Rapid weight gain and weight differential predict competitive success in 2100 professional combat-sport athletes.

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Abstract:

Purpose: Combat sports athletes commonly undergo rapid weight loss (RWL) prior to pre-bout weigh-in and subsequently rapid weight gain (RWG) prior to competition. This investigation aimed to evaluate the effect of RWG and weight differential (WD) between opponents on competitive success.

Methods: A retrospective cohort study was performed using data from professional mixed martial arts (MMA) and boxing events held between 2015-2019. The primary outcome was RWG (relative and absolute) between weigh-in and competition stratified by bout winners and losers. Binary logistic regression was used to explore the relationships amongst bout outcome, RWG and WD between competitors on the day of their bout.

Results: Among 708 MMA athletes included, winners regained more relative body mass (BM) (8.7 ± 3.7% vs. 7.9 ± 3.8%; $p<0.01$) than losers. In 1392 included male boxers, winners regained significantly more relative BM (8.0 ± 3.0% vs. 6.9 ± 3.2%; $p<0.01$) than losers. Each percentage BM increase resulted in a 7% increased likelihood of victory in MMA and a 13% increase in

boxing. The relationship between RWG and competitive success remained significant in regional and male international MMA athletes, as well as boxers. WD predicted victory in international mixed martial artists and boxers. WD predicted victory by KO/TKO in international MMA athletes and regional boxers.

Conclusion: This analysis of combat sports athletes indicates RWG and WD influence competitive success. These findings raise fair play and safety concerns in these popular sports and may help guide risk-mitigating regulation strategies.

Introduction

Professional mixed martial arts (MMA) and boxing are popular global combat sports attracting millions of spectators each year.[1] Competitors are separated into body mass (BM) divisions (colloquially known as weight classes or categories) intended to promote fair and safe competition between athletes of similar morphology.[2 3] In order to qualify for a selected division, it is common practice for participants to reduce their BM in a process known as rapid weight loss (RWL), with over 90% of athletes employing this strategy over similar timescales before official weigh-ins held the day prior to competition.[4-6] This practice appears to be guided by cultural and structural factors within combat sports, including the desire to attain a BM advantage over an opponent or to avoid a size disadvantage.[7] Combat sports athletes often accomplish these targeted reductions in BM via dietary restriction supplemented by extreme dehydration, achieved through activities such as training in vapor impermeable clothing, hot baths, and prolonged sauna sessions aiming to induce total body water loss, particularly in the 24-48 hours prior to weigh-in.[4 8] Extreme dehydration with RWL has been linked to severe adverse health effects including acute kidney injury[9] and even fatalities.[2 10] Following official weigh-in, athletes attempt to

rehydrate and refuel to elicit rapid weight gain (RWG) over the 26-32 hours preceding the bout.[9 11 12]

Evidence has highlighted that even a relatively low magnitude of RWL (<5% BM) can result in decrements in force output.[13] This magnitude of RWL is less than that of the 6-14% reductions in BM employed in actual practice,[4 5 14 15] suggesting these decrements may be more relevant in the competition setting. Conversely, there is also evidence that RWG may restore performance to pre-RWL levels.[16] This suggests that different RWG strategies, and extent to which athletes engage in these methods, may have differing effects on recovery and performance. Adequate recovery is dependent on sufficient energy intake and rehydration during RWG. Attaining each of these to the extent required is not achieved by all athletes.[9 17] As such, it may be that discrepancies in competitive advantage are influenced by weight cycling methodology.

Literature to date has not conclusively linked weight cycling with successful bout outcome, with competitive success reported in grappling events such as high school wrestling[18] and international judo[19], but not in striking disciplines, with most evidence highlighted within amateur and professional boxing events.[6 20 21] Competitive success outcomes in MMA are inconsistent, with

RWG being evidenced to have either a positive effect,[17] a negative effect,[22] or no effect.[14] This picture has recently been complicated further in MMA by data showing a positive effect at the 'national' standard, but none at the 'regional' or 'elite' level.[23]

Many of the aforementioned investigations examining the association between RWG and bout outcome were limited by small sample sizes. In addition, the weight differential (WD) or the BM advantage held by one competitor over their opponent on the day of their bout remains largely unexplored. We have previously reported RWG in large cohorts of professional mixed martial artists[5] and professional boxers[15] using data provided by the California State Athletic Commission (CSAC). Recently, this database has been augmented to include bout outcome, facilitating further study pertinent to the ongoing debate of athlete safety, fair play, and weigh-in regulations in combat sports. Analyses of these data may enable a deeper understanding of the prevalence, magnitude, and effects of RWL/RWG on MMA and boxing performance outcomes and athlete health. Therefore, this investigation aimed to describe the comparative incidences and effects of RWG and WD on bout outcome in professional MMA and boxing.

Methods

Study Design & Data Sources

This retrospective cohort study was performed based on deidentified data collected by the CSAC. The study protocol was approved by the Institutional Review Board at Beth Israel Deaconess Medical Center (Protocol #2020P001224) with a waiver of informed consent due to the minimal risk related to deidentified data used for the present investigation.

