Validation of Hydration Non-Invasive Indices during the Weightcutting and Official Weigh-In for Olympic Combat Sports

Valentín E. Fernández-Elías1, Alberto Martínez-Abellán2, José María López-Gullón2, Ricardo Morán-Navarro2, Jesús G. Pallarés1,2, Ernesto De la Cruz-Sánchez2, Ricardo Mora-Rodriguez1*

1 Exercise Physiology Laboratory, University of Castilla-La Mancha, Toledo, Spain, 2 Department of Physical Activity and Sport, University of Murcia, Murcia, Spain

Abstract

Background: In Olympic combat sports, weight cutting is a common practice aimed to take advantage of competing in weight divisions below the athlete’s normal weight. Fluid and food restriction in combination with dehydration (sauna and/or exercise induced profuse sweating) are common weight cut methods. However, the resultant hypohydration could adversely affect health and performance outcomes.

Purpose: The aim of this study is to determine which of the routinely used non-invasive measures of dehydration best track urine osmolality, the gold standard non-invasive test.

Method: Immediately prior to the official weigh-in of three National Championships, the hydration status of 345 athletes of Olympic combat sports (i.e., taekwondo, boxing and wrestling) was determined using five separate techniques: i) urine osmolality (UOsm), ii) urine specific gravity (USG), iii) urine color (UCOL), iv) bioelectrical impedance analysis (BIA), and v) thirst perception scale (TPS). All techniques were correlated with UOsm divided into three groups: euhydrated (G1; UOsm 250–700 mOsm·kg H2O−1), dehydrated (G2; UOsm 701–1080 mOsm·kg H2O−1), and severely dehydrated (G3; UOsm 1081–1500 mOsm·kg H2O−1).

Results: We found a positive high correlation between the UOsm and USG (r = 0.89; p = 0.000), although this relationship lost strength as dehydration increased (G1 r = 0.92; G2 r = 0.73; and G3 r = 0.65; p = 0.000). UCOL showed a moderate although significant correlation when considering the whole sample (r = 0.743: p = 0.000) and G1 (r = 0.702: p = 0.000) but low correlation for the two dehydrated groups (r = 0.498–0.398). TPS and BIA showed very low correlation sizes for all groups assessed.

Conclusion: In a wide range of pre-competitive hydration status (UOsm 250–1500 mOsm·kg H2O−1), USG is highly associated with UOsm while being a more affordable and easy to use technique. UCOL is a suitable tool when USG is not available. However, BIA or TPS are not sensitive enough to detect hypohydration at official weight-in before an Olympic combat championship.

Introduction

Severe dehydration has physiological consequences negatively affecting health and athletic performance. Body water losses exceeding 2% of body weight reduce physical work capacity and exercise performance [1–3] and higher dehydration levels (i.e., >4–5%) has been reported to increase heat-stroke risk [1,4]. These adverse effects include impaired glycogen use [9], increases in core temperature inducing central nervous system fatigue [10,11], cardiovascular strain [12,13] and loss of efficacy of the metabolic acid buffer system [14]. All these effects could compromise health and physical performance in military personnel, firemen, athletes training and competing in hot environments, or those involved in Olympic weight-class sports (e.g., wrestling, boxing, judo, taek-wondo and weightlifting). In these sports weight loss throughout dehydration is a very common strategy prior to competition [15]. Weight loss by dehydration has been shown to affect boxing and wrestling performance [5,6]. If that weight loss is quickly recovered the effects on performance are not evident [7,8]. Many techniques are available to assess body water deficit, however it is not clear which it is best to use in a pre-competition setting. Ideally, this should be a non-invasive index, as well as being fast, accurate, inexpensive and easy-to-use.

