to athlete health. Furthermore, the RWLQ was validated in judokas and wrestlers who compete regularly in tournament formats (Artioli et al., 2010d; Steen & Brownell, 1990). The questions may not reliably capture RWL behaviours in sports where athletes compete in single bouts and typically have longer periods in between competitions.

The results show RWL of a similar magnitude to that which led to the deaths of three collegiate wrestlers in 1997 (CDC, 1998). Over 10-12 weeks, the three athletes reduced their body mass by a reported 10.5 kg, 5.9 kg, and 4.5 kg. This period of gradual body mass reduction was followed by more aggressive RWL, as the three athletes aimed to reduce body mass by a further 6.8 kg (7.1%) in the final three days, 5.5 kg (7.3%) in the final six days, and 7.7 kg (10%) in the final four days, respectively. This is comparable to RWL of 8 ± 1.8%

(Matthews & Nicholas, 2017) and 10% (Coswig et al., 2015) in the present review. These values describe the average changes in body mass and athletes in the highest percentiles of RWL may be at greater risk of an adverse event.

As a result of glycogen depletion and emptying the intestinal contents, a ~3% reduction in body mass could be expected in a short duration i.e. 1 to 7 days (Reale et al., 2017b). Beyond this, athletes utilise other potentially harmful methods involving passive sweating (e.g. sauna, hot salt baths, and wearing plastic suits without exercising) (Artioli et al., 2010a; Matthews & Nicholas, 2017), which cause marked decreases in plasma volume (Caldwell et al., 1984) and have been implicated in the previously mentioned fatalities. Active sweating (e.g. exercise-induced) is also common, but causes a smaller decrement in physical performance and plasma volume when compared to passive methods (Caldwell et al., 1984). Side effects are frequently reported even at modest magnitudes (~5%) of RWL, these include, feeling fatigue or weakness, dizziness, feverish, nausea, nosebleeds, headaches, hot flashes, cramps, and feeling disorientated or anxious (Alderman et al., 2004; Viveiros et al., 2015). Overall, it is clear RWL can pose an actual or potential health risk to athletes.

4.3 Rapid Weight Gain

Rapid weight gain was found across a variety of combat sports and age levels. Females were scarcely represented, at 3.5% (n = 156) of the total athlete sample. This does not reflect RWLQ research, where female participation is as high as 26-35% (Artioli et al., 2010a; Reale et al., 2018). Of the seven studies which observed female athletes, only four provided female-specific data (n = 118, [2.78%]) (Kazemi et al., 2011; Reale et al., 2016a, 2016b; Viveiros et al., 2015). Gender differences in RWG were observed in wrestling (larger in females) and amateur boxing (larger in males) (Reale et al., 2016b; Viveiros et al., 2015) but not in judo or taekwondo (Kazemi et al., 2011; Reale et al., 2016a). The findings of Viveiros et al. (2015) are counterintuitive, as males have greater relative muscle mass and total body water content, a favourable composition for acutely manipulating body mass. A cause for concern here is the young cohort (age range 11-15 yrs) and the observed RWG in females, which was the second largest across all included studies. These data are consistent with other research showing that athletes begin to reduce body mass for competition during puberty (Artioli et al., 2010a), with some engaging in RWL from the age of four (Berkovich et al., 2015). For young athletes, making-weight may have detrimental effects on growth and maturation due to sustained periods of low energy availability (Loucks et al., 2011). Furthermore, RWL is associated with abnormal eating behaviours (Oppliger et al., 2003), and weight-category athletes display a higher prevalence of eating disorders (Sundgot-Borgen & Torstveit, 2004).

Rapid weight gain in US-based wrestling and MMA showed striking homogeneity (Alderman et al., 2004; Jetton et al., 2013; Scott et al., 1994; Utter & Kang, 1998). The only outlier, Wroble and Moxley (1998), held the second weigh-in on the morning of competition, with bouts taking place throughout the day. This was similar to Daniele et al. (2016) who recorded RWG from the official weigh-in up to 12 hours pre-competition. Both studies left several hours for athletes to further increase their body mass and likely underestimated the full extent of RWG. To gather externally valid data, studies should record body mass as close to competition as possible, ideally ≤1 hour pre-competition.

