A survey of combat athletes' rapid weight loss practices and evaluation of the relationship with concussion symptom recall

Nasir Uddin, MRes[1,2], Mark Waldron, PhD[3,4,5], Stephen D Patterson, PhD[1], Stacy Winter, DProf[1] and Jamie Tallent, PhD[6, 7]

[1]Centre for Applied Performance Sciences, St Mary's University, Twickenham, UK.

[2]School of Human Sciences, London Metropolitan University, UK.

[3]A-STEM Research Centre, College of Engineering, Swansea University, Swansea, UK.

[4]School of Health and Behavioral Sciences, University of the Sunshine Coast, Queensland, Australia.

[5]Welsh Institute of Performance Science, Swansea University, Swansea, UK.

[6]School of Sport, Rehabilitation, and Exercise Sciences, University of Essex, Colchester, UK.

[7]Department of Physiotherapy, Faculty of Medicine, Nursing and Health Sciences, School of Primary and Allied Health Care, Monash University, Australia

Correspondence Address:

Nasir Uddin,

Centre for Applied Performance Sciences;

St Mary's University.

Waldegrave Road

TW1 4SX

140211@live.smuc.ac.uk

Acknowledgments: The authors would like to thank all the athletes who took part, Dr Yiannis Mavrommatis (St Mary's University), Tanat Tiraposin (313 Fitness Centre), Tahseen Takleh (Rise 'N Glide) and Legion Grappling Academy for their assistance with this study.

Manuscript word count: 3050

Abstract word count: 246

Abstract

Objective – There is a high incidence of concussion and frequent utilization of Rapid Weight Loss (RWL) methods among combat sport athletes, yet the apparent similarity in symptoms experienced as a result of a concussion or RWL has not been investigated. This study surveyed combat sports athletes to investigate the differences in symptom-onset and recovery between combat sports and evaluated the relationships between concussion and RWL symptoms.

Design – Cross-Sectional Study

Setting – Data were collected via an online survey.

Participants – 132 (male 115, female 17) combat sport athletes.

Interventions – Modified Sport Concussion Assessment Tool (SCAT) symptom checklist and weight-cutting questionnaire.

Main Outcome Measures – Survey items included combat sport discipline, weight loss, and medical history, weight-cutting questionnaire, and concussion & weight-cutting symptom checklists.

Results – Strong associations ($r_s = 0.6 – 0.7$, $p < 0.05$) were observed between concussion and RWL symptoms. The most frequently reported symptom resolution times were 24 - 48 h for a weight-cut (WC; 59%) and 3 - 5 days for a concussion (43%), with 60 - 70% of athletes reporting a deterioration and lengthening of concussion symptoms when undergoing a WC. The majority of athletes (65%) also reported at least one WC in their career to ‘*not go according to plan’*, resulting in a lack of energy (83%) and strength/power (70%).

Conclusions – RWL and concussion symptoms are strongly associated, with the majority of athletes reporting a deterioration of concussion symptoms during a WC. The results indicate that concussion symptoms should be monitored alongside hydration status to avoid any compound effects of prior RWL on the interpretation of concussion assessments and to avoid potential misdiagnoses among combat athletes.

Keywords: Traumatic brain injury; martial arts; boxing; wrestling; dehydration

Introduction

Concussions are mild traumatic brain injuries, generally experienced in sport from direct or indirect contact to the head, leading to linear and rotational acceleration of the brain (1). Concussions occur commonly in combat sports, such as Mixed Martial Arts (MMA), boxing, and kickboxing/Muay-Thai (KB/MT) due to head impacts in training and competition (2). Within boxing and MMA, concussion rates range between 16 and 25 per 100 athletic exposures (2, 3, 4), but this may be underestimated due to the absence of medical personnel in a large proportion of training time. With evidence of both short- and long-term health consequences as a result of repetitive head trauma (5, 6, 7), there is an emerging concern for the welfare of combat sport athletes. Therefore, determining the factors that contribute to concussion risk has become a priority.

Combat sports are categorized by weight divisions to ensure fair bouts between opponents and reducing potential injuries that might occur as a result of major weight differences (8). Typically, athletes aim to lose body mass (via water) in the shortest time possible, utilizing rapid weight loss (RWL) methods to obtain a perceived advantage of competing against a lighter, or weaker opponent (9). Common forms of RWL are fluid restriction, dehydration by sweating, diuretics, laxatives, and 'water-loading' – a method by which large volumes of fluid are consumed to manipulate renal hormones (e.g., aldosterone) and urine output, resulting in further weight loss (10, 11). These strategies can lead to hypo-hydration and, subsequently, alterations to renal function (12), immunoendocrine status (13), brain ventricular volume, and metabolic activity (14).

Both cellular dehydration, induced by hypo-hydration or 'water-cutting', and concussive events have been reported to impair central nervous system function (1, 14). While the mechanistic basis of these effects is currently uncertain and meaningful links are unestablished, disruption of fluid or ion homeostasis have been commonly reported among hypo-hydrated subjects and those experiencing concussions (14, 15). Hypo-hydration is also reported to lead to cognitive and neuromuscular deficits (16, 17), which could theoretically lead to reduced performance and a heightened risk of concussion. Patel et al. (18) investigated the symptomology of hypo-hydrated, non-concussed subjects, and found an increase in concussion-related symptoms, indicating that hypo-hydration and concussion may elicit similar effects. Indeed, any synergistic effects caused by hypo-hydration or concussive events could exacerbate the reported symptoms. Whether such physiological and physical alterations lead to combat athletes competing or training with a higher risk (or perceived risk) of brain trauma is unknown, though this has been anecdotally reported by mainstream media outlets (19). It is also unclear if certain combat sports place athletes at greater risk, particularly among striking-dominant disciplines or those with stringent weight classifications. Likewise, the clear overlap in the symptoms associated with hypo-hydration and concussion is problematic because diagnostic criteria for both conditions, and apparent severity thereof, are heavily dependent on subjective scoring processes. This increases the risk of concussion misdiagnosis around competition and could jeopardise athlete welfare.

