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Urine specific gravity as an indicator of dehydration in Olympic combat sport athletes; considerations for research and practice

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ABSTRACT

Urine specific gravity (USG) is the most commonly reported biochemical marker used in research and applied settings to detect fluid deficits in athletes, including those participating in combat sports. Despite the popularity of its use, there has been a growing debate regarding the diagnostic accuracy and the applicability of USG in characterizing whole-body fluid status and fluctuations. Moreover, recent investigations report universally high prevalence of hypohydration (~90%) via USG assessment in combat sport athletes, often in spite of stable body-mass. Given the widespread use in both research and practice, and its use in a regulatory sense as a ‘hydration test’ in combat sports as a means to detect dehydration at the time of weigh-in, understanding the limitations and applicability of USG assessment is of paramount importance.

Inconsistencies in findings of USG readings, possibly as a consequence of diverse methodological research approaches and/or overlooked confounding factors, preclude a conclusive position stand within current combat sports research and practice. Thus the primary aim of this paper is to critically review the literature regarding USG assessment of hydration status in combat sports research and practice. When taken on balance, the existing literature suggests: the use of laboratory derived benchmarks in applied settings, inconsistent sampling methodologies, the incomplete picture of how various confounding factors affect end-point readings, and the still poorly understood potential of renal adaptation to dehydration in combat athletes; make the utility of hydration assessment via USG measurement quite problematic, particularly when diet and training is not controlled.

Keywords: Urine specific gravity, dehydration, combat sports, weigh in, weight cutting

Introduction

The importance of adequate hydration in the optimization of many physiological functions relevant to sports performance is well recognized. While the majority of research and applied recommendations have focused on endurance and team sports, athletes participating in all sports are encouraged to develop hydration plans and maintain an adequate fluid intake in order to prevent physiological disturbances associated with suboptimal body-water status (Shirreffs, 2005). In combat sports in particular, extreme patterns of dehydration (often to reduce body mass (BM) prior to weigh-in) are well documented (Franchini, Brito, & Artioli, 2012); and hypohydration even during non-competitive periods among combat sport athletes is documented to exceed that of athletes in non-weight category sports (Reale, Slater, & Burke, 2017; Shirreffs & Maughan, 1998; Zubac, Antelj, Olujic, Ivančev, & Morrison, 2017a).

Being able to accurately categorize athletes as dehydrated or euhydrated offers increased confidence in interpreting research findings, as well as appropriately prescribing hydration interventions. In the acute setting, changes in BM alone have been shown to satisfactorily reflect body-water changes (Armstrong, 2005); however, in the absence of repeated measures (such as in the case of cross-sectional research or in the setting of a single athlete consult), biochemical markers are required. Scientists and practitioners use various biochemical markers in order to screen fluid balance in athletes,
with urinary indicators being the most commonly reported (Armstrong, 2005; Sawka et al., 2007). The validity of such measures is derived from an understanding of renal physiology; i.e. the kidney’s ability to concentrate urine in response to changes in total body-water volume and subsequent dehydration. Plasma fluid deficit(s) raise sodium concentrations and subsequently elevate anti-diuretic hormone (ADH), which reduces water excretion (urine production), thereby increasing the concentration of dissolved particles in the urine. Taking advantage of this homeostatic mechanism, and the ease in which urine samples can be collected and assessed, field-based assessments of urine concentration and colour have emerged as popular methods to characterize acute dehydration among athletes. While urine colour is a cost-effective and quick measure, it has been shown to be relatively imprecise when compared to other measures (Cheuvront, Ely, Kenefick, & Sawka, 2010); thus measures of urine concentration (i.e. urine osmolality, U\text{OSM}) and urine specific gravity (U\text{SG}) are generally preferred. Urine osmolality is a direct measure of the number of dissolved particles within a urine sample, whereas U\text{SG} is a measure of the weight of urine and the particles contained in it. In general, the weight of urine will increase similarly to increases in solute numbers; however, as U\text{OSM} is a direct measure of solute concentration, it is often considered to better reflect true changes in total body fluid balance (Voinescu, Shoemaker, Moore, Khanna, & Nolph, 2002). The requirement for laboratory equipment and expertise in the measurement of U\text{OSM} means the less resource intense, yet commonly suggested to be comparably valid measure of U\text{SG} via refractometry has traditionally been recommended as a suitable alternative for the scientist or practitioner (Chadha, Garg, & Alon, 2001). In fact, modern refractometer units may be calibrated in mOsmol\cdot kg\textsuperscript{-1} H\textsubscript{2}O and show good validity when compared to laboratory-based measures (Sparks & Close, 2013).

Urine assessment in combat sport athletes

Although not as extensively investigated as other sports, a growing body of literature has documented urine measures alongside BM changes in combat sport athletes; however, concerns remain regarding study methodologies and the validity of interpretations (Table I).