Out of the available techniques to measure hydration status, blood osmolality is the gold standard [16–18]. However, the measurement of blood osmolality requires an invasive technique,
costly measurement apparatus and qualified personnel to handle blood. All these conditions are rarely available to scientists and coaches at the field. Urine analysis of hydration status has been recommended as an alternative measurement because it involves a non-invasive evaluation of body fluid [19]. The main criticism of the use urine as an index of dehydration is that urine does not respond as fast or as accurately as blood to body fluid deficit [16]. However, we have recently found that urine readily tracks blood responses during progressive dehydration induced by exercise [20,21]. Urine can be analyzed for color, density, osmolality or its constituents resulting in a wide range of hydration indexes. Nonetheless, not all indexes are adequate, accurate or practical, and some are costly and require technical expertise [22].

A non-invasive surrogate of blood osmolality is urine osmolality (UOSM) considered the most valid measurement of hydration status through urine [16,23]. However, similarly to blood osmolality it requires expensive biochemical analysis. Urine specific gravity (USG) assessment requires a simpler apparatus (i.e., refractometer). Some authors have found that USG [20,21,24] and urine color (UCOL) [22,25] are highly correlated to urine osmolality (UOSM). Armstrong and co-workers, found acceptable validity of USG and color analysis in different populations at moderate dehydration levels [17]. However, the agreement between these urine indexes after severe dehydration in weight class sports [15], has not been reported.

Finally, there are non-invasive indexes that do not entail urine collection and analysis. Bioelectrical impedance analysis (BIA; [26–29]) and thirst perception scale (TPS; [30–33]) have been proposed as simpler indexes of body fluid deficit. Despite all these studies, to our knowledge, there is insufficient evidence to decide about the suitability of these indexes to readily detect whole body dehydration. Furthermore, these indexes have not been evaluated in a large population of athletes undergoing different degrees of dehydration. We believe that a good test for BIA and TPS will be to assess its agreement with UOSM during the weight cutting in Olympic combat sports.

Therefore, the purpose of this study was to compare several non-invasive indexes of hydration in a large number of Olympic combat sport athletes undergoing different degrees of weight loss by dehydration before a real competition. Our intention is to obtain a wide range of hypohydration levels to fully evaluate the detection power of all indexes in comparison to UOSM. We hypothesized that techniques involving urine analysis may have high levels of agreement while other estimations (i.e., BIA and TPS) will not.

**Methods**

**Participants**

Two hundred and forty-four male (age 22.8 ± 4.1 yr, body mass 74.1 ± 15.1 kg, height 176.1 ± 6.7 cm) and one hundred one female (age 22.7 ± 4.5 yr, body mass 57.1 ± 8.9 kg, height 164.9 ± 7.2 cm) high performance athletes of three different Olympic combat sports volunteered to participate in this study: wrestling (n = 157), taekwondo (n = 152) and boxing (n = 36). All participants had at least 4 years of training and competition experience, and all of them made the weight in the official weigh-in of their respective National Championship during the experimental phase of this study. The subjects and coaches were informed in detail about the experimental procedures and the possible risks and benefits of the project. The study, which complied with the Declaration of Helsinki, was approved by the Bioethics Commission of the University of Murcia, and written informed consent was obtained from athletes prior to participation.

**Study design and experimental protocol**

Athletes’ hydration status was evaluated through 5 different techniques (i.e., UOSMO, USG, UCOL, TPS and BIA) between 60 and 5 minutes before the official weigh-in of their respective National Championship. No instructions were given to athletes or their coaches about their weight control management. Participants filled out a nutritional questionnaire and twelve of them were excluded from the study for being ingesting vitamins, nutritional supplements or prescription drugs prone to alter urine color, amount or composition [25]. Women were tested out of the proliferative phase of their menstruation.

At arrival to the official weigh-in facilities, a 10 ml mid flow urine sample was obtained from each athlete. After the recipient with the urine sample was handed over and codified, subjects filled out the thirst perception scale, and their body impedance was determined using a Bio-impedance analyzer. Urine specimens were immediately analyzed in duplicate for urine osmolality (UOSM), urine specific gravity (USG), and urine color (UCOL) by the same experienced investigator. The final value for each assessment was the average of the two trials.