Another key factor determining the magnitude of RWG is the competition level and structure. Athletes at national and international-level tournaments, with a similar recovery duration, showed comparable RWG (Ööpik et al., 2013; Pettersson & Berg, 2014). Rapid weight gain was smaller at regional-level tournaments in Iran (2.2%) (Kordi et al., 2012) and Canada (1.6 and 2.2%) (Kazemi et al. 2011), and in tournaments with the weigh-in held on the day of competition (Ööpik et al., 2013; Pettersson & Berg, 2014). The exceptions to this were Alderman et al. (2004) and Utter & Kang (1998) who observed RWG of 4.1% and 4.8%, despite athletes participating in multiple-day tournaments. Both were national-level competitions and included the top 5-10% of athletes from the US. This is consistent with the evidence that competitive level and athlete calibre correlate with the severity of RWL practices (Artioli et al., 2010a; Reale et al., 2018). It remains unknown whether this is a causative factor, that is, athletes directly benefit from RWL and individuals who can tolerate the extremes of RWL have greater success over time. Conversely, the association may be incidental and reflective of a longer training history, more competitive experience, and exposure to high-quality training environments, which all improve performance concurrent to exposure to RWL practices (Reale et al. 2018).

The variation in RWG across studies with a competition day weigh-in may be due to cultural differences between combat sport disciplines. Athletes rely most heavily on their coaches and teammates for advice on making-weight, and qualified professionals (i.e. dietitians and physical trainers) are among the least influential (Artioli et al., 2010a; Berkovich et al., 2015). Therefore, similarities should be expected within each sport and geographical region. Wrestlers report a preference towards acute weight loss only, whereas boxers and judokas prefer a combined approach of chronic and acute weight reduction (Reale et al., 2018). Acute changes are largely from body fluid, intestinal contents, and glycogen, which can be restored to a greater extent than fat mass and muscle mass following the weigh-in. This is consistent with our results showing greater RWG in wrestlers, compared to boxers and judokas, when the recovery duration is similar duration (Alderman et al., 2004; Utter & Kang, 1998).

The methods used in RWL and RWG influence the magnitude of body mass regained. Following 5% RWL, wrestlers experienced a 54% decrease in muscle glycogen, which was restored to an estimated 83% of baseline with a 17-hour recovery duration (Tarnopolsky et al., 1996). Assuming a 1:3 molar ratio of glycogen: water (*wt/vol*) the authors suggested the initial reduction could account for ~0.37 kg of body mass. This estimate is markedly lower than the ~1.6-2.0 kg losses from a 4-day very-low carbohydrate diet (Kreitzman et al., 1992) and evidence that glycogen loading from a depleted state increases body mass by ~3.4% (Bone et al., 2017). The latter changes may reflect the changes in MMA, where athletes typically utilise a low-carbohydrate diet during RWL and have high-carbohydrate intakes during RWG (Coswig et al., 2018; Matthews & Nicholas, 2017). Smaller RWG in boxing, judo, and taekwondo could be a result of less glycogen restoration, as athletes consume a moderate carbohydrate intake during RWL (Filaire et al., 2001; Pettersson & Berg, 2014; Reljic et al., 2015). Body water presents the largest compartment of body mass for acute manipulation and may not be adequately restored prior to competition. Prevalence of serious dehydration was 5.3 times higher in wrestlers who reported RWL, compared to those who did not reduce body mass for competition (Ööpik et al., 2013). Jetton et al. (2013) found 50% of MMA athletes were significantly or seriously dehydrated 2-hours before competition, despite a 24-hour recovery and 4.4% of RWG. If glycogen and body water are not fully recovered, RWG may not reflect the magnitude of RWL.