Data was included for professional mixed martial artists and boxers, who competed in California between 2015 and 2019 in events sanctioned by the CSAC. BM values were obtained from digital or mechanical scales provided by individual event promotors with each assessed for accuracy and proper calibration by a CSAC inspector. CSAC officials recorded BM values at the event's official weigh-in, typically held the day prior to competition, and on the day of the event upon the athlete's arrival to the venue. The same scales were used for official and secondary weigh-ins with athletes weighed in only undergarments, each in accordance with standard CSAC weigh-in procedures. A period of 26-32 hours is estimated between BM measurements in this study. Sex, weight class and bout outcome data including method of victory were provided by the CSAC and/or verified by one of the

authors (VB, DL or KM). BM classifications utilized by the CSAC are reported elsewhere for MMA[5] and boxing.[15]

Participants

Athletes who were disqualified from competition or did not participate in the officially sanctioned weigh-ins were not included. Athletes were excluded if either their BM or complete bout data were not available. Heavyweight athletes were excluded as they typically do not engage in RWL or RWG prior to bouts. Female boxers were excluded from analysis due to a minimal representation in our sample. Given the interest in bout outcome, athletes whose bouts ended in a draw (i.e. no winning athlete) were excluded in the primary analysis as has been done in similar studies previously.[14 17]

Statistical Methods

BM regained was assessed using independent t-tests between bout winners and losers. Descriptive statistics were reported for the change in absolute (kg) and relative (%) BM between official weigh-in and competition. Variables of interest in logistic regression models are presented as well as the model area under the receiver operative curve (AUROC). Normality was assessed

and confirmed using the Shapiro-Wilk test. BM data is presented as mean ± standard deviations.

BM regained was described by weight class using one-way analysis of variance (ANOVA). Analyses were conducted using Stata (version 15.0 for MA; StataCorp., College Station, TX). Two-sided p-values <0.05 were considered statistically significant.

Analysis of the Primary Outcome

The primary outcome was BM regained (relative and absolute) between weigh-in and competition stratified by bout winners and losers. Athletes were grouped by promotion with international MMA promotions including the Ultimate Fighting Championship (UFC) and Bellator. International boxing promotions included Top Rank and Golden Boy. All other promotions were classified as regional.[5 15] Subgroup analyses were utilized to observe comparative incidences of relative RWG at 5% and 10% thresholds as previously described.[5 15]

Analysis of Secondary Outcomes

In a series of prespecified analyses, we explored the relationship between RWG and competitive outcome using logistic regression analysis adjusting for the following confounders: relative BM

regained, competitive level, weight class, and event year. These variables were defined *a priori* due to their perceived relevance to the association between BM gain and competitive outcome. Individual observations with significant collinearity to predictor variables were dropped from each logistic regression model as appropriate. Results are presented as odds ratio (OR) with 95% confidence interval (CI).

The relationship between competitive outcome and RWG was explored as a continuously scaled variable. The relationship between competitive outcome and WD or relative BM difference between opponents in a single bout on the day of competition at the bout level was also analyzed. WD was calculated as follows:

$$WD = \frac{[(\text{Heavier Athlete Event BM}) - (\text{Lighter Athlete Event BM})]}{(\text{Lighter Athlete Event BM})}$$

This calculation was elected to reflect athlete behavior (i.e. seeking a desirable BM advantage), the effects of weight cycling at the bout level and normalized to limit effects of weight classification.[7] [24] WD was treated as a continuously scaled variable in this model and only athletes with the greater bout-day BM than their opponent were included (the lighter fighter in each bout was excluded). Finally, the relationship between victory by knockout or technical knockout (KO/TKO) and RWG was evaluated. The model was

also applied to explore the relationship between victory by KO/TKO and WD at the bout level. For this analysis, only bout winners were included.

Results

MMA

A total of 983 mixed martial artists were assessed for inclusion. Athletes were excluded (n=275) due to incomplete bout information (n=236), heavyweight class (n=18), or if their bout ended in a draw (n=12), no contest (n=5), or was cancelled (n=4). In all, 708 mixed martial artists including 632 males and 76 females were included in the final cohort with 354 winning competitors and 354 athletes who lost their bouts.

In all, 696 (98.3%) mixed martial artists regained BM between weigh-in. Absolute and relative BM regained stratified by weight class and bout outcome are presented in Table 1. Relative BM stratified by sex, competitive level and weight class are presented in Table 2. Winners regained significantly more absolute (5.9 ± 2.5 kg vs. 5.3 ± 2.6 kg, $p<0.01$; Cohen's d = -0.24, 95% CI [-0.38, -0.09]) and relative (8.7 ± 3.7% vs. 7.9 ± 3.8%, $p<0.01$; Cohen's d = -0.23, 95% CI [-0.38, -0.08]) BM than losers. Among winners, 352 (99.4%) regained BM between weigh-in and competition, including 304 (85.9%) who regained more than 5% relative BM and 130 (36.7%) who regained more than 10% relative BM during this time period. Among losers, a total of 344 (97.2%) regained BM between weigh-in and competition, including 274 (77.4%)

who regained more than 5% relative BM and 99 (28.0%) who regained more than 10% relative BM during this period. There were four bouts excluded from WD analysis as each pair of fighters had the same event BM: two bouts between international competitors and two among regional competitors. The heavier athlete won in 204 (58.3%) bouts and lost in 146 (41.7%). WD stratified by bout outcome and competitive level are presented in Figure 1. Results of the logistic regression models are presented in Table 3.

Among 204 MMA athletes competing in international promotions (190 males and 14 females) there were 102 winners and 102 athletes who lost their bouts. Winners regained more absolute (6.4 ± 2.6 kg vs. 5.7 ± 2.8 kg p=0.07; Cohen's d = -0.25, 95% CI [-0.53, 0.02]) and relative (9.2 ± 3.7% vs. 8.3 ± 4.4%, p=0.10; Cohen's d = -0.23, 95% CI [-0.50, 0.05]) BM than losers; however, these differences did not reach statistical significance. The heavier athlete won in 53 (53.0%) bouts and lost in 47 (47.0%). Logistic regression revealed no significant association between relative RWG and bout outcome (OR 1.06; 95% CI 0.99-1.14); however, the relationship between WD and bout outcome was significant (OR 1.20; 95% CI 1.01-1.41.). WD predicted victory by KO/TKO (OR 1.13; 95% CI 1.02-1.25) among international competitors.