Studies investigating concussion symptoms, in isolation, have frequently reported neck pain, fatigue or low energy, trouble falling asleep, and headaches (20), with 60% of MMA athletes returning to sparring within two days or less of their first symptom (21). Symptoms pertaining to heat stress and hypo-hydration are also reported to include headaches, dizziness, and increased perception of fatigue (18,22). Despite the incidence of concussions and abundant use of RWL among combat athletes (10, 23), to date, there has been no study of both self-reported concussion and RWL symptoms in combat athletes or evaluation of their inter-relationships. Therefore, the aims of this survey were to; i) investigate the differences in RWL and concussion symptom-onset and recovery between combat sports and ii) evaluate the relationships between concussion and RWL symptoms among combat athletes who have previously suffered from a concussion and undergone RWL prior to competition.

Methods

Participants

Following institutional ethical approval, participants were recruited via websites and social media, with informed consent obtained in accordance with the Declaration of Helsinki (2013). Participants were required to be over the age of 18 years, competed (at least once) in a combat sport, and had ‘cut weight’ prior to a competition. A ‘weight-cut’ (WC) was defined as any method leading to the loss of water, including but not limited to sauna, fluid restriction, diuretics, sweating gels, hot water baths, laxatives, fat burners, vomiting, and 'water-loading'. A total sample size of 132 (115 male, 17 female) combat athletes (age: 29 ± 8 years, body mass: 77.0 ± 12.9 kg, training experience: 13 ± 6 years) completed the survey. Sporting modalities reported were MMA (31%), KB/MT (20%), boxing (22%), wrestling (5%), Brazilian Jiu-Jitsu (BJJ; 10%), judo (8%) and 'others' (6%). Of the total sample, 70% of athletes were actively competitive, with 50% of male athletes and 29% of female athletes competing professionally.

The Survey

The survey combined two validated questionnaires: the Mixed Martial Arts Weight-Cutting Questionnaire (MAWC-Q; 24) and the Sport Concussion Assessment Tool 5 (SCAT-5; 25). Participants were asked preliminary questions regarding demographic, sporting, and medical history, after which the questionnaire was split into three sections, which aimed to address 1) WC practices, 2) WC symptoms, and 3) concussion history and symptoms.

The survey was piloted through completion by 15 combat athletes, a wrestling coach, and two experts (current researcher in the field of nutrition and a ringside medic). Written feedback was provided on the suitability and clarity of questions and amendments were made before the finalized version was released online (Joint Information Systems Committee Online surveys).

MAWC-Q

The MAWC-Q consisted of 26 questions, aiming to establish the prevalence and magnitude of RWL methods, specifically amongst MMA athletes. Modifications were made to the MAWC-Q, as follows: a) re-phrasing of questions to ensure appropriateness to all combat athletes, b) omission of questions regarding age of first WC, specific method of weight loss and symptoms, c) addition of questions related to cumulative number of WCs and time in between a WC, and d) the addition of a question, asking if a WC had '*not gone according to plan*' and a series of resultant scenarios. This was to establish the frequency and experiences of worst-case scenarios in weight-cutting practices.

SCAT-5

Symptom profiles for concussion and WCs were assessed using a 22-point symptom checklist from the SCAT-5. Each symptom was assessed using a Likert scale of severity, ranging from 0 (none) to 6 (severe +), however modifications were made to the checklist through the addition of two physical symptoms '*physically weak*' and '*unable to train*'. This resulted in a 'symptom score' of 24 (sum of each selected symptom) and a 'symptom severity' of 144 (sum of all Likert scale selections). Thereafter, participants answered six additional 'Yes or No' questions (Table 2, Figure 4) related to the relationship between symptom recovery, fluid consumption, and head impacts. The sum of the symptom score and six additional questions led to a third measure: an 'adjusted symptom score' of 57.

Statistical Analysis

Statistical analyses were completed using SPSS (v22, IBM Corp., Armonk, NY). Data were presented as means ± standard deviations (SD), frequency of responses to each item (n), range (where appropriate), or median and interquartile range (IQR) if non-normally distributed. Assumptions of normality and equality of variance were assessed via Shapiro–Wilk and Levene's tests, respectively. For parametric (WC symptom variables) data, a one-way analysis of variance (ANOVA) was used to assess the difference between each sport (MMA, Boxing, KB/MT, Judo, Wrestling, & BJJ). For non-parametric data, a Kruskal-Wallis test was used to establish differences in concussion symptom variables between each sport. Where there was a significant main effect, pairwise comparisons were examined by a Tukey (parametric) or Dunn-Bonferroni *post-hoc* (non-parametric) to account for the homogeneity of variance. A Spearman's Rho correlation was used to assess the relationship between concussion and WC symptom variables (symptom severity, symptom score, adjusted symptom score). An alpha level of ≤0.05 was set for all analyses.

Results

Modified MAWC-Q

The majority of athletes (83%) reported using a fight preparation camp, with the highest reported WCs being 10 kg (10 days), 8.6 kg (7 days), 7 kg (3 days), and 5 kg (24 h). Median WC was 6.6% of body mass (Table 1A). Most athletes (65%) reported a WC to '*not going according to plan*', with the most frequent consequences being a lack of energy (83%), lack of strength/power (70%), and suboptimal coordination and reaction time (55%) (Table 1B). Responses included in the 'other' section were: '*collapsed*' & '*cramping*' (n = 2), and '*coughing blood and unable to function*', '*projectile vomiting*', '*was asked to keep weight off for an extra 36 hours*', '*felt cold and lips became blue during fight*', '*menopause*', '*fluid ascites*', and '*process was more grueling due to period making me retain more water*' (n = 1).

******Insert Table 1A & 1B here******

WC and concussion symptom profiles

There was a significant relationship between WC and concussion symptom severity (r_s = 0.68, 95% CI [0.54, 0.74], $p < 0.001$), symptom scores (r_s = 0.60, 95% CI [0.44, 0.72], $p < 0.001$) and adjusted symptom scores (r_s = 0.72, 95% CI [0.59, 0.81], $p < 0.001$) (Figure 1).