The largest RWG (11.7 ± 4.7%) was demonstrated in MMA athletes (Matthews & Nicholas, 2017). Authors reported one athlete increased body mass by 12.7 kg (20.6%) during the 32-hour recovery period and subsequently entered competition three weight categories higher than at the official weigh-in. This is not an isolated finding, in junior international-style wrestlers RWG ranged up to 16.7 kg with a 3-7 hours recovery duration (Alderman et al., 2004). This increase would also allow an athlete to climb up to three weight categories higher. The practical implications of this are concerning and undermine the purpose of matching competitors of an equal body mass (Franchini et al., 2012). By exploiting these rules, an athlete can gain an advantage over an opponent who chooses to compete in a weight category that is commensurate with their natural training weight. It also creates a culture whereby athletes may feel they have to manipulate their body mass, not to seek an advantage over an opponent, but to avoid being disadvantaged (Pettersson & Berg, 2014). This places athletes in unnecessary risk and those who use RWG to gain an advantage could be violating the spirit of the sport.

4.4 Role of the Recovery Duration

Due to the various competition structures and weigh-in regulations, it is challenging to isolate the role of the recovery duration on the magnitude of RWG. Utter & Kang (1998) provided unique insight to the same group of wrestlers competing in tournaments with a 6-hour (4 meets) or 24-hour (11 meets) recovery duration. No significant differences were observed (mean difference 0.3 kg), suggesting that the recovery duration, if six hours or greater, may have less of an impact on weight-making behaviours than typically thought. In contrast, athletes were used to competing in a particular weight category and, given the short time interval between some competitions (3-7 days), may have had to control their weight irrespective of the recovery duration. This would prevent the large fluctuations in body mass commonly seen following a competitive event.

Across the remaining studies, there was a trend towards a larger RWG with a longer recovery duration (figure 2). Pettersson & Berg (2014) showed significantly greater RWG in athletes with an evening before weigh-in, compared to a morning weigh-in (mean difference 1.3 kg [2.3%]). All athletes were on the Swedish national team, had a high national ranking, or competed at international level. This helps standardise competitive level and, although the culture of making-weight in each sport may differ, it demonstrates that increasing the recovery duration leads to greater RWG.

Due to alarming RWL behaviours and recent fatalities, there have been calls to reduce the recovery duration to ≤24 hours in MMA (Crighton et al., 2015) and to ≤1 hour in judo (Artioli et al., 2010c). The Ultimate Fighting Championship, America's flagship MMA organisation, previously operated an afternoon-before weigh-in (approx. 24h), but in 2016 changed to a morning-before weigh-in (approx. 32h). Unofficial figures show this has resulted in an increase of competitors missing weight from 3.4% to 6.4% (Bohn, 2018). It is possible athletes may be attempting more extreme RWL knowing that they have longer to rehydrate and refuel prior to competition. Reducing the recovery duration is a viable strategy and would be easy to implement for sport governing bodies. Coswig et al. (2015) observed MMA athletes who did not engage in RWL when the official weigh-in was held 30 minutes pre-competition. This is consistent with our findings as no eligible studies reported RWL or RWG with a recovery duration of ≤2 hours.

Following the fatalities in 1997, the NCAA made four changes to weigh-in regulations in an attempt to minimise RWL practices. Alongside other criteria, they moved the weigh-in ≤1 hour pre-competition. A review showed the rule change has been effective in reducing unhealthy RWL behaviours and promoting competitive equity in collegiate wrestlers (Oppliger et al., 2006). To emphasise this, we highlight the findings of Alderman et al. (2004), where wrestlers improved their weight management behaviours during the scholastic season (under the NCAA rules) but showed aggressive RWL when competing in international-style wrestling, which is not subject to the same weight control regulations. Moreover, all other studies reporting RWG in US wrestling were performed prior to the NCAA rule change. This supports call for the implementation of strict rule changes to prevent potentially harmful RWL. It was outside the scope of this review to provide a framework for the prevention of RWL and RWG in combat sports. Instead, we direct readers to a point, counter-point debate for recent discussions on this topic (see Artioli et al., 2016; Davis, 2017). Furthermore, while the recovery duration is important, it should be considered alongside the multiple factors that influence RWL and RWG behaviours.