In 504 mixed martial artists competing in regional promotions (442 males and 62 females), there were 252 winning and 252 losing competitors. Winners regained significantly more absolute (5.7 ± 2.4 kg vs. 5.2 ± 2.5 kg, p=0.01; Cohen's d = -0.23, 95% CI [-0.40, -0.05]) and relative (8.5 ± 3.6 kg vs. 7.7 ± 3.6%, p<0.01; Cohen's d = -0.24, 95% CI [-0.41, -0.06])) BM than losers. The heavier athlete won in 151 (60.4%) bouts and lost in 99 (39.6%). Logistic regression demonstrated a significant association between RWG and bout outcome (OR 1.08; 95% CI 1.02-1.14). Relative WD did not predict victory (OR 0.97; 95% CI 0.90-1.05).

Boxing

A total of 1660 boxers were assessed for inclusion. Boxers were excluded (n=268) due to incomplete bout data (n=122), heavyweight class (n=38), female sex (n=10) and bouts ending in draws (n=86) or cancellation (n=12). In all, 1392 boxers were included in the final cohort with 696 winners and 696 boxers who lost their bout.

In this cohort, 1,375 (98.8%) boxers regained BM between weigh in and competition. Absolute and relative BM regained stratified by weight class and bout outcome are presented in Table 4.

Relative BM regained stratified by competitive level and weight class are presented in Table 5. Winners regained significantly more absolute (5.0 ± 1.9 kg vs. 4.3 ± 2.0 kg, $p<0.01$; Cohen's d = -0.35, 95% CI [-0.45, -0.24]) and relative (8.0 ± 3.0% vs. 6.9 ± 3.2%, $p<0.01$; Cohen's d = -0.34, 95% CI [-0.45, -0.23]) BM than losers. Among winners, 690 (99.1%) regained BM between weigh-in and competition, including 586 (84.2%) who regained more than 5% relative BM and 174 (25.0%) who regained more than 10% relative BM during this time period. Among losers, a total of 685 (98.4%) regained BM between weigh-in and competition, including 503 (72.3%) who regained more than 5% relative BM and 106 (15.2%) who regained more than 10% relative BM during this time period. There were eleven bouts excluded from WD analysis as each pair of fighters had the same event BM; eight bouts among international competitors and three among regional competitors. The heavier athlete won in 401 (58.5%) bouts and lost in 284 (41.5%). WD stratified by bout outcome and competitive level are presented in Figure 2. Results of the exploratory logistic regression models are presented in Table 6.

In 466 boxers competing in international promotions, there were 233 winners and 233 athletes who lost their bouts. Winners regained significantly more absolute (5.4 ± 1.7 kg vs. 4.7 ± 1.8 kg,

p<0.01; Cohen's d = -0.41, 95% CI [-0.59, -0.23]) and relative (8.8 ± 2.7% vs. 7.7 ± 3.0%, p<0.01; Cohen's d = -0.41, 95% CI [-0.59, -0.22]) BM than losers. The heavier athlete won in 139 (61.8%) bouts and lost in 86 (38.2%). Logistic regression revealed a significant association between relative RWG and bout outcome (OR 1.17; 95% CI 1.09-1.26), and between relative WD and bout outcome (OR 1.24; 95% CI 1.08-1.44). Neither RWG nor WD predicted victory by KO/TKO among international competitors.

In 926 boxers competing in regional promotions, there were 463 winning competitors and 463 who lost their bouts. Winners regained significantly more absolute (4.7 ± 1.9 kg vs. 4.1 ± 2.0 kg, p<0.01; Cohen's d = -0.33, 95% CI [-0.46, -0.20]) and relative (7.6 ± 3.0% vs. 6.6 ± 3.3%, p<0.01; Cohen's d = -0.32, 95% CI [-0.45, -0.19]) BM than losers. The heavier athlete won in 262 (57.0%) bouts and lost in 198 (43.0%). Logistic regression demonstrated a significant association between RWG and bout outcome (OR 1.11; 95% CI 1.07-1.16), and between relative WD and bout outcome (OR 1.12; 95% CI 1.04-1.20). WD predicted victory by KO/TKO (OR 1.05; 95% CI 1.01-1.10) among regional competitors.

Discussion

In this study of professional combat sports athletes, winners regained significantly more BM than losers prior to competition. Each percentage BM increase resulted in a 7% increased likelihood of victory in MMA and a 13% increase in boxing. The relationship between RWG and competitive success remained significant in regional and male international MMA athletes as well as boxers. WD predicted bout outcome in international MMA athletes and boxers. WD also predicted victory by KO/TKO in international MMA athletes and regional boxers. To put our results into context, in the case of a male, international lightweight mixed martial artist in 2019 holding a 1% relative WD advantage, our model predicted a 53.6% chance of winning. For the same athlete, a 5% WD advantage would correspond with a 64.0% probability, and a 10% WD advantage would predict a 77.2% chance of victory.

Despite subgroup variation, our results suggest that a more successful RWL/RWG process measured in terms of RWG and WD is related to a competitive advantage. This appears mostly consistent with findings in judo[19] and MMA,[17] but may contrast from prior findings in professional and amateur boxing.[6 20] The data provided by Coswig et al.[17] highlights that different approaches to RWL/RWG by bout winners and losers may explain

the outcomes of each of these studies. In their sample, bout winners consumed greater energy than bout losers during both RWL and RWG phases. This may suggest that RWG alone is not the determining factor in success, but rather the RWL/RWG process employed, enabling more effective recovery prior to competition. Though direct evidence for this is lacking in both MMA and boxing, a gradual reduction of dietary intake resulting in a state of low energy availability, yet followed by a subsequent acute period of appropriate refeeding, has been shown to maintain health and physiological/competitive performance outcomes in an international taekwondo athlete.[25] While our results reveal several incidences of bout winners having greater RWG and/or BM than bout losers, these differences are small in absolute and practical terms, thus are unlikely to have resulted in great enough performance advantages to determine the bout winner alone. As such, winning in boxing and some levels of MMA may partially result from maintenance of sufficient energy intake and hydration during RWL and RWG phases. The resulting greater BM post weigh-in may be coincidental to physiological recovery enabling more successful performance.[26-28]