******Insert Figure 1 here******

Mean scores for WC symptom severity, symptom score, and adjusted score were 49 ± 30 out of 144, 15 ± 7 out of 24, and 19 ± 9 out of 57, respectively. A significant main effect was observed in WC symptom severity ($F_{(5, 118)} = 5.464$, $p < 0.001$), with differences between MMA and KB/MT (59.2 *vs.* 36.5, $p = 0.01$), MMA and boxing (59.2 *vs.* 38.0, $p = 0.02$), judo and KB/MT (67.5 *vs.* 36.5, $p = 0.02$), judo and boxing (67.5 *vs.* 38.0, $p = 0.03$), judo and BJJ (67.5 *vs.* 31.9, $p = 0.04$). A significant main effect was also observed in adjusted symptom scores ($F_{(5, 118)} = 3.213$, $p = 0.009$), with a difference between MMA and KB/MT (22.0 *vs.* 15.6, $p = 0.03$) (Figure 2A & B).

Median (IQR) scores for concussion symptom severity, symptom score, and adjusted score were 48 (57) out of 144, 18 (14) out of 24 and 26 (19) out 57, respectively. A significant main effect was observed in concussion symptom severity ($X^2_{(5)} = 14.142$, $p = 0.015$), with a difference between MMA and boxing (56.0 *vs.* 31.9, $p = 0.023$). A main effect was also observed in adjusted symptom scores ($X^2_{(5)} = 13.348$, $p = 0.02$), with pairwise comparisons showing a significant difference between MMA and boxing (55.5 *vs*. 32.8, $p = 0.04$) (Figure 2C & D).

Insert Figure 2 here

Of the 132 combat athletes who completed the survey, approximately two-thirds (64%) reported sustaining at least one concussion during their professional career, but only 45% were hospitalized or underwent imaging and 34% were medically diagnosed. The median (IQR) reported time before returning to training after a concussion, was 7 (12) days.

Insert Figure 3 here

The majority of athletes (70%) reported deterioration of concussion symptoms during and after a fight or sparring session, while 37% reported deterioration of WC symptoms. A summary of symptom recovery responses can be found in Table 2.

Insert Figure 4 here

Insert Table 2 here

Discussion

This study surveyed combat sports athletes to investigate the differences in symptom-onset and recovery between combat sports, and evaluated the relationships between concussion and RWL symptoms. There were strong associations between concussion and RWL symptom profiles, particularly for feelings of dizziness, headaches, physical weakness, and fatigue. The majority of athletes (60 - 70%) reported a deterioration and lengthening of concussion symptoms when undergoing a WC, suggesting that prior RWL might affect concussion symptoms.

This is the first study to assess the relationship between reported symptoms experienced as a result of previous RWL events and concussions among combat athletes. Our findings indicate a positive relationship between symptoms associated with RWL (via dehydration and leading to hypo-hydration) and concussions, based on both the reported total number and severity of symptoms (Figure 1). Analysis of individual symptoms revealed that the most common WC symptoms were physical weakness, fatigue, dizziness, not feeling 'right', difficulties in concentration and irritability. The most frequently selected concussion symptoms comprised the same responses as WC, in addition to headaches, head pressure, and neck pain (Figure 3). These findings are in accordance with previous literature (18, 29), indicating that RWL via dehydration increases concussion-related symptoms. The possible reasons for feelings of weakness and fatigue could relate to perturbations in ionic balance to restore osmotic equilibrium (30), and subsequent alterations to cell excitability and excitation-contraction coupling capabilities (31, 32). Hypo-hydration also leads to a reduction in total blood volume (hypovolemia), leading to light-headedness and dizziness, while dizziness post-concussion may also be related to vestibular system damage, further increasing headaches, feelings of confusion and concentration difficulty (33). This may explain why the most frequently reported symptom (for both concussed and RWL athletes) after a WC or sparring session was headaches (18) (Figure 3 & 4). Therefore, the implications of less discernible concussion-related symptoms (e.g., dizziness, headaches) in athletes undergoing RWL, might mask or exacerbate the effects of cumulative sub-concussive impacts received throughout the bout. This challenges the accuracy of concussion identification tools, particularly if baseline protocols do not account for hydration status. The extreme practices of WC are likely to introduce a source of external noise to the assessment of concussion symptoms, meaning that knowledge of hydration status is necessary during all protocols to avoid erroneous results. Given that the risks associated with extreme WC could endanger athlete welfare in pursuit of a competitive advantage, further consideration of sporting governing bodies to set limits on weight-cutting is warranted (34).

To the best of our knowledge, our study is the first to report the various experiences of combat athletes who felt their WC did not go according to plan, with 70 - 80% of athletes reporting a lack of energy, strength, and power, as well as 40 - 50% reporting a reduction in coordination and feeling more susceptible to concussion (Table 1B). It was also found that 60 - 70% of athletes reported their concussion symptoms to deteriorate and lengthen during a camp where they were weight-cutting, and a fight in which they were dehydrated (Table 2). Furthermore, ~ 50% of athletes reported increased feelings of being 'slowed down', experiencing fatigue, irritability, and physical weakness after fighting in a hypo-hydrated state or cutting weight in camp (Figure 4). These reports could indicate mechanisms by which hypo-hydration exacerbates the physiological responses to a concussion. Indeed, concussions are known to lead to hyper-glycolysis, coupled with relative depletion of energy reserves, in order to restore ionic imbalances (35). The combination of hyper-glycolysis, alongside additional physiological stressors (in a bout) and hypo-hydration, may induce a competing substrate demand, which could be further exacerbated by reduced overall blood volume. In addition, it is possible that damage to neurons (e.g., diffuse axonal or shear injuries) is enhanced secondary to hypo-hydration due to altered membrane stability (32), tissue elasticity (36) and cerebrospinal fluid production (37), leaving the brain more vulnerable to cortical damage from trauma. This could, subsequently, lead to prolonged recovery or further exposure to head trauma, which in chronic cases has been associated with later development of neurodegenerative diseases e.g., dementia pugilistica, chronic traumatic encephalopathy, and Alzheimer's disease (38, 39, 40).

