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Hydration Status of Arabic Adolescents and Young Men: Measurement, Evaluation, and a School-Based Initiative to Improve Drinking Behavior

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Background: Despite the importance of hydration, limited research on the topic has been undertaken in Arabic populations. ***Methods:*** *Study 1*. Five sequential daily midmorning urine samples were provided by 88 adult military cadets and 32 school-based adolescents. Hydration thresholds were produced using percentiles of estimated urine osmolality (U_{osm}) and urine color (U_{col}). *Study 2*. The authors assessed 1,077 midmorning urine samples from 120 military cadets and 52 adolescents for the U_{osm}:U_{col} relationship using regression. *Study 3*. The authors conducted a 4-wk hydration campaign in which 21 adolescents participated, providing urine samples before (PreC), at the end of (EndC), and 2 wk after the campaign (PostC). ***Results:*** *Study 1*. Euhydration (41–60th percentile) was 881–970 mOsmol/kg in adults and 821–900 mOsmol/kg in adolescents. *Study 2*. In both cohorts, U_{osm} and U_{col} were associated ($p < .01$): adults $R^2 = .33$, adolescents $R^2 = .59$. *Study 3*. Urine osmolality was significantly higher PreC than at EndC and PostC. ***Conclusions:*** Urinary output of Arabic adolescents and military cadets was more concentrated than frequently recommended for euhydration. Further work in similar populations is required to determine if these values represent hypohydration or merely reflect dietary and cultural differences. In male Arabic adolescents and adults, U_{col} was an adequate indicator of hydration status. Favorable hydration changes were made after a school-based health campaign.

Keywords: urine osmolality, urine refractometry, health promotion, Middle East

Water is an essential nutrient for life, responsible for a variety of physiological functions vital for health and well-being. Low to moderate levels of hypohydration may alter cognitive performance and academic achievement (Bar-David, Urkin, & Kozminsky, 2005; Gopinathan, Pichan, & Sharma, 1988), while the beneficial effects of euhydration on physical capacity have been well documented in athletic and military studies (Sawka et al., 2007; Sawka, Montain, & Latzka, 2001). From a sports nutrition perspective, dehydration during exercise has been reported to increase muscle glycogen utilization and may result in a lowered lipid metabolism due to reductions in the uptake of free fatty acids (Gonzalez-Alonso, Calbet, & Nielsen, 1999; Hargreaves, Dillo, Angus, & Febbraio, 1996). Linked to this are the recent reports of indirect associations between increased water intake and concomitant reductions in overweight and obesity (Dubnov-Raz, Constantini, Yariv, Nice, & Shapira, 2011; Muckelbauer et al., 2009). Regarding chronic diseases, which often have complex and multifactorial origins, there is evidence for a beneficial or preventive effect of appropriate hydration. Strong links have been reported for severe hypohydration and morbidity (Manz, 2007), although the relationship between mild hypohydration and disease is less clear. Acute, chronic, and local mild hypohydration have all been linked with a number of diseases, including urinary tract infections, hypertension, stroke, and coronary heart disease, although such associations require robust scientific support from well-controlled clinical trials to determine a true cause-and-effect relationship (Manz, 2007; Popkin, D'Anci, & Rosenberg, 2010).

During recent years, particularly in school settings, much greater exposure in Western Europe and North America has been given to the importance of drinking water and adequate hydration. However, maintaining appropriate levels of body water is more difficult in hotter climates such as the Arabian Gulf (Bates, Miller, & Joubert, 2010), especially for children, with their relatively high proportion of body surface to body mass (Bar-David et al., 2005; Bar-David, Urkin, Landau, Bar-David, & Pilpel, 2009). In these Arab populations, there is emerging evidence of an obesity epidemic, with recent data suggesting that adult and adolescent combined overweight and obesity is as high as 60–75% in adults and 25–40% in adolescents (Ng, Zaghloul, Ali, Harrison, & Popkin, 2011).