Subgroup variation at the international standard of MMA is notable in the context of previous findings of RWG having no

statistically relevant effect at the 'international' standard of MMA.[14 23] Our results among international MMA opponents suggest RWL/RWG methods used have similar effects for both winners and losers. These findings are plausibly related to greater equality of resources and experience available to international athletes, allowing them to employ similar RWL/RWG strategies. Equally, it may also be the case that competitors in international bouts are more closely matched in terms of skill than those in 'regional' bouts. As such, regional athletes may be less able to overcome small BM disadvantages when compared to more closely matched international competitors. Further studies are required to analyze the skill and performance requirements of MMA, as well as the differing strategies utilized based on competitive level and region.

Given the relationship between RWL and RWG, our results suggest that otherwise healthy athletes may be exposing themselves to the risks of severe hypohydration and energy restriction in the name of competitive success. Extreme hypohydration with RWL has been linked to harmful biochemical and hormonal changes.[29 30 9]. A survey of elite judokas found that 21% of respondents experienced a fainting episode during RWL.[8] Such severe physiological responses have led to multiple lay media

reports of fatalities across all combat sports[31] and at least one fatality in MMA from RWG-induced exertional collapse in an athlete with sickle cell trait.[10] The long-term, non-fatal effects of such practices are currently underreported but may include rebound hyperphagia and acute kidney injury.[9 11 25] The association of RWG with competitive success in the setting of legitimate safety concerns raises questions about the nature of competition in modern combat sports as large magnitude RWG undermines the intention of BM categories to promote fair play.[16] Multiple methods for mitigating RWG have been suggested with variable implementation. These include moving weigh-ins to the day of competition, creating more weight classes to reduce the BM increment between them, enforcing minimum hydration requirements, and providing a 2-6 hour time window for the athlete to choose their own weigh-in and therefore RWG time.[4] The CSAC has also suggested licensing for weight classes requiring physician approval and weight class restrictions for fighters who miss weight on multiple occasions. However, few of these methods are widespread in professional MMA or boxing, therefore there is little evidence supporting their efficacy for minimizing RWL/RWG or protecting the athlete's health.[32]

The present investigation has notable limitations. RWG was measured based on BM checks upon athlete arrival to bout venue as opposed to the gold standard of measurement within one hour of competition. In addition, measures of RWG and WD are presented without control for baseline BM or RWG strategies utilized. As such, it is unknown whether these differences were caused by specific rehydration/fueling practices or by differing RWL magnitudes between participants. Equally, due to the complex nature of the sports being discussed, it cannot be claimed that differences in RWG and/or WD were the sole cause of bout outcomes.

Practical Applications

Though safety concerns have long existed surrounding the practice of weight cutting, this investigation lends evidence that competitors who do not engage in, or practice a lesser degree of, RWG put themselves at a competitive disadvantage. The advantages that bout winners appear to have may be related more to the use of more appropriate RWL/RWG strategies (ensuring sufficient energy intake and minimizing hypohydration), therefore enabling more effective post weigh-in recovery concomitant to greater BM regain. Athletes engaging in RWG resulting in WD realize a size advantage over their opponents, undermining the

intent of BM divisions to promote fairness. Strategies aimed at risk-mitigation with respect to RWL practices and promotion of more appropriate RWL/RWG methods should be prioritized by regulatory bodies. High-quality studies are needed to evaluate the efficacy of strategies enacted.

Conclusion

This study of professional combat sports athletes found that winners regained significantly more BM than losers prior to competition in boxing and 'regional' MMA, with increased likelihood of victory based on greater magnitude of RWG and WD. Future studies should prioritize establishing safe practices and thresholds for RWL as well as appraising changes in sport regulation with respect to BM management. We hope this leads to greater athlete safety and a more level playing field as combat sports continue to evolve.

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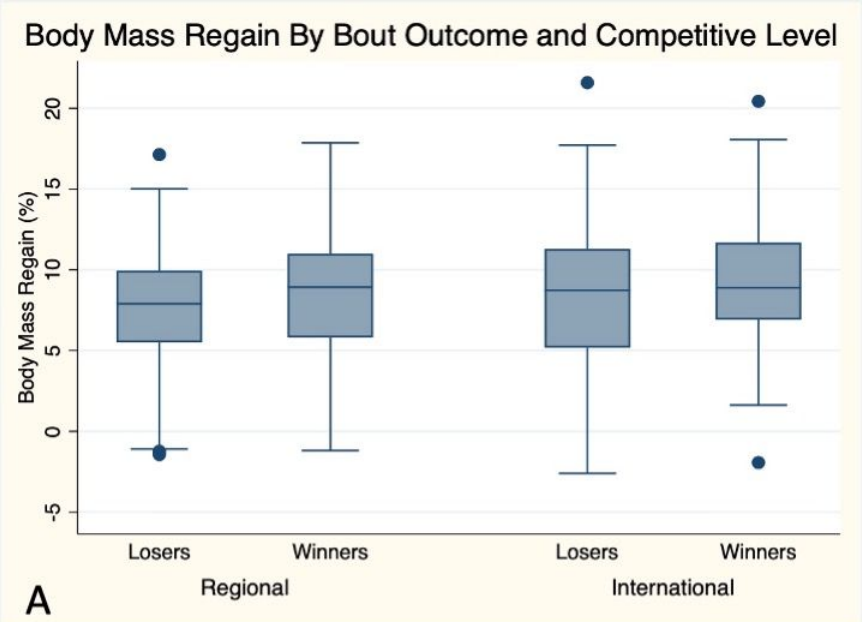