The individual reports of mishaps during WC practices, while anecdotal and possibly related to factors unknown in this study, expose a plethora of additional negative outcomes associated with RWL. In addition, the majority of athletes (65%) stated at least one incident of RWL to "*not go according to plan*", indicating the perceived competitive advantage may often not be achieved by combat athletes

(41). It is crucial these reports do not go ignored and athletes seek medical/professional advice with regards to RWL strategies, as many poor outcomes in individual athletes have been documented (42). In addition, MMA athletes presented higher symptom severity and adjusted scores for both concussion and RWL (Figure 2), indicating RWL and concussion symptoms to be more severe in MMA. Symptom severity of RWL in MMA was similar to wrestling, which is also associated with larger and more aggressive RWL magnitudes and methods (23). Interestingly, concussion symptom severity and adjusted scores were not different between sports, except between MMA and boxing. This may be explained by the higher range of weight-classes and lack of indirect head impacts (e.g., takedowns) experienced by boxing athletes in comparison to MMA. Given the differences in symptom severity across various combat sports, we recommend that combat sport organizations aim to incorporate baseline concussion and continual hydration testing protocols to verify the effects of hypo-hydration and concussions independently.

To date, this is the first study to report on the resolution of combined RWL and concussion symptoms. Almost all athletes (94%) reported their WC symptoms to improve with fluid replenishment; however, the most frequently reported recovery time (for those with increased symptom scores following a fight) was 24-48 h (Table 2). This indicates that, despite fluid replenishment, over a day was required for said symptoms to resolve. An explanation for this could, in part, be due to a) the method of hydration i.e., bolus *vs.* tapered drinking strategies (43), b) electrolyte and carbohydrate deficient fluids insufficiently restoring blood osmolality, volume, and glucose (44), or c) concussive/sub-concussive impacts further adding to alterations in cell integrity and ionic imbalances (45, 46). Coaches, athletes and clinicians, should consider the implications of RWL and all aspects of training load (particularly different modes, such as sparring), as this could heavily impact recovery and preparation for a bout (13).

One of the main limitations of our study was that we did not account for the additional weight-loss methods used during fight preparation (e.g., food restriction). Furthermore, it is possible that symptoms were misreported due to surpassed time, which could mean that the effects of RWL on concussion-related symptoms have been over- or under-estimated in the current study.

Conclusion

Overall, our findings suggest that RWL symptoms are strongly associated with concussion symptoms, and though these varied between sports, MMA athletes present with the most severe symptoms associated with RWL and concussions. Based on our findings, it is possible that prior WC practices could exacerbate the deleterious effects of a concussion. Indeed, given that WC practices occur before most concussive events and that athletes are unlikely to have recovered from the effects of hypo-hydration by this time, it is possible that WC increases the risk of misdiagnosis. If hydration status is unmonitored during any neurocognitive assessment, such as that performed during baseline concussion assessment protocols or pre-competition, the results are likely to be affected. Where an athlete is safe and able, we recommend that clinicians should monitor hydration status (e.g., point-of-care urine or blood analysis and gross body mass), when performing baseline and post-recovery neurocognitive tests, such as those used to screen for concussion symptoms. More generally, the findings of the current survey suggest that RWL via WC methods should be avoided near to combat training or competition, as it is possible that this could interfere with the decision making of medical professionals' diagnosis of concussion.

References

1. Blennow K, Hardy J, Zetterberg H. The neuropathology and neurobiology of traumatic brain injury. *Neuron*. 2012;76(5):886-99.
2. Hutchison MG, Lawrence DW, Cusimano MD, et al. Head Trauma in Mixed Martial Arts. *Am J Sports Med*. 2014;42(6):1352-1358.
3. Buse GJ. No holds barred sport fighting: a 10-year review of mixed martial arts competition. *Br J Sports Med*. 2006;40(2):169-172.
4. Zazryn TR, McCrory PR, Cameron PA. Injury rates and risk factors in competitive professional boxing. *Clin J Sport Med*. 2009;19(1):20-25.
5. Gosselin N, Bottari C, Chen JK, et al. Evaluating the cognitive consequences of mild traumatic brain injury and concussion by using electrophysiology. *Neurosurgical Focus*. 2012;33(6):E7.
6. Bernick C, Banks SJ, Shin W, et al. Repeated head trauma is associated with smaller thalamic volumes and slower processing speed: the Professional Fighters' Brain Health Study. *Br J Sports Med*. 2015;49(15):1007-1011.
7. Bernick C, Shan G, Zetterberg H, et al. Longitudinal change in regional brain volumes with exposure to repetitive head impacts. *Neurology*. 2020;94(3):e232-e240.
8. Mendes SH, Tritto AC, Guilherme JP, et al. Effect of rapid weight loss on performance in combat sport male athletes: does adaptation to chronic weight cycling play a role?. *Br J Sports Med*. 2013;47(18):1155-1160.
9. Pallarés JG, Martínez-Abellán A, López-Gullón JM, et al. Muscle contraction velocity, strength and power output changes following different degrees of hypohydration in competitive olympic combat sports. *J Int Soc Sports Nutr*. 2016;13:10.

10. Matthews JJ, Nicholas C. Extreme Rapid Weight Loss and Rapid Weight Gain Observed in UK Mixed Martial Arts Athletes Preparing for Competition. *Int J Sport Nutr Exerc Metab*. 2017;27(2):122-129.

11. Reale R, Slater G, Cox GR, et al. The Effect of Water Loading on Acute Weight Loss Following Fluid Restriction in Combat Sports Athletes. *Int J Sport Nutr Exerc Metab*. 2018;28(6):565-573.

12. Kasper AM, Crighton B, Langan-Evans C, et al. Case Study: Extreme Weight Making Causes Relative Energy Deficiency, Dehydration, and Acute Kidney Injury in a Male Mixed Martial Arts Athlete. *Int J Sport Nutr Exerc Metab*. 2019;29(3):331-338.