Despite the accepted importance of hydration for health, metabolism, and performance, coupled with the

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difficulty of maintaining euhydration in hot climates, there has been a scarcity of research investigating body-water status in the indigenous population of the Arab region. Limited information is available on Arab hydration norms, while the suitability of a simple test of hydration, urine color (U_{col}), in these populations has not been assessed. Such a test, which is recognized as a valid field measure of hydration status in Western individuals (Armstrong, 2007), may be adversely affected by the Arabic diet and environment (Shirreffs, 2000). Furthermore, the efficacy of interventions to improve hydration in Middle Eastern inhabitants is not well known, especially those involving adolescents in a school-based setting. Consequently, in this article we attempt to address the following related aims in two populations indigenous to a country in the Gulf Cooperation Council (GCC):

Study 1: Examine the typical daily hydration values (estimated urine osmolality [U_{osm}] measured using a portable, field-expedient technique and U_{col}) for male adolescents and young male adults in a military training environment and define thresholds for eu-, hypo-, and hyperhydration in these cohorts.

Study 2: Quantify whether U_{col} can be used as a valid surrogate of estimated urine U_{osm}, measured using a portable, field-expedient technique, in these populations.

Study 3: Investigate the effects of a school-based campaign focused on improving hydration status through education and drinking opportunities in male adolescents.

The associated hypotheses are as follows:

Study 1: Hydration thresholds for estimated U_{osm} and U_{col} would be higher in both male Arabic adolescents and young male Arabic adults than the previously published norms for Western populations.

Study 2: Urine color would be demonstrated to be a valid surrogate field measure of estimated U_{osm} in both Arabic cohorts.

Study 3: The 4-week school-based hydration campaign would improve hydration status in male Arabic adolescents.

Methods

Participants

The participants described in this article are from two Arabian Gulf cohorts: adolescent boys attending a military preparatory school in the GCC and young men attending five separate residential military training establishments in the GCC. The cohorts were tested at different times throughout the calendar year and, therefore, were exposed to the range of environmental conditions experienced in the region. All participants provided written informed consent, and ethical clearance was granted by the School of Sport and Exercise Sciences Ethics Committee at the University of Birmingham, UK, and the Al Ain Medical District's Human Research Ethics Committee in the United Arab Emirates. All procedures were in accordance with the Helsinki Declaration of 2004.

Urine Analysis

Midstream morning urine samples, typically from the second void of the day, were provided by participants and deposited directly into 30-ml, clear, sterile, plastic containers. Samples were analyzed for U_{osm} and U_{col} within 30 min of collection. U_{osm} was estimated by a handheld digital refractometer (Osmocheck, Vitech Scientific Ltd., West Sussex, UK). Before each individual U_{osm} analysis, the urine refractometer was calibrated by pipetting a drop of distilled water on the face of the prism. Using distilled water as the standard, the refractometer instrument was set to zero and U_{osm} measured according to the manufacturer's instructions. This device has been used previously to provide a valid measure of hydration status (Kilding et al., 2009; Tam, Nolte, & Noakes, 2011). U_{col} was graded on a scale from 1 to 8 using Armstrong's color chart held adjacent to the urine container in a well-lit room (Armstrong et al., 1994; Armstrong et al., 1998). The same investigator measured U_{col} within each cohort, although the investigator differed between studies and between different study cohorts. This difference was intentional and was designed to reflect free-living occasions, where U_{col} will be measured by the general population.

Study 1

Eighty-eight young male adults (*M* ± *SD* age 19.8 ± 1.7 years, height 1.71 ± 0.06 m, body mass 70.5 ± 13.5 kg, and body-mass index [BMI] 24.1 ± 4.2 kg/m^2) and 32 male adolescents (age 16.5 ± 1.3 years, height 1.69 ± 0.06 m, body mass 82.4 ± 21.0 kg, and BMI 28.7 ± 6.5 kg/m^2) participated in the study, which formed part of a larger trial to measure the health status of these Arabic populations. Morning urine samples were collected on five sequential days and analyzed for U_{osm} (both cohorts) and U_{col} (young male adult cohort only), as described previously. Participants providing fewer than five urine samples were excluded from the analysis.