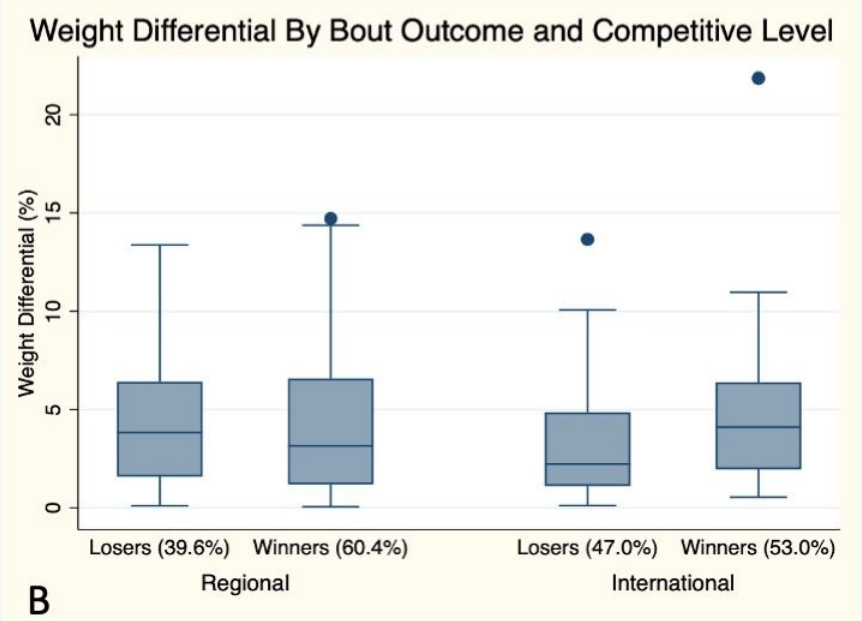

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Figure 1: Rapid Weight Gain and Weight Differential by Bout Outcome in Mixed Martial Artists. Panel A: RWG in bout winners (n=354) and losers (n=354) stratified by competitive level. Panel B: WD advantage held by heavier competitor stratified by competitive level. The heavier fighter won in 204 (58.3%) bouts and lost in 146 (41.7%) bouts overall.

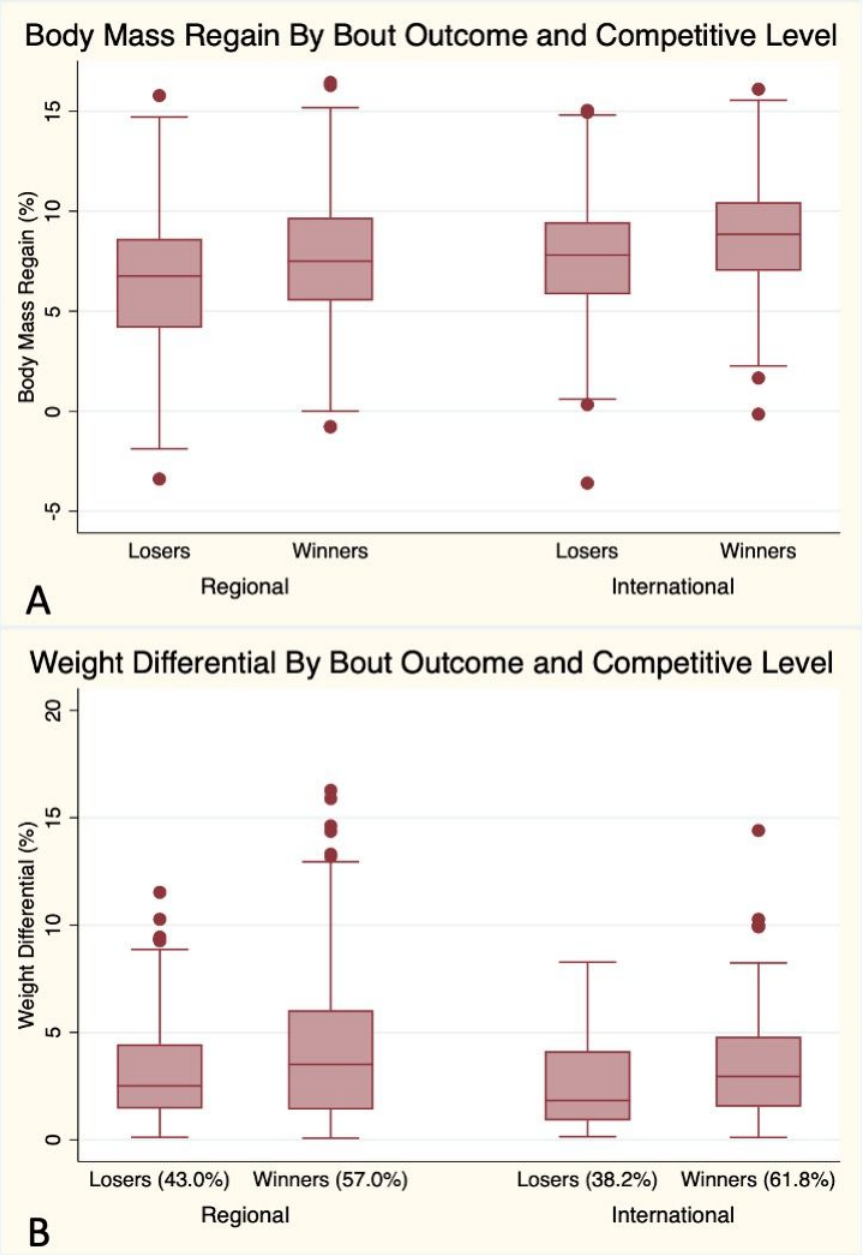

Figure 2: Rapid Weight Gain and Weight Differential by Bout Outcome in Boxers. Panel A: RWG in bout winners (n=696) and losers (n=696) stratified by competitive level. Panel B: WD advantage held by heavier competitor stratified

by competitive level. The heavier fighter won in 401 (58.5%) bouts and lost in 284 (41.5%) bouts overall.