13. Uddin N, Tallent J, Waldron M. Physiological and perceptual responses to a five-week pre-event taper in professional mixed martial arts athletes. *The Journal of Sport and Exercise Science*. 2020;4(2):90-.

14. Kempton MJ, Ettinger U, Foster R, et al. Dehydration affects brain structure and function in healthy adolescents. *Hum Brain Mapp*. 2011;32(1):71-79.

15. Giza, CC., & Hovda, DA. (2014). The new neurometabolic cascade of concussion. *Neurosurgery*, *75*(suppl_4), S24-S33.

16. Cian C, Koulmann N, Barraud PA, et al. Influences of variations in body hydration on cognitive function: Effect of hyperhydration, heat stress, and exercise-induced dehydration. *Journal of Psychophysiology*. 2000;14(1):29.

17. Bigard AX, Sanchez H, Claveyrolas G, Martin S, Thimonier B, Arnaud MJ. Effects of dehydration and rehydration on EMG changes during fatiguing contractions. *Med Sci Sports Exerc*. 2001;33(10):1694-1700.

18. Patel AV, Mihalik JP, Notebaert AJ, et al. Neuropsychological performance, postural stability, and symptoms after dehydration. *J Ath Train*. 2007;42(1):66-75.

19. Raimondi, M. May 3, 2015. Invicta's Rothenhausler retires due to concussions. from https://www.mmafighting.com/2015/5/3/8532391/invictas-veronica-rothenhausler-retires-due-to-concussions-is-it. Accessed 16 June 2021.

20. Brown DA, Grant G, Evans K, Leung FT, Hides JA. The association of concussion history and symptom presentation in combat sport athletes. *Phys Ther Sport*. 2021;48:101-108.

21. Heath CJ, Callahan JL. Self-reported concussion symptoms and training routines in mixed martial arts athletes. *Res Sports Med*. 2013;21(3):195-203.

22. Armstrong LE, Hubbard RW, Kraemer WJ, et al. Signs and Symptoms of Heat Exhaustion During Strenuous Heat Acclimation Exercise. *ARMY RESEARCH INST OF ENVIRONMENTAL MEDICINE NATICK MA.*1986.

23. Barley OR, Chapman DW, Abbiss CR. Weight Loss Strategies in Combat Sports and Concerning Habits in Mixed Martial Arts. *Int J Sports Physiol Perform.* 2018;13(7):933-939.

24. Hillier M, Sutton L, James L, et al. High Prevalence and Magnitude of Rapid Weight Loss in Mixed Martial Arts Athletes. *Int J Sport Nutr Exerc Metab.* 2019;29(5):512-517.

25. Echemendia RJ, Meeuwisse W, McCrory P, et al. The Sport Concussion Assessment Tool 5th Edition (SCAT5): Background and rationale. *Br J Sports Med*. 2017;51(11):848-850.

26. Weber AF, Mihalik JP, Register-Mihalik JK, et al. Dehydration and performance on clinical concussion measures in collegiate wrestlers. *J Athl Train*. 2013;48(2):153-160.

27. Iida S. The Effects of Hypohydration on Neurocognitive, Balance, Vestibular Ocular Motor Functions and Mood State. University of Arkansas; 2016.

28. Collins SM, Lininger MR, Bowman TG. The Effect Of Mild Exercise Induced Dehydration On Sport Concussion Assessment Tool 3 (SCAT3) Scores: A within-subjects design. *Int J Sports Phys Ther*. 2021;16(2):511-517.

29. Castor-Praga C, Lopez-Walle JM, Sanchez-Lopez J. Multilevel Evaluation of Rapid Weight Loss in Wrestling and Taekwondo. *Front Sociol*. 2021;6:637671.

30. Cheuvront SN, Kenefick RW. Dehydration: physiology, assessment, and performance effects. *Compr Physiol*. 2014;4(1):257-285.

31. McKenna MJ, Bangsbo J, & Renaud JM. Muscle K+, Na+, and Cl− disturbances and Na+-K+ pump inactivation: implications for fatigue. *J Appl Phys*. 2008;104(1):288-295.

32. Hackney KJ, Cook SB, Fairchild TJ, et al. Skeletal muscle volume following dehydration induced by exercise in heat. *Extreme physiology & medicine*. 2012;1(1), 1-9.

33. Sharp DJ, Jenkins PO. Concussion is confusing us all. *Pract Neurol.* 2015;15(3):172-86.

34. Artioli GG, Saunders B, Iglesis RT, et al: It is time to ban rapid weight loss from combat sports. *Sports Med.* 2016;46:1579-84.

35. Giza CC, Hovda DA. The new neurometabolic cascade of concussion. *Neurosurgery*. 2014;75 Suppl 4(0 4):S24-33.

36. Kreft B, Bergs J, Shahryari M, et al. Cerebral Ultrasound Time-Harmonic Elastography Reveals Softening of the Human Brain Due to Dehydration. *Front Physiol*. 2021;11:616984.

37. Duning T, Kloska S, Steinsträter O, et al. Dehydration confounds the assessment of brain atrophy. *Neurology*. 2005;64(3):548-550.

38. Bazarian JJ, Cernak I, Noble-Haeusslein L, et al. Long-term neurologic outcomes after traumatic brain injury. *J Head Trauma Rehabil*. 2009;24(6):439-451.

39. Gavett BE, Stern RA, McKee AC. Chronic traumatic encephalopathy: a potential late effect of sport-related concussive and subconcussive head trauma. *Clin Sports Med*. 2011;30(1):179-xi.

40. Rabadi MH, Jordan BD. The cumulative effect of repetitive concussion in sports. *Clin J Sport Med*. 2001;11(3):194-198.

41. Kirk C, Langan-Evans C, Morton JP. Worth the weight? Post weigh-in rapid weight gain is not related to winning or losing in professional mixed martial arts. *Int J Sport Nutr Exerc Metab*. 2020;30(5):357-61.