4.5 Relationship Between RWL and RWG

Despite several studies interpreting the magnitude of RWG as a proxy for the magnitude of RWL, there were insufficient data to appraise this relationship. Only Matthews & Nicholas (2017) objectively measured both RWL and RWG. However due to the small sample size, the link between the two variables was not explored. It is conceivable that a relationship exists between both changes in body mass, although it is unknown to what extent ≤7d RWL predicts weight regain following the weigh-in. We recommend that until this relationship is substantiated, RWG alone should not be used to *directly* infer the magnitude of RWL.

4.6 Limitations

The research question provided eligible studies in which athletes engaged in RWL or RWG practices. Some studies have excluded athletes who reduced body mass for competition, whereas others have not. The presentation of mean data without insight into the range or inter-individual variability limits the applicability for clinicians and sporting governing bodies. We acknowledge that, while unpleasant side effects occur at lower thresholds, any fatal risks from RWL likely occur at the extremes and not at the magnitude of the reported means.

The present results do not encompass data showing gradual reductions in body mass in the weeks preceding competition. Depending on the diet followed, athletes could enter the competition week glycogen depleted, dehydrated, and with little intestinal content to manipulate. In this scenario, there may be greater risk from performing RWL, even at smaller magnitudes. The review is qualitative in nature and our interpretation of the findings was primarily based on reported probability values and descriptive statistics. This can be misleading due to low sample sizes and the heterogeneity in the pool of participants studied.

5 Conclusions and Future Research

This study presents the most comprehensive review to date on the magnitude of RWL and RWG in combat sport athletes preparing for competition. Across sports, RWG is diverse and may be dependent on a variety of factors, including the type of combat sport, recovery duration permitted, and the competition format (single event vs. multiple-day tournament). Evidence that RWG can enable athletes to enter competition up to three weight categories above the official weigh-in is concerning and may threaten the spirit of the sport.

Given the widespread prevalence of RWL, a cause for concern is the lack of published data outside of the small samples in wrestling and MMA, and absence of objective RWL data in female athletes. As such, strong conclusions on the magnitude of RWL across sports cannot be drawn from the available research. It is unknown to what extent ≤7d RWL predicts weight regain following the weigh-in. Until this is established, RWG should not be used to *directly* infer the magnitude of RWL.

It is essential that future research is carried out in female athletes and in underrepresented, high-participation combat sports (e.g. Muay Thai). Studies should recruit a complete or representative sample to account for selection bias. In addition, there is a need for high-quality observational studies which closely monitor body mass throughout the week preceding competition. It is imperative that researchers report inter-individual differences where possible, as the athletes undergoing the greatest changes in body mass may be at the highest risk of adverse effects.

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Table 1. Standardised electronic search strategy.

Step	Search Terms	Boolean Operator	PubMed Central	EBSCOhost
1	Combat Sport$ Judo* Box* Kickbox* Martial Art* Taekwondo Wrestl* Karate Muay Thai Jiu-Jitsu	OR	22310	24386
2	Competition		249834	27719
3	Rapid Weight Acute Weight Weight Loss Weight Gain* Weight Cycl* Weight Cut* Mak* Weight	OR	1398037	44664
4	1, 2, 3	AND	1720	174
5	Body Mass Body Weight	OR	943315	174321
6	4, 5	AND	1378	129
7	Injury Injuries	OR	784344	1412064
8	6, 7	NOT	632	122
	Duplicates		32	
	Remaining articles		722	
	Full-texts screened		7	40

Table 2. Risk of bias assessment using Downs and Black (1998) tool.