**Urine osmolality.** UOSM is the measure of the total urine solute content. As has been repeatedly reported [16,23], we considered this assessment as our gold standard measurement to determine the athletes’ hydration status. Athletes urine specimens (20 μL) were immediately analyzed in duplicate by freezing point depression osmometry (Model 3250, Advanced Instruments, USA).

**Urine specific gravity.** USG is the analysis of urine density compared to double distilled water (density = 1.000). After apparatus calibration and thorough mixing of the urine specimen, a few drops were placed on the refractometer (URC-NE, Atago, Japan) visor and USG was determined.

**Urine color.** UCOL is determined by the amount of urochrome present in the urine specimen. When large volumes of urine are excreted, the urine is dilute and pale. Conversely, when small volumes of urine are excreted, the urine is concentrated and dark [23]. UCOL was determined as described by Armstrong et al., [17,18,22,23,25]. Briefly, an 8 number scale ranging from very pale yellow (number 1) to brownish green (number 8), was used. UCOL was determined in duplicate by holding each specimen container next to a validated color scale in a well-lit room.

**Bioelectrical impedance analysis.** BIA has the potential to assess changes in hydration status and has been previously used and validated in combat sports athletes [29]. Athletes BIA was determined using an 8-contact electrode segmental and monofrequency body composition analyzer (Tanita BC-418, Tanita Corp., Tokyo, Japan) while they were barefoot, wearing shorts and a sports-top for females.

**Thirst perception scale (TPS).** Thirst perception is physiologically related to the hydration status of an individual since it is mediated by fluid-regulating hormones urging the “need to drink” [31]. Thirst perception was assessed using a Likert scale [32,34] that ranged perceived thirst from 1 (“not thirsty at all”) to 9 (“very, very thirsty”).

**Statistical analysis**

Descriptive values were provided for all the outcome variables. Engagement scores were non-normally distributed for all measures, as assessed by Shapiro-Wilk’s test (p < 0.05). A Spearman’s rank-order correlation was run to assess the relationship between UOSM and the rest of the hydration status markers (USG, UCOL, TPS and BIA). The size of the correlation was evaluated as follows; r < 0.7 low; 0.7 ≤ r < 0.9 moderate; and ≥ 0.9 high [35].
Subjects were stratified according to their hydration status using U\textsubscript{OSMO} values. A value of 700 mOsm·kg\textsuperscript{-1} H\textsubscript{2}O\textsuperscript{-1} marks the limits between a correct hydration status and dehydration [1]. Thus, three intervals of equal amplitude (according to measurement units) were established according to the following cutoffs: from 250 to 700 mOsm·kg\textsuperscript{-1} H\textsubscript{2}O\textsuperscript{-1} (euhydrated - G\textsubscript{1}), from 701 to 1,080 mOsm·kg\textsuperscript{-1} H\textsubscript{2}O\textsuperscript{-1} (dehydrated - G\textsubscript{2}) and from 1,081 to 1,500 mOsm·kg\textsuperscript{-1} H\textsubscript{2}O\textsuperscript{-1} (severely dehydrated - G\textsubscript{3}). Also, a Kruskal-Wallis test was performed between groups. Pairwise comparisons were performed using Dunn’s [36] procedure with a Bonferroni correction for multiple comparisons.

**Results**

Hydration status indexes were not different between males and females (U-Mann Whitney Wilcoxon test; p>0.05) or between sports (wrestling, taekwondo and boxing; Kruskal-Wallis test; p>0.05) and thus results are reported with all athletes as a group. A high linear and positive correlation was detected between USG and U\textsubscript{OSMO} in the whole sample (r = 0.89; p = 0.000; n = 345). However, the correlation became lower as the dehydration status increased (G\textsubscript{1} r = 0.92; p = 0.000; G\textsubscript{2} r = 0.73; p = 0.000 and G\textsubscript{3} r = 0.63; p = 0.000; Figure 1A).