42. Magraken, E. September 3, 2014. Documenting The Tolls of Rapid Extreme Weight Cuts in MMA. from https://combatsportslaw.com/2014/09/03/yes-athletes-have-been-hurt-from-weight-cutting-in-mma/. Accessed 16 June 2021.

43. Jones EJ, Bishop PA, Green JM, Richardson MT. Effects of metered versus bolus water consumption on urine production and rehydration. *Int J Sport Nutr Exerc Metab*. 2010;20(2):139-144.

44. Shirreffs SM. Hydration in sport and exercise: water, sports drinks and other drinks. *Nutrition bulletin*. 2009;34(4):374-379.

45. Zonner SW, Ejima K, Bevilacqua ZW, et al. Association of Increased Serum S100B Levels With High School Football Subconcussive Head Impacts. *Front Neurol*. 2019;10:327.

46. Wirsching A, Chen Z, Bevilacqua ZW, Huibregtse ME, Kawata K. Association of Acute Increase in Plasma Neurofilament Light with Repetitive Subconcussive Head Impacts: A Pilot Randomized Control Trial. *J Neurotrauma*. 2019;36(4):548-553.

Table 1. Participant preparation camp and WC characteristics (average) (A), WC characteristics (frequency) (B).

Table 2. Symptom recovery profile, Y = yes.

Figure 1. Significant correlations between concussion and WC with 95% confidence intervals. (A) symptom severity (r_s = 0.68), (B), symptom scores (r_s = 0.60), and (C) adjusted symptom scores, (r_s = 0.72). (N = 80).

Figure 2. Average WC symptom severity (A), adjusted symptom score (B), concussion symptom severity (C) and adjusted symptom score (D) for each combat sport.

Figure 3. Percentage of athletes who selected each symptom severity for WC (3A) and concussions (3B).

Figure 4. Percentage of athletes who reported symptoms to deteriorate after hypo-hydration or head impact, WC (N – 49), concussion (n = 56).

Table 1. Participant preparation camp and WC characteristics (average) (A), WC characteristics (frequency) (B).

A

	Mean ± SD / Median (IQR)	**Range**
Average camp length (weeks)	7 ± 3	4 - 12
Shortest camp length (weeks)	3 ± 2	1 - 5
General 'walking' weight (kg)	76.3 ± 13.0	47 - 105
Usual weight cut (kg)	5 (5)	0 - 22
Usual weight regain (kg)	3 (3.5)	0 - 10
Shortest weight cut timing (days)	3 (6)	0 - 15
Weight lost (kg)	5 (4)	0 - 13
Weight loss in 24 h before weigh-in (kg)	2 (2)	0 - 5
Total no. of weight cuts in career	15 (20)	0 - 147

B

	n	**%**
Time between weigh-in and bout (h)		
24 – 36	75	56.8
12 – 23	14	10.6
6 – 12	10	7.6
2 – 5	20	15.2
< 2	6	4.5
Time between each weight cut (months)		
< 1	76	57.6
1 – 2	31	23.5
3 – 4	18	13.6
≥ 5	7	5.3
Weight-cut not according to plan (Y/N)	Y = 86	65.1
Felt a lack of energy	71	82.6
Felt a lack of strength/power	60	69.8
Coordination & reaction time felt suboptimal	47	54.7
Felt dehydrated during the fight	41	47.7
Felt easier to get 'rocked' during the fight	33	38.4
Initially failed to make weight	30	34.9
Fell ill in the lead up to the fight	27	31.4
Felt too bloated going into the fight	20	23.3
*Other**	11	12.8

Table 2. Symptom recovery profile, Y = yes.

Symptom recovery related questions	**WC**		**Concussion**	
	% (n)	**Total n**	**% (n)**	**Total n**
Do you feel that these symptoms became worse during/after the fight (or sparring session) within which you were dehydrated? (Y)			70 (56)	80
Do you feel that these symptoms improved when you were able to consume fluids again? (Y)	94 (124)	132	30 (17)	56
Do you feel that these symptoms lasted longer in comparison to a camp/session when you were not cutting weight? (Y)	61 (81)	132	60 (48)	80
Do you feel that you experienced less of these symptoms in a camp/session when you were not cutting weight? (Y)	89 (117)	132	70 (56)	80
Do you feel that these symptoms became worse during/after the fight (or sparring session)? (Y)	37 (49)	132		
How long did these symptoms tend to last for?		49		56
Less than 24 h	22 (11)		15 (12)	
24-48 h	59 (29)		28 (23)	
3-5 days	10 (5)		43 (34)	
6-13 days	2 (1)		8 (6)	
14-28 days	6 (3)		4 (3)	
Over 28 days	0		3 (2)	