Measures of urine concentration are not only common in research and as tools for sports nutrition professionals working with athletes, but may also form a component of regulatory practices aimed at discouraging dehydration. For example, in 1998, the National College Athletic Association (NCAA) initiated a process of U\text{SG} assessment via a single-time-point urine sample collection at the time of weigh-in for competitions, and also as part of assessments to determine a safe ‘minimum wrestling weight’. This regulation was developed in an effort to counter the prevalence of extreme dehydration commonly associated with rapid weight loss practices among college wrestlers, which have resulted in deaths (Loenneke, Wilson, Barnes, & Pujol, 2011). In line with the broader body of research and its use in a regulatory sense by the NCAA, U\text{SG} assessment is the most commonly reported dehydration marker used to detect whole-body fluid deficits in Olympic combat athletes (Zubac et al., 2017b). Fernandez-Elias et al. (2014) reported U\text{SG} to be a valid alternative to U\text{OSM} in individuals who were moderately dehydrated, based on the 79% common variance between measures in Spanish Olympic combat sport athletes at the time of weigh-in prior to competition. Similarly, in well-controlled laboratory-based work from Bartok et al. (2004), U\text{SG} < 1.020 g\cdot mL\textsuperscript{-1} was reported to be a valid cut-off point to distinguish between hydrated and dehydrated college wrestlers. It has even been suggested in specific circumstances in the laboratory setting, U\text{SG} may be a superior index to screen for low-level hypohydration (e.g. 1–3%), when compared to serum osmolality (S\text{OSM}) in trained athletes, as Pearson’s correlation coefficient between these variables was 0.99 (Hamouti, Del Coso, & Mora-Rodriguez, 2013), following 3-h intense exercise in heat.