The relationship between the U\textsubscript{OSMO} and other hydration status markers was weak. U\textsubscript{COL} showed a moderate although significant correlation when considering the whole sample (r = 0.743; p = 0.000) or the euhydrated group (G\textsubscript{1}: r = 0.702; p = 0.000). However, the correlation was low for the two dehydrated groups (G\textsubscript{2}: r = 0.498; p = 0.002; G\textsubscript{3}: r = 0.398; p = 0.004) (Figure 1B). TPS showed a significant but low correlation with the U\textsubscript{OSM} in the whole sample and for G\textsubscript{3} group (r<0.315 and r = 0.298, respectively; p<0.05) (Figure 1C). No significant correlation (p>0.05) was detected between the BIA assessments and U\textsubscript{OSM} in any group (Figure 1D).

Finally, a complementary Kruskal-Wallis analysis according to the athletes’ dehydration status (euhydrated – G\textsubscript{1}, dehydrated – G\textsubscript{2}; and severely dehydrated – G\textsubscript{3}) reveals significant differences (p<0.05) between the 3 groups for the USG and U\textsubscript{COL} methods. Nevertheless, the TPS cannot differ (p>0.05) between the first two groups (G\textsubscript{1} and G\textsubscript{2}), and BIA do not distinguish (p>0.05) between any of the 3 groups (G\textsubscript{1}, G\textsubscript{2} and G\textsubscript{3}) (Figure 2).

![Figure 1. Correlation between U\textsubscript{OSM} and USG (A), Urine color (B), Thirst perception scale (C) and Bioelectrical impedance analysis (D) in the whole sample and in each group. G\textsubscript{1}: U\textsubscript{OSM} 250–700 mOsm·kg\textsuperscript{-1} H\textsubscript{2}O\textsuperscript{-1}; G\textsubscript{2}: U\textsubscript{OSM} 701–1,080 mOsm·kg\textsuperscript{-1} H\textsubscript{2}O\textsuperscript{-1}; G\textsubscript{3}: U\textsubscript{OSM} 1,081–1,500 mOsm·kg\textsuperscript{-1} H\textsubscript{2}O\textsuperscript{-1}.](https://doi.org/10.1371/journal.pone.0095336.g001)
Discussion

The current study compares different indexes of hydration status to urine osmolality (UOSM) as the gold standard non-invasive index [16,23]. This comparison took place in a large sample of Olympic combat sports athletes (i.e. 345 athletes) during the official weigh-in of a real competition. While rapid reduction in body weight before competition is the easier non-invasive index of weight cutting thru dehydration it requires knowing what the “normal” weight of the athlete is. Referees and medical personnel at the competition arena do not have this information and thus require another index that is accurate, fast and non-invasive. Our aim was to determine which of the available non-invasive indexes (USG; UCOL; BIA and TPS) showed the better combination of sensitivity to detect hypohydration, with affordability and simplicity in its use. This may prove useful to sport’s governing bodies which are interested in preventing rapid weight loss during competition. Coaches and trainers can benefit too from easily assessing the degree of hypohydration in their combat athletes. We believe that fast and accurate identification of hypohydration is the first step into the prevention of weight cutting unhealthy practices.

While a similar question has been addressed in previous studies [14,17,18,23], to our knowledge, this is the first study identifying the best non-invasive index using a large sample with a wide range of hydration statuses under a real competition situation. As a consequence of the real situation, we detected a large number of competitors with severe dehydration (176 samples with UOSM above 701 mOsm·kg H₂O⁻¹ and 122 samples with UOSM above 1080 mOsm·kg H₂O⁻¹) beyond what has been previously reported [19,37,38]. Also, we observed that independent of sport discipline and gender a similar distribution of athletes were dehydrated or extremely dehydrated suggesting, as previously reported [37–41], that weight cutting is a broadly extended practice in Olympic combat sports.