	Winners, n=354 (50.0%)		**Losers, n=354 (50.0%)**	
Weight Class	*Body Mass Gain (kg)*	*Body Mass Gain (%)*	*Body Mass Gain (kg)*	*Body Mass Gain (%)*
Atom (47.7 kg) 1	5.1 ± 1.8 (n=5)	10.6 ± 3.7 (n=5)	3.7 ± 1.7 (n=5)	7.7 ± 3.4 (n=5)
Straw (52.2 kg) 2	4.2 ± 1.7 (n=14)	8.2 ± 3.3 (n=14)	4.2 ± 2.1 (n=14)	7.9 ± 3.9 (n=14)
Fly (56.7 kg) 3	5.6 ± 1.4 (n=30)	9.7 ± 2.5 (n=30)	5.5 ± 2.1 (n=30)	9.7 ± 3.6 (n=30)
Bantam (61.2 kg) 4	5.9 ± 2.2 (n=55)	9.4 ± 3.7 (n=55)	5.7 ± 2.5 (n=55)	9.2 ± 4.1 (n=55)
Feather (65.8 kg) 5	6.2 ± 2.5 (n=76)	9.4 ± 3.7 (n=76)	4.9 ± 2.6 (n=76)	7.4 ± 4.0 (n=76)
Light (70.3 kg) 6	6.4 ± 2.6 (n=77)	9.1 ± 3.8 (n=77)	6.0 ± 2.4 (n=77)	8.5 ± 3.4 (n=77)
Welter (77.1 kg) 7	6.5 ± 2.6 (n=51)	8.5 ± 3.5 (n=51)	5.2 ± 2.7 (n=51)	6.8 ± 3.5 (n=51)
Middle (83.9 kg) 8	4.9 ± 2.9 (n=31)	5.9 ± 3.5 (n=31)	5.2 ± 2.9 (n=31)	6.3 ± 3.5 (n=31)
Light Heavy (93.0 kg) 9	5.1 ± 1.9 (n=15)	5.6 ± 2.1 (n=15)	4.9 ± 2.9 (n=15)	5.4 ± 3.1 (n=15)
Entire Cohort	5.9 ± 2.5[a]	8.7 ± 3.7[b]	5.3 ± 2.6[a]	7.9 ± 3.8[b]

[a] $p<0.01$
[b] $p<0.01$

Table 1: Absolute and Relative Body Mass Gain Stratified by Weight Class and Bout Outcome in Mixed Martial Artists (n=708)

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	Males, n=632 (89.3%)				**Females, n=76 (10.7%)**			
	International Promotions (n=190, 30.1%)		*Regional Promotions* (n=442, 69.9%)		*International Promotions* (n=14, 18.4%)		*Regional Promotions* (n=62, 81.6%)	
Weight Class	*Winners* (n=95)	*Losers* (n=95)	*Winners* (n=221)	*Losers* (n=221)	*Winners* (n=7)	*Losers* (n=7)	*Winners* (n=31)	*Losers* (n=31)
Atom	---	---	---	---	---	---	10.6 ± 3.7 (n=5)	7.7 ± 3.4 (n=5)
Straw	---	---	---	---	8.2 ± 2.2 (n=2)	10.6 ± 0.6 (n=2)	8.1 ± 3.6 (n=12)	7.5 ± 4.0 (n=12)
Fly	9.7 ± 1.6 (n=4)	10.0 ± 5.0 (n=4)	9.6 ± 2.7 (n=16)	9.6 ± 3.2 (n=16)	8.8 ± 3.1 (n=4)	12.3 ± 2.5 (n=4)	10.8 ± 2.6 (n=6)	7.8 ± 3.9 (n=6)
Bantam	9.3 ± 4.0 (n=15)	11.2 ± 4.9 (n=15)	9.4 ± 3.6 (n=38)	8.5 ± 3.6 (n=38)	---	---	12.4 ±3.7 (n=2)	6.9 ± 2.9 (n=2)
Feather	10.3 ± 3.8 (n=29)	7.2 ± 4.3 (n=29)	9.0 ± 3.5 (n=40)	7.4 ± 3.8 (n=40)	3.4 ± 0.0 (n=1)	2.9 ± 0.0 (n=1)	8.7 ± 3.4 (n=6)	8.8 ± 3.6 (n=6)
Light	9.9 ± 3.3 (n=16)	9.0 ± 4.5 (n=16)	8.9 ± 3.9 (n=61)	8.4 ± 3.1 (n=61)	---	---	---	---
Welter	9.4 ± 3.2 (n=14)	7.5 ± 3.6 (n=14)	8.2 ± 3.6 (n=37)	6.5 ± 3.4 (n=37)	---	---	---	---
Middle	7.5 ± 4.6 (n=11)	6.4 ± 3.7 (n=11)	5.1 ± 2.4 (n=20)	6.2 ± 3.5 (n=20)	---	---	---	---
Light Heavy	6.4 ± 2.5 (n=6)	6.2 ± 2.7 (n=6)	5.0 ± 1.6 (n=9)	4.8 ± 3.4 (n=9)	---	---	---	---
Entire Cohort	9.3 ± 3.7[a]	8.2 ± 4.4[a]	8.4 ± 3.7[b]	7.7 ± 3.6[b]	7.9 ± 3.1[c]	10.5 ± 3.9[c]	9.4. ± 3.4[d]	7.8 ± 3.6[d]