Concerns regarding U\text{SG} assessment

The assertions of U\text{SG} validity have been recently challenged however, with a growing body of evidence suggesting field-based measures to be inconclusive and inconsistent (Singh & Peters, 2013; Wilcoxson, Johnson, Pribylsavka, Green, & O’Neal, 2017; Zubac et al., 2017b). Indeed, a series of papers published on Olympic combat sport athletes (Zubac et al., 2017b), college wrestlers (Cutrufello & Dixon, 2014) and runners (Singh & Peters, 2013; Wilcoxson et al., 2017) criticized the applicability of U\text{SG} readings in the context of characterizing whole-body fluid fluctuations. Zubac and co-workers (2017b) found high variability in both U\text{SG} and U\text{OSM} readings (intra-class correlation coefficients ranged from 0.38 to 0.55) in elite youth boxers, even during a period of weight stability and ad libitum fluid intake, Cutrufello and Dixon (2014) suggested intense wrestling practice interferes with diagnostic accuracy; while Singh and Peters (2013)
Table I. Overview of the studies included in the narrative review.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Participants (n)</th>
<th>Assessment techniques</th>
<th>Study design</th>
<th>Outcome BM change (%Δ)</th>
<th>Sampling Setting</th>
<th>Sampling Time-frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buford, Rossi, Smith, O’Brien, and Pickering (2006)</td>
<td>Wrestling (n = 12)</td>
<td>USG↑ No No</td>
<td>Cohort</td>
<td>–6%</td>
<td>Field</td>
<td>&gt; 24 h</td>
</tr>
<tr>
<td>Cutrufello and Dixon (2013)</td>
<td>Wrestling (n = 25)</td>
<td>USG↑ No No</td>
<td>Cross-sectional</td>
<td>–1–2%</td>
<td>Field</td>
<td>&lt; 12 h</td>
</tr>
<tr>
<td>Cutrufello and Dixon (2014)</td>
<td>Wrestling (n = 12)</td>
<td>USG↑ No No</td>
<td>Cohort</td>
<td>Stabile</td>
<td>Field</td>
<td>&lt; 12 h</td>
</tr>
<tr>
<td>Fernandez-Elias et al. (2014)</td>
<td>All (n = 345)</td>
<td>USG↑ UOSM↑ UCOL↑</td>
<td>MS</td>
<td>Not reported</td>
<td>Field</td>
<td>Not reported</td>
</tr>
<tr>
<td>Gonçalves, Matias, Santos, Sardinha, and Silva (2015)</td>
<td>Judo (n = 32)</td>
<td>USG↑ No No</td>
<td>Cross-sectional</td>
<td>Not reported</td>
<td>Field</td>
<td>Not reported</td>
</tr>
<tr>
<td>Kutlu, Demirkiran, and Özbek (2015)</td>
<td>Wrestling (n = 52)</td>
<td>USG↑ No No</td>
<td>Cohort</td>
<td>–5%</td>
<td>Field</td>
<td>&gt; 24 h</td>
</tr>
<tr>
<td>Lingor and Olson (2010)</td>
<td>Wrestling (n = 9)</td>
<td>USG↑ UOSM↑ No</td>
<td>Cross-sectional</td>
<td>Not reported</td>
<td>Field</td>
<td>Not reported</td>
</tr>
<tr>
<td>Oopik et al. (2013)</td>
<td>Wrestling (n = 51)</td>
<td>USG↑ UOSM↑ No</td>
<td>Cross-sectional</td>
<td>–3–4%</td>
<td>Field</td>
<td>Not reported</td>
</tr>
<tr>
<td>Oppliger, Magnes, Popowski, and Gisolfi (2005)</td>
<td>Wrestling (n = 51)</td>
<td>USG↑ UOSM↑ No</td>
<td>Cross-sectional</td>
<td>Not reported</td>
<td>Field</td>
<td>&lt; 12 h</td>
</tr>
<tr>
<td>Pettersson and Berg (2014)</td>
<td>All (n = 63)</td>
<td>USG↑ No No</td>
<td>RCT</td>
<td>–5%</td>
<td>Field</td>
<td>Not reported</td>
</tr>
<tr>
<td>Reljic, Feist, Jost, Kieser, and Friedmann-Bette (2015)</td>
<td>Judo (n = 29)</td>
<td>USG↑ No No</td>
<td>Cross-sectional</td>
<td>–1.5%</td>
<td>Field</td>
<td>&gt; 24 h</td>
</tr>
<tr>
<td>Rivera-Brown and De Félix-Dávila (2012)</td>
<td>All (n = 27)</td>
<td>USG↑ UOSM↑ No</td>
<td>Cross-sectional</td>
<td>–2%</td>
<td>Laboratory</td>
<td>&gt; 24 h</td>
</tr>
<tr>
<td>Ratames et al. (2012)</td>
<td>Wrestling (n = 18)</td>
<td>USG↑ No No</td>
<td>Cohort</td>
<td>–3–4%</td>
<td>Field</td>
<td>&gt; 24 h</td>
</tr>
<tr>
<td>Shirreffs and Maughan (1998)</td>
<td>Boxing &amp; wrestling (n = 21)</td>
<td>No UOSM↑ No</td>
<td>Cohort</td>
<td>Not reported</td>
<td>Field</td>
<td>&gt; 24 h</td>
</tr>
<tr>
<td>Stuempfe and Drury (2003)</td>
<td>Wrestling (n = 21)</td>
<td>USG↑ No UCOL↑</td>
<td>MS</td>
<td>Stabile</td>
<td>Laboratory</td>
<td>&gt; 24 h</td>
</tr>
<tr>
<td>Stuempfe et al. (2012)</td>
<td>Wrestling (n = 56)</td>
<td>USG↑ UOSM↑ No</td>
<td>Cohort</td>
<td>–3%</td>
<td>Laboratory</td>
<td>Immediately</td>
</tr>
<tr>
<td>Timpmann et al. (2012)</td>
<td>Wrestling (n = 16)</td>
<td>USG↑ UOSM↑ No</td>
<td>RCT</td>
<td>–5%</td>
<td>Laboratory</td>
<td>&gt; 24 h</td>
</tr>
<tr>
<td>Utter, McAnulty, Sarvasyan, Query, and Landram (2010a)</td>
<td>Wrestling (n = 23)</td>
<td>USG↑ UOSM↑ No</td>
<td>Cohort</td>
<td>–3%</td>
<td>Laboratory</td>
<td>Immediate</td>
</tr>
<tr>
<td>Utter, Quindry, Emerzenziani, and Valiente (2010b)</td>
<td>Wrestling (n = 47)</td>
<td>USG↑ UOSM↑ No</td>
<td>Cohort</td>
<td>–3%</td>
<td>Laboratory</td>
<td>Immediate</td>
</tr>
<tr>
<td>Utter, McAnulty, Riha, Pratt, and Grose (2012)</td>
<td>Wrestling (n = 56)</td>
<td>USG↑ UOSM↑ No</td>
<td>Cohort</td>
<td>–3%</td>
<td>Laboratory</td>
<td>Immediate</td>
</tr>
<tr>
<td>Valiente et al. (2009)</td>
<td>Wrestling (n = 21)</td>
<td>USG↑ UOSM↑ No</td>
<td>RCT</td>
<td>–3%</td>
<td>Laboratory</td>
<td>Immediate</td>
</tr>
<tr>
<td>Zubac, Karmincic, and Zaja (2016)</td>
<td>Boxing (n = 21)</td>
<td>USG↑ No No</td>
<td>Cross-sectional</td>
<td>Not reported</td>
<td>Field</td>
<td>Not reported</td>
</tr>
<tr>
<td>Zubac, Cular, and Marušić (2017b)</td>
<td>Boxing (n = 16)</td>
<td>USG↑ UOSM↑ No</td>
<td>Cohort</td>
<td>Stabile</td>
<td>Field</td>
<td>&lt; 12 h</td>
</tr>
<tr>
<td>Zubac et al. (2017a)</td>
<td>Boxing (n = 23)</td>
<td>USG↑ UOSM↑ No</td>
<td>MS</td>
<td>Stabile</td>
<td>Field</td>
<td>&lt; 12 h</td>
</tr>
<tr>
<td>Yamashita, Ito, Nakano, and Matsumoto (2015)</td>
<td>Boxing (n = 8)</td>
<td>USG↑ UOSM↑ No</td>
<td>Cohort</td>
<td>–2%</td>
<td>Laboratory</td>
<td>&gt; 24 h</td>
</tr>
<tr>
<td>Weber et al. (2013)</td>
<td>Wrestling (n = 32)</td>
<td>USG↑ No No</td>
<td>RCT</td>
<td>–4%</td>
<td>Field</td>
<td>Not reported</td>
</tr>
</tbody>
</table>