	Downs & Black Item Number										
References	1	2	3	6	7	10	11	12	16	18	20
Alderman et al. (2004)	1	1	0	1	1	1	0	0	1	1	1
Coswig et al. (2015)	1	1	1	1	1	1	0	0	1	1	0
Daniele et al. (2016)	1	1	0	1	1	1	0	0	1	1	0
Irfan (2015)	1	1	1	1	1	1	0	0	1	1	0
Jetton et al. (2013)	1	1	0	1	1	1	0	0	1	1	1
Kazemi et al. (2011)	1	1	0	1	1	0	0	0	1	1	1
Kordi et al. (2012)	1	1	0	1	1	0	0	0	1	1	1
Matthews & Nicholas (2017)	1	1	1	1	1	1	0	0	1	1	1
Ööpik et al. (2013)	1	1	0	1	1	1	0	0	0	1	1
Pettersson & Berg (2014)	1	1	1	1	1	1	0	0	1	1	1
Reale et al. (2016a)	1	1	0	1	1	1	0	0	1	1	1
Reale et al. (2016b)	1	1	0	1	1	1	1	1	1	1	1
Scott et al. (1994)	1	1	0	1	1	0	0	0	1	1	1
Utter & Kang (1998)	1	1	0	1	1	0	0	0	1	1	1
Viveiros et al. (2015)	1	1	0	1	1	0	0	0	1	1	1
Wroble & Moxley (1998)	1	1	0	1	1	0	0	0	1	0	1

1; yes, 0; no or unable to determine.

Item appraisal criteria from the modified Downs and Black (1998) tool.
(1) Is the hypothesis/aim/objective of the study clearly described?
(2) Are the main outcomes to be measured clearly described in the Introduction or Methods section?
(3) Are the characteristics of the patients included in the study clearly described?
(6) Are the main findings of the study clearly described?
(7) Does the study provide estimates of the random variability in the data for the main outcomes?
(10) Have actual probability values been reported for the main outcomes except where the probability value is less than 0.001?
(11) Were the subjects asked to participate in the study representative of the entire population from which they were recruited?
(12) Were those subjects who were prepared to participate representative of the entire population from which they were recruited?
(16) If any of the results of the study were based on “data dredging”, was this made clear?
(18) Were the statistical tests used to assess the main outcomes appropriate?
(20) Were the main outcome measures used accurate (valid and reliable)?

Table 3. Study characteristics and the magnitude of rapid weight loss and rapid weight gain.

Study (Region)	Sample Size	Age Height Body Mass	Combat Sport (Level of Competition)	RWL or RWG	Magnitude of RWL/RWG	Duration for RWL/RWG	Final Body Mass → Competition
Alderman et al. (USA)	*N* = 2638 m (1270 Cadets, 1368 Juniors)	Cadets 15-16 yrs Juniors 17-18 yrs	International Style Wrestling (National Champ., Multiple-Day)	RWG	3.4 ± 1.8 kg (4.1%) [-2.68 to 16.73 kg (-2.1 to 13.4%)]	3-7 h	0 h
Coswig et al. (Brazil)	*N* = 5 m (RWL) Total *N* = 17 m	27.4 ± 5.3 yrs 171 ± 5 cm 76.2 ± 12.4 kg	MMA (Professional, exp. 6.7 ± 5 bouts)	RWL	7.4 ± 1.1 kg (~10%) (self-reported data)	RWL 7 d RWG ~24 h	N/A
Daniele et al. (Europe)	*N* = 142 (m 126, f 16)	28.5 ± 5.1 yrs 76.2 ± 11.3 kg (HWs exc.)	Boxing (Professional, IBF)	RWG	2.52 ± 1.37 kg (3.8 ± 2.2%) [-0.3 to 6.4 kg (-0.4 to 9.3%)]	12 h	~12 h
Irfan (Turkey)	*N* = 56 m	22.3 ± 2.43 yrs 174.5 ± 6.4 cm 78.9 ± 14.4 kg	Wrestling (National Inter-University Champ., Elite, Multiple-Day)	RWL	3.8 ± 1.9 kg (self-reported data)	RWL 1-5 d RWG EBWI NR	N/A
Jetton et al. (USA)	*N* = 40 (m 38, f 2)	25.2 ± 0.7 yrs 177 ± 1 cm 75.8 ± 1.5 kg	MMA (4.8 ± 3.5 yrs exp.)	RWG	3.4 ± 2.2 kg (4.4%)**	22 h	~2 h
Kazemi et al. (Canada)	*N* = 108 (m 72, f 36)	16.2 ± 0.7 yrs 62.7 kg (m) 55.5 kg (f)	Taekwondo (Junior)	RWG	Males 1 kg (1.6%) Females 1.2 kg (2.2%)	16-20 h	0 h
Kordi et al. (Iran)	*N* = 251 (RWL) Total *N* = 365 m	NR (HWs exc.)	Wrestling (Tehran High School Champ.)	RWG	1.3 ± 0.9 kg (2.2 ± 1.7%) [0.1 to 6.1 kg (0.1 to 9.3%)]	20 h	~1 h
Matthews & Nicholas (UK)	*N* = 7 m	24.6 ± 3.5 yrs 69.9 ± 5.7 kg	MMA (Professional/Amateur Comp., 3.1 ± 2.2 yrs exp.)	Both	RWL 5.6 ± 1.4 kg (8.0 ± 1.8%)*** RWG 7.4 ± 2.8 kg (11.7 ± 4.7%)**	RWL 5 d RWG 32 ± 1 h	45 ± 31 mins