Our results indicate that USG is the hydration index that better correlates with UOSM (r = 0.89; p = 0.000; Figure 1) the assessment of USG being easier, cheaper and faster than that of UOSM. These results are consistent with the finding of Popowski et al [16] who compared the validity of USG and UOSM to plasma osmolality, and concluded that both, USG and UOSM correlate and are good measurements of hydration status. This data is also in agreement with results from our laboratory [21] reporting that USG is as sensitive as serum osmolality to detect 2 to 3% hypohydration. Based on the present results using an important sample size of elite athletes in a wide range of hydration statuses, we can substantiate that USG is a highly recommended index to assess hypohydration. Nevertheless, when dehydration increases USG presents lower correlation values (G2: r = 0.75; G3: r = 0.66; both p = 0.000; Figure 1). This validity decline, as body water loss increase, has been previously observed by Opplinger et al [24]. Nevertheless, dehydration is usually assessed based on a threshold value that is much below the values where USG starts to deviate from UOSM. Thus, a lowering in this correlation will rarely affect the classification of an individual as dehydrated or euhydrated.

Previous studies agreed that UCOL presents lower precision and accuracy values to determine the hydration status in humans compared to UOSM and USG [17,18,25]. Nevertheless, different researchers consider that UCOL would be helpful in athletic, army or industrial settings where high precision assessment of body fluid deficit is not required [17,22,25]. Likewise, our data coincides in that UCOL is effective at discriminating different levels of dehydration (Figure 2) despite its lack of preciseness (G2: r = 0.498; p = 0.002, G3: r = 0.398; p = 0.004; Figure 1). As in previous studies, we can recommend UCOL analysis as an index to estimate hydration status of combat sports athletes; especially when water loss is not extreme. The low precision level of UCOL could be offset by its simplicity and low cost to assess hydration status on the field.

Some studies propose that BIA is a valid tool to assess hydration status in different populations [26,27,29]. However, our data suggests that BIA is not a good instrument to assess hydration level in combat sports athletes (Figure 1). In agreement with our results, other investigations argued that BIA may be a non-adequate instrument to evaluate exercise induced dehydration [28,42–44]. Furthermore, our results show that during dehydration and severe dehydration (G2 and G3) BIA agreement with UOSM worsens compared to euhydration (G1) (Figure 1). This is in accordance with the investigation of Asselin et al [45] which indicated that with dehydration levels of 2–3% of body mass, BIA standard equations failed to predict changes in total body water. As a limitation we used segmental BIA but mono-frequency analysis since, in our experience, this are the technical characteristics of the BIA equipment commonly found in combat sports clubs and high performance sports centers. Novel systems of BIA employ multi-frequency to determine the characteristics of the body fluids and tissues. Although they have shown even lower validity to estimate body composition [46], it has been recently reported that they are sensitive to evaluate acute dehydration in wrestlers [29]. It is unclear if the use of multi-frequency BIA could have increased its association with UOSM in our data set.

Engell et al. [30] showed a high correlation between the perceived thirst and hypohydration before and after exercise in the heat. Young et al [33] agreed with this statement and added that using the 9 point scale (1 = not at all thirsty; 9 = very, very thirsty) a score between 3 and 5 could be a good indication that an individual is mildly dehydrated. Our results suggest that this perception scale is a valid indicator of hydration status, but only discriminating between euhydration and extreme dehydration. However, it does not distinguish low levels of dehydration from correct hydration (Figure 2). Maresh group [31,32] provided data showing a thigh correlation between hypohydration and thirst perception when subjects are moderately dehydrated (i.e., ~4%). It is known that numerous factors, apart from body water deficit, may alter the perception of thirst such us fluid palatability, time allowed for fluid consumption, time since last fluid ingestion, gastric distention, older age, gender, and heat acclimatization status[17]. Thus, while thirst perception may serve as an indicator of extreme dehydration, our data suggest that TPS is not accurate enough to correctly evaluate low and moderate levels of hypohydration during weight cutting in Olympic combat athletes.