Abbreviations: USG – Urine specific gravity; UOSM – Urine osmolality; UCOL – Urine colour; BM – body mass; ↑ – Increased values (exceeded threshold); ↓ – decreased values; ALL – athletes from all Olympic combat sports; RCT – randomized controlled trails; QRCT – quasi randomized controlled trial; MS – Methodological study; Sampling time-frame – time span from previous exercise to urine sampling, immediate) immediately after exercise; < 12 h – within 12 hours; > 24 h – greater than 24 hours.
reported poor association between BM change and $U_{\text{OSM}} (r = 0.08, p > 0.05)$ during a 3-day running competition. Urinary readings may be somewhat misleading in characterizing dehydration and subsequent rehydration, as 48-h may be necessary for body-water to reach homeostasis, due to the physiological barriers of fluid retention that preclude the incorporation of consumed fluids into various body compartments (Costill & Sparks, 1973). Therefore, the commonly accepted proposition that increases in urinary concentration readings originate from whole-body fluid deficits entirely is not accurate in all cases.

It has been suggested that several important factors may interfere with the diagnostic accuracy of $U_{\text{SG}}$, irrespective of any true fluid deficit. Factors, such as vigorous training (Gleim, 2000), increased muscle mass (Baxmann et al., 2008), urinary metabolites (Poortmans & Vanderstraeten, 1994) and high protein diets (Martin et al., 2006) have all been documented to ‘artificially’ increase urine concentration. Furthermore, handling and storage of samples can also impact end-point readings (Adams et al., 2017). In line with these identified confounding variables, a narrative review from Cheuvront, Kenefick, and Zambraski (2015) criticized the use of single-time-point assessments as the principal method for assessing hydration status. Indeed many investigations report the vast majority (∼90%) of combat sport athletes in real-life settings to be hypohydrated (Pettersson & Berg, 2014; Rivera-Brown & De Félix-Dávila, 2012; and Zubac et al., 2017). In line with these identified confounding variables, a narrative review from Cheuvront, Kenefick, and Zambraski (2015) criticized the use of single-time-point assessments as the principal method for assessing hydration status. Indeed many investigations report the vast majority (∼90%) of combat sport athletes in real-life settings to be hypohydrated (Pettersson & Berg, 2014; Rivera-Brown & De Félix-Dávila, 2012; and Zubac et al., 2017) when evaluated via a single-time-point $U_{\text{SG}}$ assessment utilizing the widely accepted cut-off of $>1.020 \, \text{g} \cdot \text{mL}^{-1}$. It is important to note however, many of the aforementioned confounding factors are likely present during intense training blocks and/or in the competition setting. Thus, questions of the ecological validity of the research used to inform current references must be considered when assessing the applicability of urinary markers and associated cut-off values in the identification of dehydration.

It can be stated on the balance of the available literature, inconsistencies and abnormalities in the identification of dehydration based on urinary measures preclude a conclusive position stand within current combat sports research and practice. Correspondingly, on-going debate remains in this space, specifically:

1. Do single-time point urine sample measures provide any useful information regarding dehydration in combat sports?
2. Are laboratory findings on urinary dehydration markers able to be applied to real-life settings?

3. To what degree is the diagnostic accuracy of $U_{\text{SG}}$ (and $U_{\text{OSM}}$) influenced by different confounding variables?

Accordingly, the overarching aim of this paper is to critically review the literature regarding different aspects of measurement resolution and possible influences of confounding factors on the efficacy of urinary dehydration markers applied to combat sports research. Utilizing both a wide body of literature as well as narrow examples focused on combat sports, one can appreciate the extended relevance to much of the content discussed in a sport-specific context throughout this review.