[a] p=0.05
[b] p=0.03
[c] p=0.19
[d] p=0.07

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689 **Table 2**: Relative Body Mass Gain Stratified by Sex, Competitive Level, and
690 Bout Outcome in MMA Athletes (n=708)

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Exploratory Model	n	Adjusted OR (95% CI)	p-value	AUROC
RWG	708	1.07 (1.03-1.12)	<0.01	0.57
- Males	632	1.07 (1.03-1.12)	<0.01	0.57
- Females	76	1.09 (0.94-1.25)	0.25	0.57
International	204	1.06 (0.99-1.14)	0.09	0.56
- Males	190	1.08 (1.00-1.17)	0.04	0.58
- Females	14	0.42 (0.16-1.12)	0.08	0.81
Regional	504	1.08 (1.02-1.14)	<0.01	0.57
- Males	442	1.07 (1.00-1.13)	0.02	0.56
- Females	62	1.18 (0.998-1.40)	0.053	0.63
WD	345	1.02 (0.95-1.09)	0.58	0.60
- Males	313	1.03 (0.97-1.11)	0.34	0.59
- Females	29	0.79 (0.56-1.12)	0.19	0.84
International	98	1.20 (1.01-1.41)	0.03	0.71
- Males	94	1.23 (1.04-1.47)	0.02	0.72
- Females	6	*		
Regional	245	0.97 (0.90-1.05)	0.90	0.62
- Males	219	0.98 (0.90-1.07)	0.66	0.60
- Females	18	0.85 (0.59-1.21)	0.37	0.68
RWG & Victory Method (KO/TKO)	354	1.07 (1.00-1.14)	0.04	0.66
-*International*	97	1.09 (0.96-1.23)	0.19	0.70
-*Regional*	252	1.08 (0.996-1.17)	0.06	0.67
WD & Victory Method (KO/TKO)	354	1.04 (0.998-1.09)	0.06	0.66
-*International*	97	1.13 (1.02-1.25)	0.03	0.72
-*Regional*	252	1.03 (0.98-1.08)	0.27	0.67

Table 3: Effect on Rapid Weight Gain and Weight Differential on Bout Outcome and Method of Victory in Mixed Martial Artists. The value n indicates the number of athletes in each model for RWG analyses (not including victory method), n represents the number of bouts for WD and all victory method analyses. **Abbreviations:** *Adjusted OR:* Adjusted odds ratio. *95% CI:* 95% Confidence interval. *AUROC*: Area under receiver operating curve. *RWG:* Relative weight gain. *BM:* Body mass. *Int*: International. *Reg*: Regional. *WD:* Weight differential. *KO:* Knockout. *TKO:* Technical knockout.

	Winners, n=696 (50.0%)		**Losers, n=696 (50.0%)**	
Weight Class	*Body Mass Gain (kg)*	*Body Mass Gain (%)*	*Body Mass Gain (kg)*	*Body Mass Gain (%)*
Straw (47.7 kg)	5.1 ± 0.1 (n=3)	10.7 ± 0.3 (n=3)	4.4 ± 1.6 (n=3)	9.1 ± 3.4 (n=3)
Junior Fly (49.0 kg)	3.4 ± 2.2 (n=10)	6.7 ± 4.3 (n=10)	5.0 ± 1.6 (n=10)	10.0 ± 3.2 (n=10)
Fly (50.8 kg)	4.3 ± 1.1 (n=11)	8.4 ± 2.3 (n=11)	2.4 ± 1.3 (n=11)	4.5 ± 2.6 (n=11)
Super Fly (52.2 kg)	4.9 ± 1.8 (n=18)	9.6 ± 3.4 (n=18)	4.4 ± 1.7 (n=18)	8.6 ± 3.2 (n=18)
Bantam (53.5 kg)	4.3 ± 2.0 (n=28)	8.1 ± 3.7 (n=28)	4.2 ± 2.0 (n=28)	7.9 ± 3.8 (n=28)
Super Bantam (55.3 kg)	4.6 ± 1.4 (n=42)	8.4 ± 2.4 (n=42)	4.0 ± 1.9 (n=42)	7.3 ± 2.7 (n=42)
Feather (57.2 kg)	4.5 ± 1.8 (n=73)	8.0 ± 3.1 (n=73)	4.1 ± 1.6 (n=73)	7.3 ± 2.7 (n=73)
Super Feather (59.0 kg)	4.9 ± 2.0 (n=69)	8.3 ± 3.3 (n=69)	4.1 ± 2.0 (n=69)	6.9 ± 3.4 (n=69)
Light (61.2 kg)	5.0 ± 1.6 (n=93)	8.2 ± 2.6 (n=93)	4.1 ± 2.0 (n=93)	6.8 ± 3.2 (n=93)
Super Light (63.5 kg)	5.2 ± 1.9 (n=92)	8.3 ± 2.9 (n=92)	4.4 ± 1.8 (n=92)	7.1 ± 2.9 (n=92)
Welter (66.7 kg)	5.2 ± 1.9 (n=104)	7.9 ± 2.9 (n=104)	5.0 ± 1.9 (n=104)	7.6 ± 3.0 (n=104)
Super Welter (69.9 kg)	5.6 ± 2.0 (n=56)	8.1 ± 2.9 (n=56)	4.4 ± 2.4 (n=56)	6.4 ± 3.5 (n=56)
Middle (72.6 kg)	4.8 ± 1.8 (n=40)	6.7 ± 2.4 (n=40)	4.0 ± 2.3 (n=40)	5.5 ± 3.2 (n=40)
Super Middle (76.2 kg)	5.4 ± 1.9 (n=29)	7.3 ± 2.8 (n=29)	4.6 ± 2.4 (n=29)	6.3 ± 3.4 (n=29)
Light Heavy (79.4 kg)	5.2 ± 2.4 (n=22)	6.6 ± 3.0 (n=22)	3.8 ± 2.1 (n=22)	4.7 ± 2.7 (n=22)
Cruiser (88.4 kg)	3.3 ± 1.8 (n=6)	3.9 ± 2.3 (n=6)	3.8 ± 1.0 (n=6)	4.3 ± 1.2 (n=6)
Entire Cohort	5.0 ± 1.9[a]	8.0 ± 3.0[b]	4.3 ± 2.0[a]	6.9 ± 3.2[b]