Ööpik et al. (Estonia)	*N* = 27 (RWL) Total *N* = 51 m	20.7 ± 3.7 yrs 177.1 ± 7.2 cm 75.4 ± 13.8 kg	Greco-Roman Wrestling (National Champ. 10.6 ± 4.3 yrs exp.)	RWG	2.5 ± 1.2 kg (3.5 ± 1.9%)* [0.1 to 5.2 kg]	~16 h	15-20 mins
Pettersson & Berg (Sweden)	*N* = 63 (m 43, f 20)	21.2 ± 3.8 yrs 175 ± 9.4 cm 67.1 ± 13 kg (HWs exc.)	EBWI Taekwondo/Wrestling MWI Judo/Boxing (National/International Tournaments)	RWG	Evening-Before Weigh-In (n = 31) 2.7 ± 1.7 kg (4.4 ± 2.7%) [-0.1 to 7.5 kg (0.1-11.9%)] Morning Weigh-In (n = 32) 1.4 ± 1.0 kg (2.1 ± 1.4%)** [-0.8 to 4.1 (-0.9 to 5.1%])	RWG EBWI NR Boxing >6 h Judo >2 h	~30 mins
Reale et al. (Australia)	*N* = 86 (m 50, f 36)	66.5 ± 12.3 kg (HWs exc.)	Judo (Capital Territory International Judo Open, Multiple-Day)	RWG	1.7 ± 1.3 kg (2.6 ± 2.1%)** Males 1.6 ± 1.4 kg (2.3 ± 2.1%) Females 1.8 ± 1.2 kg (3.1 ± 2.1%)	15-20 h	~1 h
Reale et al. (Australia)	*N* = 100 (m 70, f 30)	64.5 ± 10.4 kg (HWs exc.)	Boxing (Elite National Amateur Champ., Multiple-Day)	RWG	1.2 ± 1 kg (1.9 ± 1.6%)** Males 1.4 ± 1 kg (2.1 ± 1.6%) Females 0.8 ± 0.9 kg (1.6 ± 1.6%) Sig. diff in RWG between genders	3-12 h	~1 h
Scott et al. (USA)	*N* = 607 m	NR (HWs exc.)	Wrestling (Divisions I, II, III NCAA Champ. Tournament, Multiple-Day)	RWG	RWG 3.7 ± 1.3 kg (5.3 ± 2.2%)	~20 h	~1 h
Utter & Kang (USA)	*N* = 11 m	NR	Wrestling (Division I, NCAA Champ., Multiple-Day, >4 yrs exp.)	RWG	6h Group 3.4 ± 1.3 kg (4.8 ± 1.7%) 24h Group 3.7 ± 1 kg (5.3 ± 1.3%)	6 or 24h	~1 h