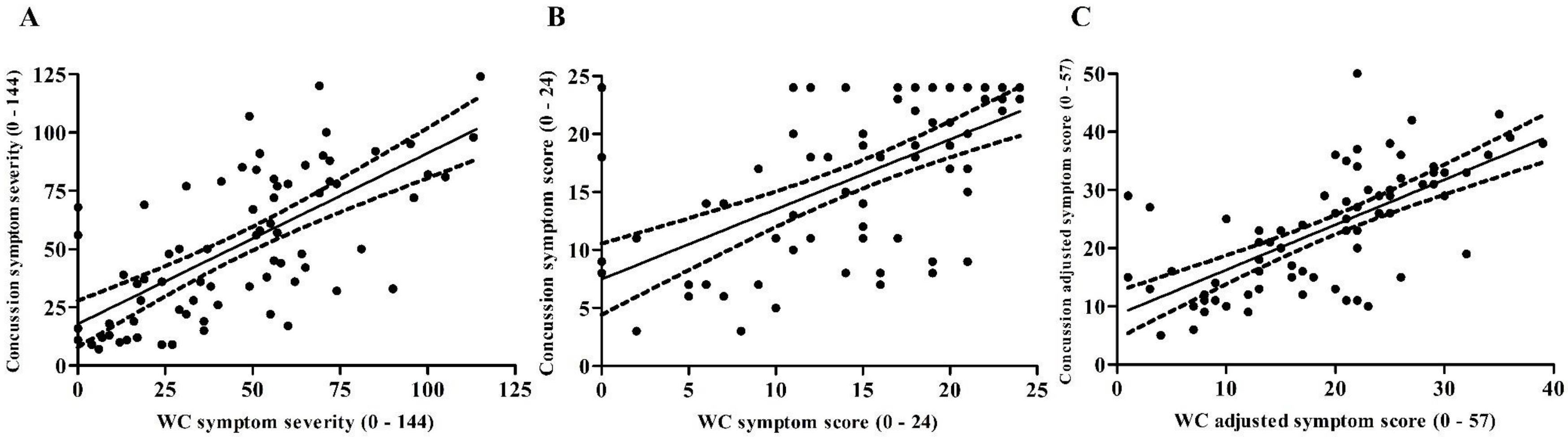

Figure 1. Significant correlations between concussion and WC with 95% confidence intervals. (A) symptom severity (r_s = 0.68), (B) symptom scores (r_s = 0.60) and (C) adjusted symptom scores, (r_s = 0.72). (N = 80).

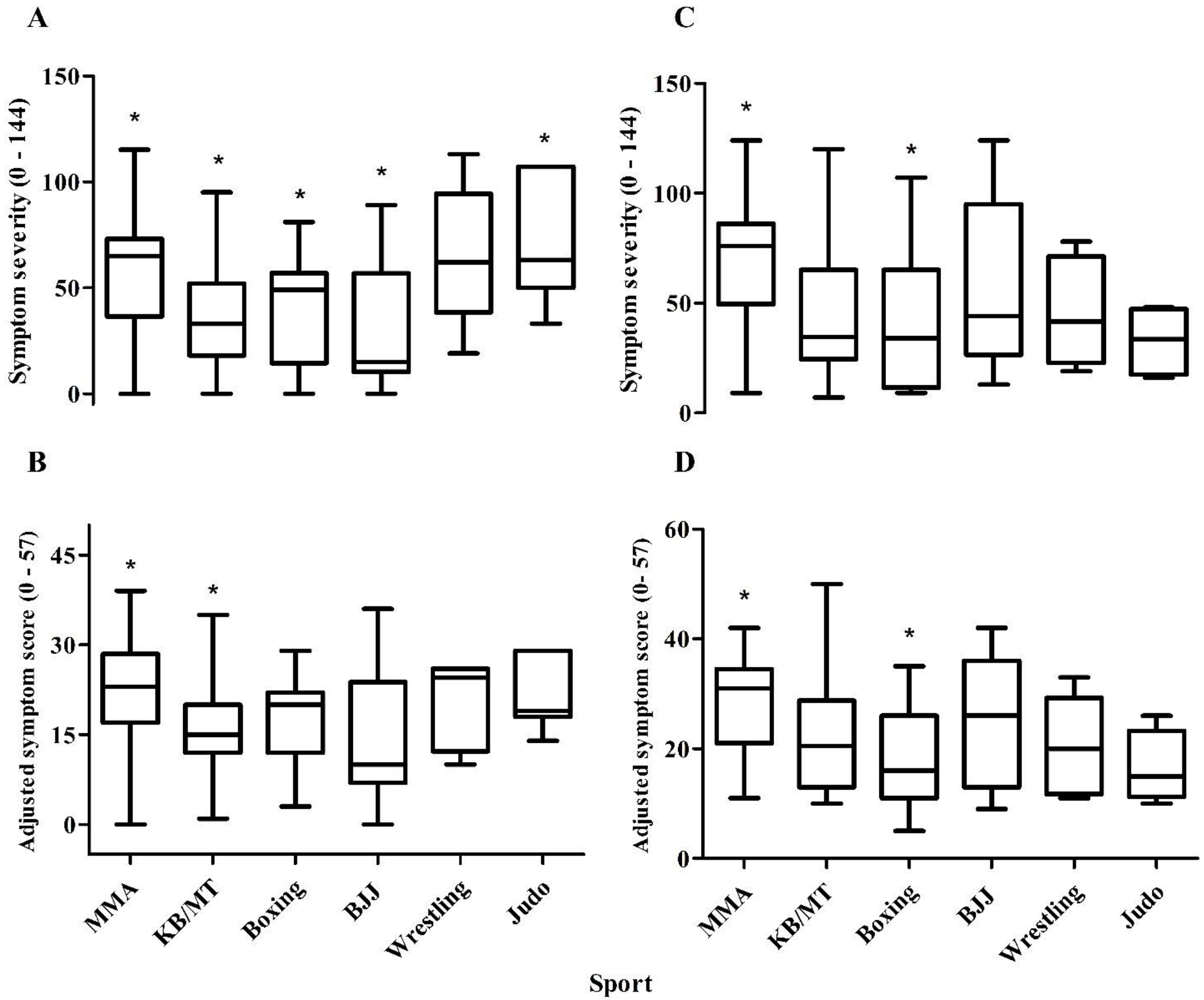

Figure 2. Average WC symptom severity (A), adjusted symptom score (B), concussion symptom severity (C) and adjusted symptom score (D) for each combat sport.