**Sampling methodology issues**

Under well-controlled laboratory conditions, $U_{\text{SG}}$ readings offer practical information concerning the hydration status of athletes in many instances; however, an appreciation of fluid balance physiology and the time course of renal adjustments is required if one is to rely on $U_{\text{SG}}$ to accurately characterize dehydration. A series of investigations in NCAA wrestlers demonstrated increases in $U_{\text{SG}}$ and blood measures alongside 3% BM loss dehydration when assessed 0–30 min post a 2 h wrestling practice (Utter et al., 2010a, 2010b, 2012); however, the statistical relationship between $U_{\text{SG}}$ and blood measures was not specifically examined. Popowski et al. (2001) examined changes in individual measures and correlations between $U_{\text{SG}}$ and plasma osmolality ($P_{\text{OSM}}$) following 1%, 3% and 5% acute dehydration, reporting $U_{\text{SG}}$ does not correlate strongly with, and lags behind, $P_{\text{OSM}}$, thus may not be a suitable alternative to identify acute dehydration immediately following fluid losses. However, when urine samples were assessed 1 hour following similar levels of dehydration in collegiate wrestlers, $U_{\text{SG}}$ was able to satisfactorily characterize dehydration, and when utilizing the cut-off value of $1.014 \, \text{g} \cdot \text{mL}^{-1}$ demonstrated sensitivity and specificity of 96% (Bartok et al., 2004). Similarly, Hamouti and colleagues (2013) investigated the relationship between $U_{\text{SG}}$ and $S_{\text{OSM}}$ in trained athletes following an exercise-dehydration protocol in the heat. They reported increases in $U_{\text{SG}}$ paralleled $S_{\text{OSM}}$ when dehydration exceeded 1% BM loss, and demonstrated that $U_{\text{SG}}$ is capable of screening fluid losses of ∼3% BM loss. In fact, $U_{\text{SG}}$ was found to better track hypohydration the morning following the exercise-dehydration protocol, as $S_{\text{OSM}}$ approached euhydration levels, whereas $U_{\text{SG}}$ remained elevated (Hamouti et al., 2013). Body fluid homeostatic and plasma volume defence mechanisms explain these findings (Nose, Mack, Shi, & Nadel, 1988). Specifically, redistribution of body fluids,
transferred from blood plasma into the interstitial compartment via increased hydrostatic pressure, result in the activation of ADH, leading to increases in renal fluid retention, and thus plasma water, thereby affecting the diagnostic accuracy of S_{OSM} and lowering its sensitivity as an accurate indicator of dehydration when extended periods of time with no further fluid loss exist following an initial dehydrating bout of exercise. Aside from the importance of the time of collection, the handling and storage of urine samples needs to be considered. Recent work revealed that U_{SG} remains stable when samples were stored at 22°C or 7°C for up to 7 days, whereas U_{OSM} was stable at 22°C for only 1 day and 7°C for 7 days (Adams et al., 2017). Both U_{SG} and U_{OSM} declined significantly at storages temperatures of −20°C and −80°C. These findings on storage effects on end-point readings are relevant both in the research setting, but also in the field, as when limited staff/resources are available, when processing large numbers of samples, or when athletes themselves collect an early morning sample; analysis cannot always be carried out immediately. Thus it would appear under well-controlled conditions that, when best practice collection and storage protocols are adhered, U_{SG} assessment is a practical and valid tool (Bartok et al., 2004; Hamouti et al., 2013); however, its use is frequently extended beyond these scenarios. It is common for researchers and practitioners to base interpretations of U_{SG} analysis of field measures on cut-off values established in the laboratory setting. Furthermore, much of the research published in combat sport athletes has utilized spot sample collection protocols, overlooking the well-known physiological misconceptions associated with this method as well as the limitations of cross-sectional research designs (Buford et al., 2006; Fernandez-Elias et al., 2014; Kutlu & Guler, 2006; Oppiliger et al., 2005; Oopik et al., 2013; Palarés et al., 2016; Shirreffs & Maughan, 1998 and Zubac et al., 2016, 2017a). Many of these studies assessed U_{SG} on competition day (or in the 24 h prior), when BM is often most unstable, and comparative baselines were not reported making these data inconclusive. Furthermore, some investigations failed to report any BM measurements (Fernandez-Elias et al., 2014; Pettersson & Berg, 2014) and there were instances of increased U_{SG} readings irrespective of weight stability and ad libitum fluid intake (Zubac et al., 2017a). These types of investigations may therefore over-emphasize elevated U_{SG} readings as a representation of whole-body fluid fluctuations. Therefore, increased urinary values may only marginally mirror changes in hydration status. Lastly, Reljic et al. (2015) demonstrated regardless of body water and plasma volume maintenance, U_{SG} values increased from 1.018 ± 0.005 to 1.025 ± 0.005 g·mL^{-1} in a control group consisting of 14 elite German combat athletes. These data were based on the rather subjective reagent strip method, which provides a measurement resolution of 0.005 g·mL^{-1}, whereas the digital refractometer method provides accurate readings in 0.001 g·mL^{-1} increments. Thus, their interpretations of actual hydration status should be treated with caution. Indeed the use of HydraTrend reagent strips as a method of urine assessment in well-trained athletes has been criticized as they were found to result in significantly greater false positive findings of dehydration than U_{SG} assessment, even when corrected for pH (Abbey, Heelan, Brown, & Bartee, 2014).