[a] $p<0.01$
[b] $p<0.01$

Table 4: Absolute and Relative Body Mass Gain Stratified by Weight Class and Bout Outcome in Boxers (n=1,402)

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	International Promotions (n=466, 33.5%)		*Regional Promotions* (n=926, 66.5%)	
Weight Class	*Winners* (n=233)	*Losers* (n=233)	*Winners* (n=463)	*Losers* (n=463)
Straw	10.9 ± 0.0 (n=1)	5.7 ± 0.0 (n=1)	10.7 ± 0.4 (n=2)	10.9 ± 2.5 (n=2)
Junior Fly	8.5 ± 5.4 (n=4)	10.8 ± 3.2 (n=4)	5.5 ± 3.5 (n=6)	9.4 ± 3.3 (n=6)
Fly	8.0 ± 2.4 (n=7)	5.6 ± 2.2 (n=7)	9.0 ± 2.2 (n=4)	2.7 ± 2.4 (n=4)
Super Fly	12.2 ± 2.3 (n=2)	9.6 ± 2.0 (n=2)	9.3 ± 3.5 (n=16)	8.4 ± 3.3 (n=16)
Bantam	11.2 ± 1.1 (n=3)	9.6 ± 1.4 (n=3)	7.7 ± 3.8 (n=25)	7.7 ± 3.9 (n=25)
Super Bantam	8.9 ± 1.7 (n=17)	8.4 ± 3.5 (n=17)	8.1 ± 2.8 (n=25)	6.5 ± 3.2 (n=25)
Feather	8.5 ± 2.7 (n=25)	7.5 ± 3.0 (n=25)	7.7 ± 3.3 (n=48)	7.2 ± 2.6 (n=48)
Super Feather	10.4 ± 2.5 (n=21)	9.2 ± 2.8 (n=21)	7.4 ± 3.2 (n=48)	5.9 ± 3.2 (n=48)
Light	8.6 ± 2.4 (n=41)	7.5 ± 2.3 (n=41)	8.0 ± 2.8 (n=52)	6.3 ± 3.7 (n=52)
Super Light	9.3 ± 2.4 (n=32)	7.5 ± 3.0 (n=32)	7.8 ± 3.1 (n=60)	6.8 ± 2.9 (n=60)
Welter	8.2 ± 2.7 (n=39)	7.9 ± 2.2 (n=39)	7.8 ± 3.0 (n=65)	7.3 ± 3.3 (n=65)
Super Welter	9.7 ± 2.9 (n=18)	6.5 ± 3.9 (n=18)	7.3 ± 2.6 (n=38)	6.3 ± 3.4 (n=38)
Middle	7.8 ± 2.1 (n=9)	6.9 ± 3.8 (n=9)	6.4 ± 2.4 (n=31)	5.1 ± 3.0 (n=31)
Super Middle	8.4 ± 2.8 (n=6)	7.2 ± 3.7 (n=6)	7.0 ± 2.7 (n=23)	6.0 ± 3.3 (n=23)
Light Heavy	6.9 ± 3.0 (n=7)	6.2 ± 3.7 (n=7)	6.5 ± 3.1 (n=15)	4.0 ± 1.9 (n=15)
Cruiser	2.3 ± 0.0 (n=1)	5.5 ± 0.0 (n=1)	4.2 ± 2.4 (n=5)	4.1 ± 1.1 (n=5)

Entire Cohort	8.8 ± 2.7[a]	7.7 ± 3.0[a]	7.6 ± 3.1[b]	6.6 ± 3.3[b]
[a] p<0.01 [b] p<0.01				

Table 5: Relative Body Mass Gain Stratified by Sex, Competitive Level and Bout Outcome in Boxing Athletes (n=1,392)

Exploratory Model	**n**	**Adjusted OR (95% CI)**	**p-value**	**AUROC**
RWG	1392	1.13 (1.09-1.17)	<0.01	0.60
International	466	1.17 (1.09-1.26)	<0.01	0.62
Regional	926	1.11 (1.07-1.16)	<0.01	0.59
WD	681	1.14 (1.07-1.22)	<0.01	0.63
International	215	1.24 (1.08-1.44)	<0.01	0.65
Regional	451	1.12 (1.04-1.20)	<0.01	0.63
RWG & Victory Method (KO/TKO)	692	1.03 (0.98-1.09)	0.25	0.58
International	229	1.10 (0.99-1.23)	0.08	0.64
Regional	458	1.02 (0.96-1.09)	0.53	0.57
WD & Victory Method (KO/TKO)	692	1.05 (1.01-1.09)	<0.01	0.60
International	229	1.04 (0.96-1.12)	0.30	0.61
Regional	458	1.05 (1.01-1.10)	0.02	0.60

Table 6: Effect on Rapid Weight Gain and Weight Differential on Bout Outcome and Method of Victory in Boxing. The value n indicates the number of athletes in each model for RWG analyses (not including victory method), n represents the number of bouts for WD and all victory method analyses. **Abbreviations:** *Adjusted OR:* Adjusted odds ratio. *95% CI:* 95% Confidence interval. *AUROC*: Area under receiver operating curve. *RWG:* Relative weight gain. *BM:* Body mass. *Int*: International. *Reg*: Regional. *WD:* Weight differential. *KO:* Knockout. *TKO:* Technical knockout.