The approach of Armstrong et al. (2010) was used to determine U_{osm} and U_{col} hydration thresholds for the two cohorts. Armstrong et al. (2010) proposed using percentiles from the normal distribution of the individual U_{osm} and U_{col} data points to determine hydration thresholds. The thresholds and hydration categories were as follows: extremely hyperhydrated (1–10th percentile); slightly hyperhydrated (11–25th percentile); well hydrated (26–40th percentile); euhydrated (41–60th percentile); slightly dehydrated (61–75 percentile); well dehydrated (76–90th percentile); extremely dehydrated (91–100th percentile).

Study 2

One hundred twenty young male adults (age 19.8 ± 1.7 years, height 1.71 ± 0.06 m, body mass 70.9 ± 14.0 kg, and BMI 24.3 ± 4.3 kg/m^2) and 52 male adolescents (age 16.0 ± 1.6 years, height 1.68 ± 0.07 m, body mass 77.1 ± 19.5 kg, and BMI 27.1 ± 5.9 kg/m^2) participated in the study, which, as with Study 1, formed part of a larger trial to measure the health status of these Arabic populations. Midmorning urine samples were collected for up to 10 days over a 1- to 2-week period and analyzed for U_{osm} and U_{col} as described previously. Participants providing fewer than three urine samples were excluded from the analysis.

Study 3

Twenty-one adolescent male participants (age 14.8 ± 0.7 years, height 1.67 ± 0.07 m, body mass 87.4 ± 10.4 kg, and BMI 31.2 ± 2.8 kg/m^2) took part in the study. They were part of a healthy-eating, food-portion-control group implemented at the school, and this study describes one of several interventions designed to promote healthy behavior change in this cohort. The study spanned 7 weeks and involved three 3-day measurement periods—precampaign (PreC, Week 1), end campaign (EndC, Week 5), and postcampaign (PostC, Week 7)—and is summarized in Figure 1. The healthy-eating group involved obese students receiving portion-controlled meals in a private area of the school cafeteria. This initiative, which was designed to reduce energy intake and promote weight loss, had been running for 12 weeks before the start of Study 3 and continued throughout the 7-week hydration campaign. Daily sodium content of the meals provided in the cafeteria, estimated using recipe analysis (Nutmeg Menu Planner program, Nutmeg, UK), was kept constant at 3,600 mg/day during the 7-week hydration study.

The 4-week hydration campaign consisted of a variety of initiatives to increase voluntary consumption of water, including exposure to hydration educational posters, leaflets, a 45-min lecture, and public announcements; participation in a hydration workshop; personalized feedback on each subject's PreC baseline hydration status; distribution of individual hydration color charts and "tick as you drink" charts with recommendations on daily drinking targets; improved access to drinking water during mealtimes. Midmorning urine samples were collected for 3 consecutive days in three separate periods and analyzed for U_{osm} and U_{col}, as described previously. In addition, participants completed the same simple hydration-awareness questionnaire during each measurement period. Participants with incomplete data were excluded from the analyses.

Data and Statistical Analysis

Percentile values, Pearson's correlations, linear regression, and comparative analyses (analysis of variance) were performed using Statistical Package for the Social Sciences (SPSS Inc., IL, USA) version 19 for Windows. Paired Student's *t* tests, with appropriate Bonferroni corrections, were used for post hoc analysis between mean U_{osm} and U_{col} data, while McNemar's chi-square test was used to determine differences in hydration awareness. All data are presented as the mean and one standard deviation (*SD*), and statistical significance was determined at the .05 level of confidence.