The cross-sectional nature of many of the aforementioned studies prevents baseline comparisons and thus conclusive statements regarding U_{SG} changes correlating with BM and body fluid changes in combat sport athletes. Interestingly, only one cross-sectional study demonstrated that there were differences in hydration status (determined via U_{SG}) between the super-heavy weights and other weight class categories in youth boxers (Zubac et al., 2016), whereas the low- and middle-weight boxers had urine concentration readings that were uniform, only the super-heavy weight boxers did not. Based on that published data, the authors used the super-heavy weight group as a means to promote internal validity. Nevertheless, there are several possible confounding factors and associated underlying mechanisms which could explain elevated U_{SG} readings independent of BM stability and/or ad libitum and sufficient fluid intake; these will now be discussed.

**Additional factors influencing measures of urine concentration**

A surface appreciation of fluid homeostasis suggests an increase in urine concentration originates from acute dehydration and concurrent BM reduction; however, various other factors, including training, urine metabolites, increased muscle mass and nutrient/supplement consumption, may artificially increase urine concentrations, leading to false positive findings.

In the aforementioned studies in combat sport athletes, most overlooked the influence of on-going intensive training and the effects on renal function. Only three (Cutrufello & Dixon, 2014; Zubac et al., 2017a, 2017b) hypothesized vigorous training interferes with the diagnostic accuracy of U_{SG} however, none of these investigations provided any measures of training load. Maughan, Shirreffs, and Leiper
(2007) proposed excessive rates of anaerobic glycolysis, induced by high-intensity exercise (>70% Vo2 max.), lead to an increase in osmolality of active muscles due to an accumulation of glycolytic intermediates, driving a whole-body osmolality increase. Further, during intense exercise blood flow to the kidneys may decline ∼30–40% in athletes (Gleim, 2000); however, due to changes in transcapillary hydraulic pressure differences, renal filtration fraction can double with maximal exercise, preserving the transfer of metabolites or substrates through the glomerulus, thereby increasing urine protein metabolite concentrations (Poortmans & Vanderstraeten, 1994). In addition to elevations in urine protein concentration as a consequence of reduced fluid loss, protein breakdown; specifically, fragments of titin (the largest protein in humans and a structural sarcopemere protein of striated muscle (Krüger & Linke, 2011) have been detected in urine following exercise induced muscle damage (Kanda, Sakuma, Akimoto, Kawakami, & Suzuki, 2017). Proteins and other larger molecules which pass into the urine (such as glucose alongside uncontrolled diabetes mellitus) increase urine density to a greater degree than osmolality; thus it is recommended USG not be used in place of U\textsubscript{OSM} in many clinical situations (Voinescu et al., 2002). This recommendation should perhaps be extended to athletes in similar situations (i.e. following intense exercise and thus protein breakdown, which may in turn pass into the urine). Interestingly, proteinuria as a consequence of exercise has been shown to be biphasic, i.e. increased protein excretion can be detected 30 min post exercise, before normalizing at 2 h, remaining until at least 8 h, before elevating again at 24 h (Şentürk, Kuru, Koçer, & Gündüz, 2007). Another factor not commonly considered when interpreting USG findings, which has been shown to accompany proteinuria, is haematuria. In judo athletes who are repeatedly thrown to the ground (common in training and competition), the presence of protein and red blood cells has been detected, alongside disturbances in glomerular filtration rate (Meersman & Wilkerson, 1982). Greater impact and severity of mechanical trauma was associated with an increased presence of protein and red blood cells; thus it is unreasonably to suggest this phenomenon would occur in other combat sports where contact is common.

Only three studies examined the influence of urine protein metabolites on diagnostic accuracy of US\textsubscript{G} readings. Recently, Zubac et al. (2017a, 2017b) presented poor associations between total protein content and US\textsubscript{G} values ($r = 0.30, p = .501$; $r = 0.27, p = .210$, respectively), suggesting inter-assay reliability of single urine sampling of total protein content may be questionable. Conversely, Hamouti, Del Coso, Avila, and Mora-Rodriguez (2010) reported high positive correlations between US\textsubscript{G} and protein metabolites ($R = 0.92, p < .001$). Importantly, the conclusions outlined by Hamouti et al. (2010) were based on a standardized, clinical gold standard supine position to address 24-h urine composition assessment. Thus, differences in methodological approaches between studies may explain the divergent results; that is the findings of Zubac et al. (2017) were restricted to a gross measure of urine protein metabolites, while Hamouti et al. (2010) reported the exact concentrations of different urine protein metabolites (such as urea, creatinine, uric acid) to determine urine composition and thus diagnostic accuracy.