Athletes involved in combat sports (e.g., wrestling, taekwondo and boxing) habitually weight-cut (i.e. weight loss through dehydration) to be included in a lower category at the official weigh-in before competition. Our study compares four different non-invasive hydration indexes (USG, UCOL, TPS, and BIA) to UOSM as our gold standard non-invasive measure in a wide sample of competitive Olympic combat sports athletes. The aim is to find an alternative measure that, unlike UOSM, does not involve costly...
biochemical analysis and that can be readily used by sports medicine doctors, coaches and trainers on the combat arena. Our data suggests that USG is a good alternative to UOSM since it highly correlates with UOSM in conditions of low and severe dehydration (i.e. G2 and G3). However, UCOL can be an alternative and adequate tool to evaluate dehydration, especially if the dehydration level is not extreme. In contrast, our data discloses the use of TPS and BIA to measure hydration status after weigh-cut in combat sports athletes.

References

1. Sawka MN, Burke LM, Eichner ER, Maughan RJ, Montain SJ, et al. (2007) American College of Sports Medicine position stand. Exercise and fluid replacement. Med Sci Sports Exerc 39: 377–390.
2. Baker LB, Dougherty KA, Chow M, Kenney WL. (2007) Progressive dehydration causes a progressive decline in basketball skill performance. Med Sci Sports Exerc 39: 1114–1123.
3. Dougherty KA, Baker LB, Chow M, Kenney WL. (2006) Two percent dehydration impairs and six percent carbohydrate drink improves boys basketball skills. Med Sci Sports Exerc 38: 1650–1656.
4. Howe AS, Boden BP. (2007) Heat-related illness in athletes. Am J Sports Med 35: 1704–1709.
5. Smith MS, Dyson R, Hale T, Harrison JH, McManness P. (2000) The effects in humans of rapid loss of body mass on a boxing-related task. Eur J Appl Physiol 83: 34–39.
6. Webster S, Rutt R, Welman A. (1990) Physiological effects of a weight loss regimen practiced by college wrestlers. Med Sci Sports Exerc 22: 229–234.
7. Schoffstall JE, Branch JD, Luetholtz BC, Swain DE. (2001) Effects of dehydration and rehydration on the one-repetition maximum bench press of weight-trained males. J Strength Cond Res 15: 102–108.
8. Slater G, Rice AJ, Turner R, Sharpe K, Gore CJ, et al. (2006) Acute weight loss followed by an aggressive nutritional recovery strategy has little impact on on-water rowing performance. Br J Sports Med 40: 55–59.
9. Houston ME, Martin DA, Green HJ, Thomson JA. (1981) The effect of rapid weight loss on physiological function in wrestlers. Physician and Sportsmedicine 9: 73–78.
10. Nybo L, Nielsen B. (2001) Hyperthermia and central fatigue during prolonged exercise in humans. J Appl Physiol 91: 1053–1060.
11. Gonzalez-Alonso J, Teller C, Andersen SL, Jensen FB, Hylgaard T, et al. (1999) Influence of body temperature on the development of fatigue during prolonged exercise in the heat. J Appl Physiol (1985) 86: 1032–1039.
12. Cheuvront SN, Carter R. (2005) Fluid balance and endurance exercise performance. Curr Sports Med Rep 4: 2: 202–208.
13. Murray B. (2007) Hydration and physical performance. J Am Coll Nutr 26: 542S–548S.
14. Horwill CA, Hickner RC, Scott JR, Costill DL, Gould D. (1990) Weight loss, dietary carbohydrate modifications, and high intensity, physical performance. Med Sci Sports Exerc 22: 470–476.
15. Clark RR, Barthol C, Sullivan JC, Schoeller DA. (2004) Minimum weight prediction methods cross-validated by the four-component model. Med Sci Sports Exerc 36: 639–647.