Viveiros et al. (Brazil)	$N = 31$ (m 15, f 16)	13 ± 2 yrs 51.3 ± 12.4 kg (m) 42.3 ± 9.1 kg (f)	Wrestling (Brazilian National High-School Games)	RWG	Males 1.5 ± 0.9 (3.1 ± 1.8%)* Females 2.7 ± 1.4 kg (6.3 ± 3.7%)* Sig. diff in RWG between genders	24 h	0 h
Wroble & Moxley (USA)	$N = 260$ m	NR (HWs exc.)	Wrestling (High School Tournament, Multiple-Day)	RWG	1.3 ± 1.1 kg (2.2 ± 1.7%) [-2.0 to +4.4 kg]	12 h	NR

Champ.; championship, comp.; competition, cm; centimetres, d; day(s), EBWI; evening-before weigh-in, exp.; experience, exc.; excluded, f; female, h; hour(s), HWs; heavyweights, kg; kilograms, m; male, mins; minutes, MMA; mixed martial arts, MWI; morning weigh-in, *N*; number, N/A' not applicable, NCAA; National Collegiate Athletic Association, NR; not reported, PWs; placewinners, RWG; rapid weight gain, RWL; rapid weight loss, yrs; years, * denotes $p<0.05$, ** denotes $p<0.001$, *** denotes $p<0.0005$.