Acute changes in posture can elicit substantial alterations to renal function, which may account for the differences between laboratory and field-based studies (Bilancio et al., 2014; Hamouti et al., 2010). Indeed, for many laboratory studies on hydration practices in athletes, measurements are taken after athletes have remained in a standardized, supine position to address 24-h urine composition (Hamouti et al., 2010). This does not occur during hydration assessment protocols on competition day in combat athletes. In addition to dehydration itself, renal dysfunction and other clinical abnormalities, a high dietary protein intake has been shown to result in increased US\textsubscript{G} readings relative to more moderate intakes (Martin et al., 2006) despite weight stability; again often overlooked when interpreting urinary measures. This point is particularly relevant as combat sport athletes are known to consume high amounts of dietary protein sources (Ubeda et al., 2010), presumably in an attempt to optimize body composition. Finally, high muscle mass itself may increase US\textsubscript{G} and lead to false positives in the identification of dehydration when typical cut-off values are used. This suggestion was put forth following the demonstrated differences in classification of dehydration and euhydration (assessed via US\textsubscript{G}) between runners and rugby players, alongside the notable differences in muscle mass (Hamouti et al., 2010). However, causation cannot be inferred as urinary metabolites correlate with muscle mass (Baxmann et al., 2008), and high protein diets are common among athletes in strength and power sports (Heaton et al., 2017). Similar to this correlation between protein intake and US\textsubscript{G}, large intercultural/ethnic differences in 24-h U\textsubscript{OSM} have been reported as a consequence of differing habitual diets (potentially sodium intake in particular) (Manz & Wentz, 2003); however, whether or not this is the case for US\textsubscript{G} readings remains to be determined. Furthermore, no studies have looked at either U\textsubscript{OSM} and US\textsubscript{G} differences relating to dietary intake in combat.
Are commonly espoused cut-off values appropriate for combat sports?

The majority of publications report high instances of dehydration among combat sport athletes. Prevalence is reported at ~90% on the basis of increased USG values (>1.020 g/mL) while corresponding BM reduction data remain equivocal (Pettersson & Berg, 2014; Shirreffs, 2012; Zubac et al., 2017a). Indeed Zubac et al. (2017a) reported 100% of elite European boxers as hypohydrated during their preparation camp, irrespective of ~2.8 L of fluid intake daily and BM stability. Similarly, despite ~7% differences in BM between measures, USG values remained unchanged in division I NCAA wrestlers (Buford et al., 2006). Here, wrestlers were classified as dehydrated (USG > 1.020 g/mL) both during the competitive season while experiencing the pressure to maintain lower BM to make weight (commonly achieved via intentional fluid loss (Franchini et al., 2012) and also post season when this pressure is removed. It is not possible to definitively state if the mid-post season changes in BM included fluid status changes, however, given the commonality and effectiveness (Reale et al., 2017) of fluid manipulation practices to make weight in these athletes; it is logical to assume so. Similarly, in boxers, Smith (2006) described universally high UOSM readings during a training camp and competition; and Zubac et al. (2017a) reported increases in USG and UOSM, and thus dehydration classification throughout a training camp, despite stable BM and ad libitum fluid intake. This leaves the possibility that urine measures and the accepted cut-off values are not sufficient in characterizing euhydration/various degrees of dehydration in these groups, or, some physiological adaptation of the renal system to intense training and what should be inadequate fluid intake in combat sport athletes takes place, which potentially persists post the fluid restriction period. Indeed it has been suggested some degree of adaptation to repeated weight cycling in combat sport athletes takes place (Artioli et al., 2010) and Yankanich, Kenney, Fleck, and Kraemer (1998) describe a so far unexplained physiological phenomenon following weight cycling in wrestlers, where average P_{OSM} values of ~300 mOsmol kg^{-1} exist even during a period of weight stability when athletes are thought to be euhydrated. Conversely, Oppliger et al. (2005) reported 35% of wrestlers misclassified as dehydrated despite P_{OSM} measures being within acceptable ranges. Thus, if there is some form of adaptation taking place, the precise nature of this is poorly understood.

Taking into consideration the following issues; the time course involved in fluid homeostatic mechanisms, reported confounding variables affecting diagnostic accuracy; the questionable ecological validity of laboratory derived references ranges; and the potential for combat sport athletes to undergo some degree of adaptation to acute weight loss and repeated dehydration, the use of USG assessment both in research and practice needs to be carefully considered. An example outlined in Table II demonstrates how, even aside from the timing of sample collection, many of these aforementioned factors may be present within one athlete, thus rendering USG, a poor indicator of absolute hydration status. Add to this random time-point sampling, and useful interpretation likely becomes impossible.