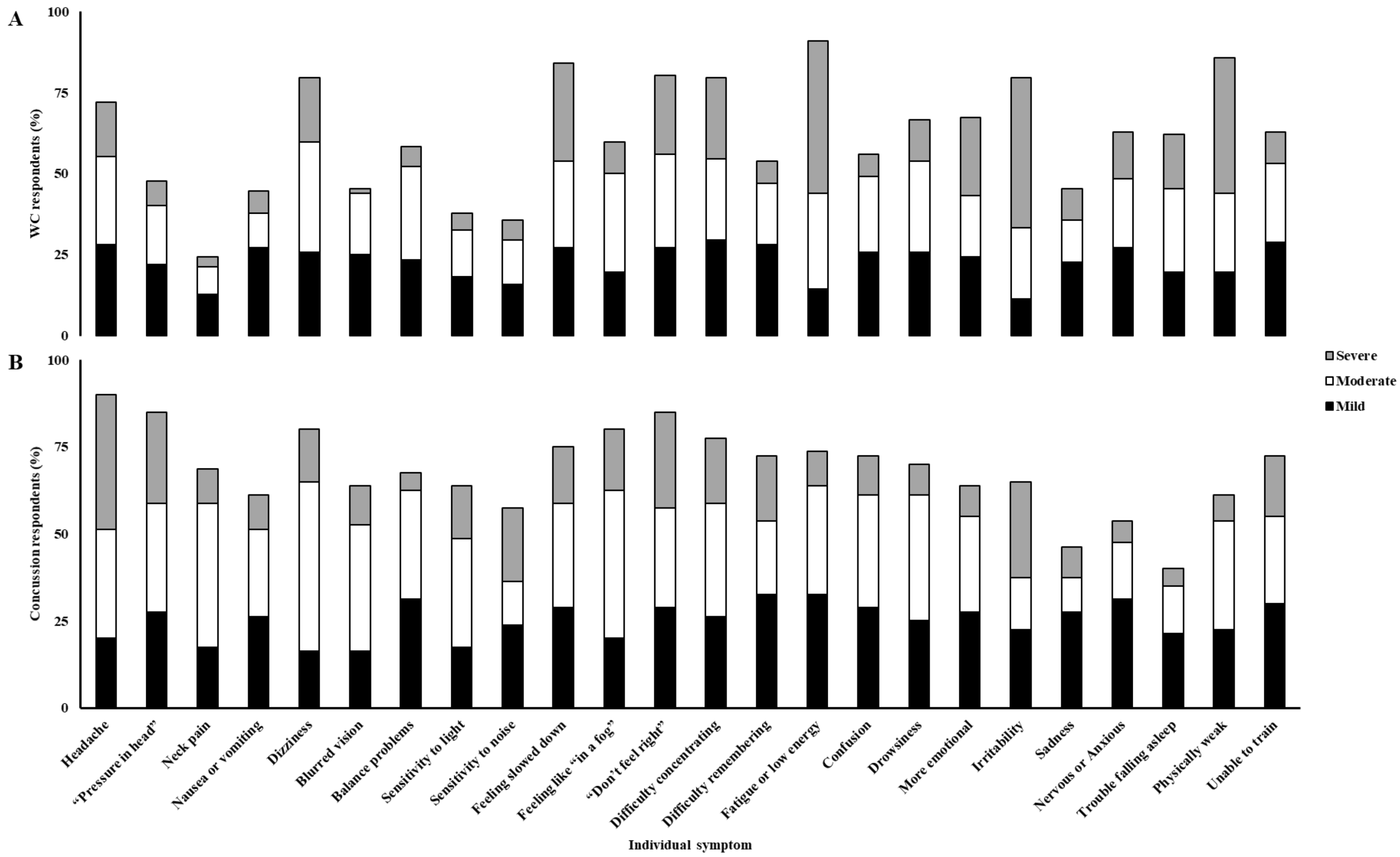

Figure 3. Percentage of athletes who selected each symptom severity for WC (3A) and concussions (3B).

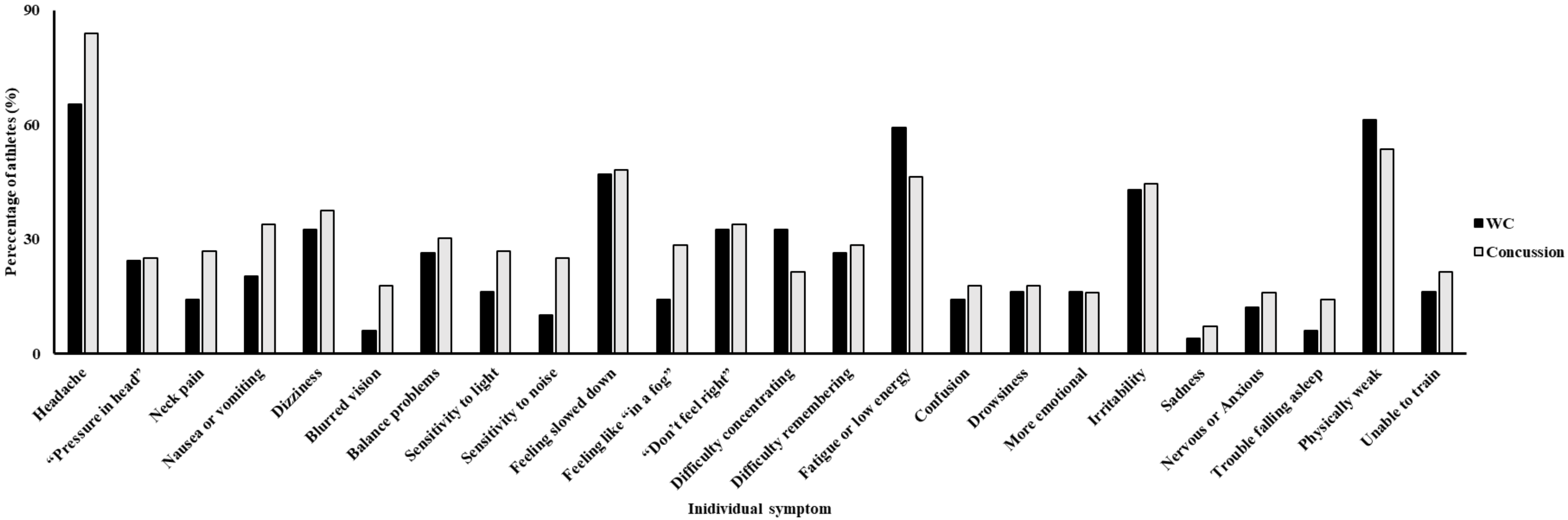

Figure 4. Percentage of athletes who reported symptoms to deteriorate after hypo-hydration or head impact, WC (n = 49), concussion (n = 56).