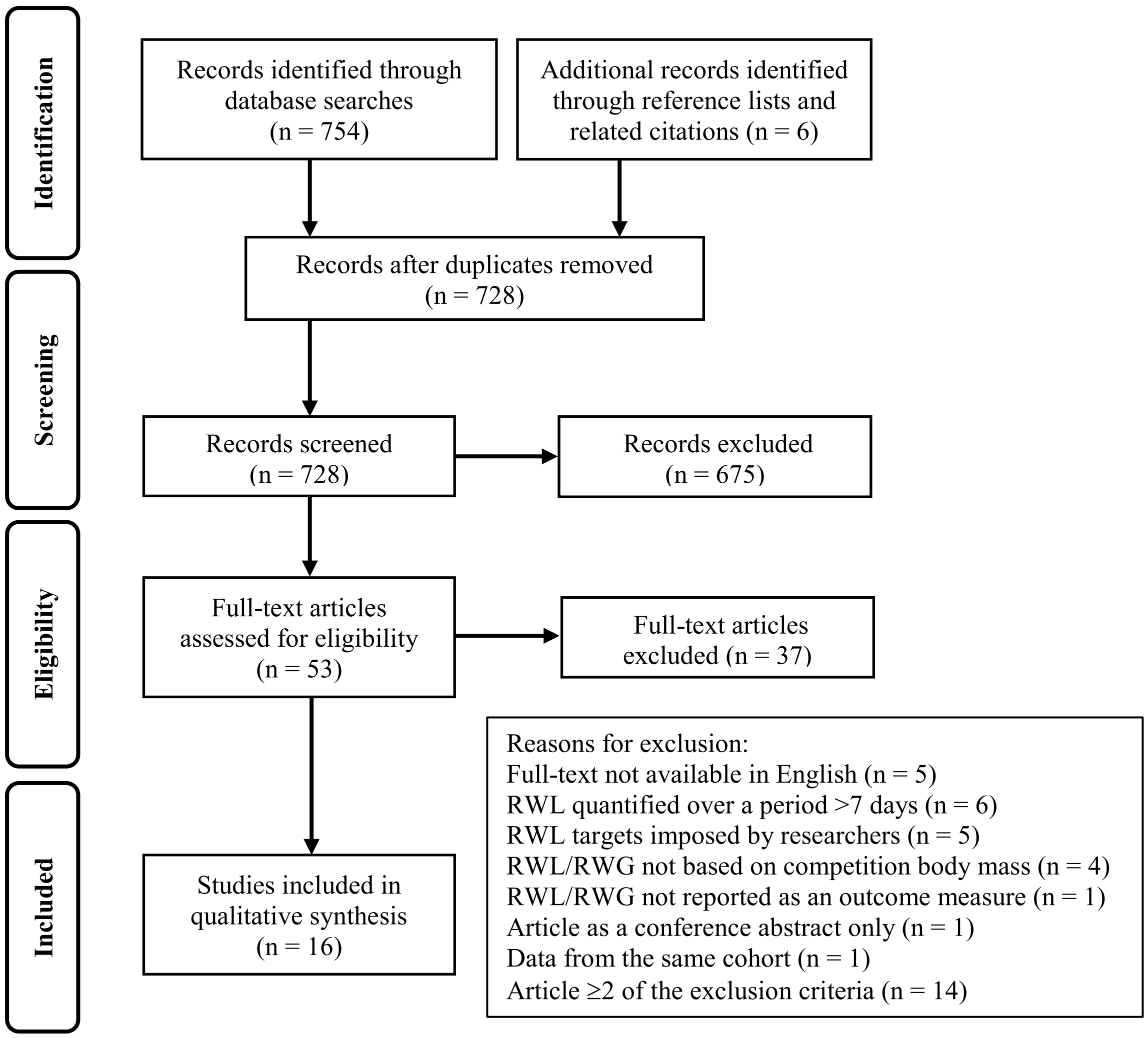

Figure 1. PRISMA flow diagram of study selection and inclusion.

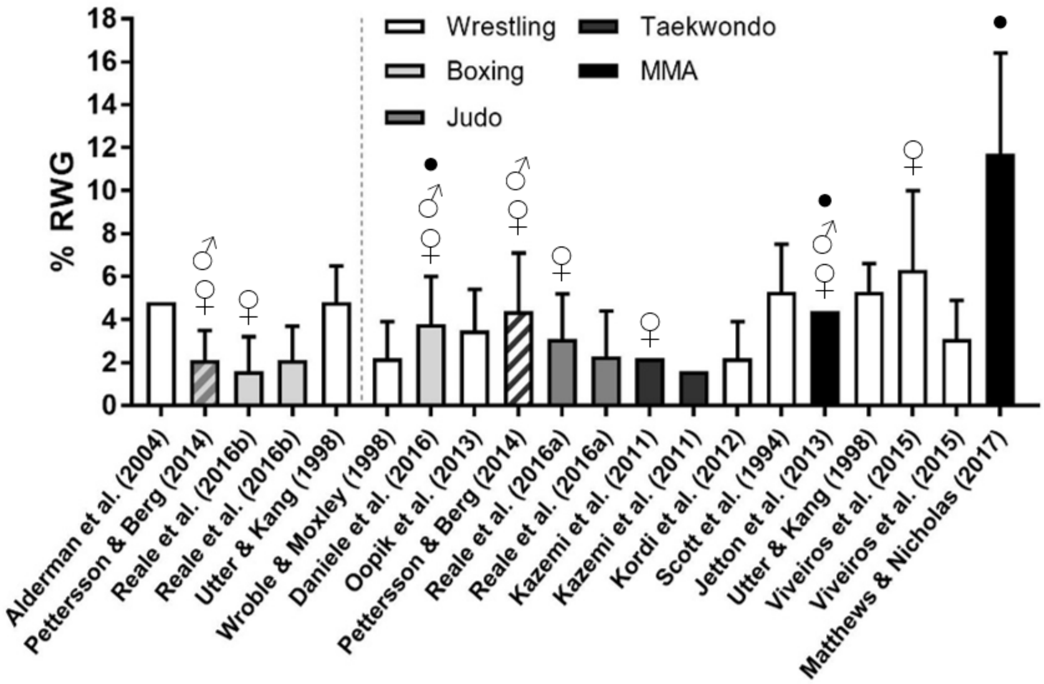

Figure 2. Relative RWG stratified from the shortest to the longest recovery duration (see table 3 for further details). The vertical dotted line separates studies with a day before competition weigh-in and those with a competition day weigh-in. Striped columns contain multiple combat sports. ● denotes a single-bout competition, ♀ denotes female-only sample, ♀♂ denotes combined male and female sample, and all remaining studies are male-only.