16. Popovski LA, Oppliera RA, Patrick Lambert G, Johnson RF, Kim Johnson A, et al. (2001) Blood and urinary measures of hydration status during progressive acute dehydration. Med Sci Sports Exerc 33: 747–753.
17. Armstrong LE. (2005) Hydration assessment techniques. Nutr Rev 63: S40–54.
18. Armstrong LE. (2007) Assessing hydration status: the elusive gold standard. J Am Coll Nutr 26: 575S–586S.
19. Zambriadi EJ, Tipton CM, Jordon HR, Palmer WK, Tcheng TK. (1974) Iowa wrestling study: urinary profiles of state finalists prior to competition. Med Sports 6: 129–132.
20. Hamouti N, Del Coso J, Avila A, Mora-Rodriguez R. (2010) Effects of athletes’ muscle mass on urinary markers of hydration status. Eur J Appl Physiol 109: 213–219.
21. Hamouti N, Del Coso J, Mora-Rodriguez R. (2013) Comparison between blood and urinary fluid balance indices during dehydration exercise and the subsequent hypohydration when fluid is not restored. Eur J Appl Physiol 113: 611–620.
22. Armstrong LE, Soto JA, Hacker FT, Jr., Casa DJ, Kavoursa SA, et al. (1998) Urinary indices during dehydration, exercise, and rehydration. Int J Sport Nutr 8: 345–355.
23. Shirreffs SM. (2003) Markers of hydration status. Eur J Clin Nutr 57 Suppl 2: S6–9.
24. Oppliera RA, Magnes SA, Popowski LA, Gicoli CV. (2005) Accuracy of urine specific gravity and osmolality as indicators of hydration status. Int J Sport Nutr Exerc Metab 15: 236–251.
25. Armstrong LE, Maresh CM, Castellani JW, Bergeron MF,kenefick RW, et al. (1994) Urinary indices of hydration status. Int J Sport Nutr 4: 265–279.
26. O’Brien C, Baker-Fuloie C, Young AJ, Sawka MN. (1999) Bioimpedance assessment of hydration. Med Sci Sports Exerc 31: 1466–1471.
27. Quiterio AL, Silva AM, Minderico CS, Camero EA, Fields DA, et al. (2009) Total body water measurements in adolescent athletes: a comparison of six field methods with deuterium dilution. J Strength Cond Res 23: 1225–1237.
28. Saunders MJ, Blevins JE, Broder CE. (1998) Effects of hydration changes on bioelectrical impedance in endurance trained individuals. Med Sci Sports Exerc 30: 883–892.
29. Utter AC, McAulay SR, Riha BF, Pratt BA, Grose JM. (2012) The validity of multifrequency bioelectrical impedance measures to detect changes in the hydration status of wrestlers during acute dehydration and rehydration. J Strength Cond Res 26: 9–15.
30. Engell DB, Moller O, Sawka MN, Francesconi RN, Drolet L, et al. (1987) Thirst and fluid intake following graded hypohydration levels in humans. Physiol Behav 40: 229–236.
31. Maresh CM, Gabarre-Boulant CL, Armstrong LE, Judekson DA, Hoffman JR, et al. (2004) Effect of hydration status on thirst, drinking, and related hormonal responses during low-intensity exercise in the heat. J Appl Physiol 97: 39–44.
32. Maresh CM, Herrera-Soto JA, Armstrong LE, Casa DJ, Kavoursa SA, et al. (2001) Perceptual responses in the heat after brief intransive versus oral rehydration. Med Sci Sports Exerc 33: 1039–1045.
33. Young AJ, Sawka MN, Epstein Y, Decristofano B, Pandolf KB. (1987) Cooling different body surfaces during upper and lower body exercise. J Appl Physiol 63: 1218–1223.
34. Riebe D, Maresh CM, Armstrong LE, Kenefick RW, Castellani JW, et al. (1997) Effects of oral and intransive rehydration on ratings of perceived exertion and thirst. Med Sci Sports Exerc 29: 117–124.
35. Vincent JW. (2003) Statistics in Kinesiology: Human Kinetics
36. Dunn CJ. (1964) Multiple comparisons using rank sums. Technometrics 6: 241–252.