Table II: Example of a common scenario in a combat sport athlete where multiple factors which confounding USG interpretation are present.

<table>
<thead>
<tr>
<th>Confounding factor</th>
<th>Effect on USG reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lean middle-weight judo athlete (91 kg competition weight)</td>
<td>High muscle mass, increasing USG; possibly as a consequence of proteinuria and elevated creatinine</td>
</tr>
<tr>
<td>Consumption of a high protein diet in the attempt to optimize body composition</td>
<td>Excess dietary protein resulting in proteinuria, increasing USG</td>
</tr>
<tr>
<td>Engaged in frequent intense training (i.e. strength or interval sprint training in the morning, judo practice in evening)</td>
<td>Alterations in renal blood flow &amp; possible proteinuria, increasing USG</td>
</tr>
<tr>
<td>Exposed to repeated impact resulting from being thrown to the ground during training</td>
<td>Haematuria, increasing USG</td>
</tr>
<tr>
<td>History of acute weight loss via dehydration to make weight for competition</td>
<td>Possible renal adaptations and an unknown effect on USG end-point readings</td>
</tr>
</tbody>
</table>
Conclusion and recommendations

Unfortunately, a definitive position stand regarding the exact application and associated cut-off values to diagnose dehydration in combat sport athletes via $U_{SG}$ assessment is not possible. As renal adjustments following dehydration and rehydration alter blood and urine differently, and do not immediately change in relation to changes in BM, the timing of sample collection is important. Inconsistencies in research methodologies used to base guidelines on, the incomplete picture of how various confounding factors (known to be commonly present in combat sport athletes) affect endpoint readings, and the still poorly understood potential of renal adaptation to dehydration in combat sport athletes; all make the utility of $U_{SG}$ assessment in this athlete group currently questionable.

If used in a regulatory sense (i.e. at weigh-in/when determining a minimum wrestling weight), maximally controlling for confounding factors is recommended, as false positives may unfairly and unnecessarily exclude athletes from competition and/or erroneously prohibit athletes from competing in a realistically achievable weight division. In many situations, achieving ideal athlete presentation and sample collection is not possible; thus, researchers and practitioners should understand how various factors may alter final readings and interpret with caution. If monitoring changes within an individual, or while following a cohort in a research sense, carefully documenting and replicating sample collection in relation to diet and training (i.e. standardize diet and training at least 24 h prior to sample collection) alongside changes in BM will allow for greater confidence in interpretation of changes in hydration status. However, categorizing combat sport athletes in the field as dehydrated based on one off sample and existing cut-off values established in the laboratory is not appropriate. While $U_{SG}$-based assessment of hydration status is increasingly becoming recognised as problematic, disregarding it altogether is premature and unwarranted. Urine sampling and $U_{SG}$ assessment still represents a valuable tool providing insight into hydration which balances cost, practicality, reliability and validity. Further, the method has strong implications in the context of discouraging the misuse of excessive dehydration as well as diuretics; both life threatening behaviours; with diuretic use being prohibited by the World Anti-Doping Agency and the International Olympic Committee. The topic of $U_{SG}$ assessment in research and practice will continue to promote debate amongst scientists and practitioners alike. Given the current state of the evidence, key considerations for researchers and practitioners conducting $U_{SG}$ assessment in combat sport athletes include:

- Hydration status assessment via a multidimensional approach (which may include; $U_{SG}$ or $U_{OSM}$ and BM measurements) is strongly recommended.
- Protein intake should be standardized prior to sample collection, in order to minimize elevated urea as consequence of excess dietary protein.
- Where possible, samples on a morning following a rest day (no intense training) are preferred, in order to minimize the likelihood of proteinuria, haematuria and acute alterations in renal blood flow affecting readings.
- Spot samples collected throughout the day, in general should be avoided as these samples do not represent the true 24-hour void and may erroneously estimate changes in body fluid balance.
- An upon-waking mid-flow urine sample from a fasted and rested athlete is the preferred protocol for collecting a urine sample.
- Currently established $U_{SG}$ cut-offs should be interpreted with caution since specific adjustments for each weight class have not been established.
- Combat sport athletes can potentially be identified as euhydrated ($U_{SG} < 1.020$); however, false positive dehydration diagnoses will be common when utilizing currently suggested cut-off points ($U_{SG} \geq 1.020$), as confounding factors may ‘artificially’ raise $U_{SG}$.
- Future research should seek to:
  - Establish appropriate cut-off values for athletes of various BM and in particular those with high lean BM
  - Quantify the duration and degree to which intense training may affect $U_{SG}$ readings
  - Understand if there is any (and if so, the mechanism of) adaptation to repeated dehydration/weight making
  - Investigate intercultural variability in $U_{SG}$ to determine if ethnically/culturally influenced dietary and/or other practices influence $U_{SG}$ similar to $U_{OSM}$

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References