Results

Study 1

In total, 440 adult and 160 adolescent urine samples were collected and analyzed for U_{osm} and U_{col}. Mean (± *SD*) U_{osm} for adults was greater than for adolescents (910 ± 154 vs. 811 ± 187 mOsmol/kg, $p < .001$); this corresponded to a mean (± *SD*) U_{col} in adults of 5 ± 2. Table 1 was designed using percentiles for the normal distribution of the 440 and 160 data points, applying the hydration categories according to Armstrong et al. (2010), whose initial morning U_{osm} and U_{col} thresholds are included in Table 1 for comparison purposes.

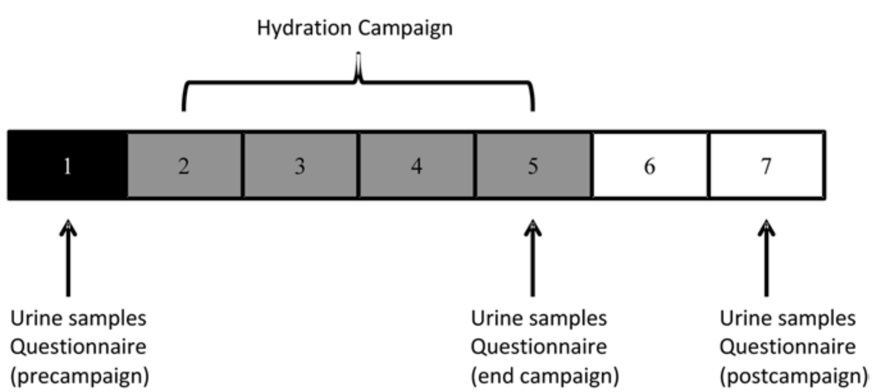

Figure 1 — A schematic describing the hydration campaign's study methodology. Numbers 1–7 = weeks; urine samples = collection of midmorning urine samples for 3 consecutive days; questionnaire = completion of the hydration-awareness questionnaire.

Table 1 Categories (Percentiles) of Hydration Status for Arabic Adolescents and Young Adults

				Adults		Armstrong et al. (2010)	
Hydration	Percentile range	Combined urine osmolality (mOsmol/kg)	Adolescents' urine osmolality (mOsmol/kg)	Urine osmolality (mOsmol/kg)	Urine color (1–8)	Urine osmolality (mOsmol/kg)	Urine color (1–8)
Extremely hyperhydrated	1–10	<611	<470	<650	1–3	<545	<4
Slightly hyperhydrated	11–25	611–780	471–700	650–810	3–4	545–713	4
Well hydrated	26–40	781–870	701–820	811–880	4–5	714–817	5
Euhydrated	41–60	871–960	821–900	881–970	5–6	818–924	5
Slightly dehydrated	61–75	961–1020	901–970	971–1,030	6–7	925–999	5
Very dehydrated	76–90	1,021–1,120	971–1,050	1,031–1,140	7	1,000–1,129	6
Extremely dehydrated	91–100	>1,120	>1,050	>1,140	7–8	>1,129	>6
95% confidence intervals	2.5–97.5	340–1,200	260–1,120	360–1,240	2–8	377–1,194	3–7

Note. Percentiles were used to determine numerical values for each category (adolescents: 160 data points, 32 participants; adults: 440 data points, 88 participants). The Armstrong et al. (2010) data are taken from the initial morning sample using a cohort of North American adult men (290 data points, 59 participants).

Study 2

In total, 625 adult and 452 adolescent urine samples were collected and analyzed for U_{osm} and U_{col}. In both cohorts, U_{osm} and U_{col} were related: adults $R^2 = .33$, $p < .01$; adolescents $R^2 = .59$, $p < .01$. The range of coefficients of determination for the five separate young adult military training establishments was $R^2 = .19–.52$. The relationships, and accompanying equation, are shown in Figure 2 and Table 2.

Study 3

Mean (± *SD*) U_{osm} during the three monitoring periods of the hydration campaign were as follows: PreC 842 ± 211 mOsmol/kg, EndC 689 ± 224 mOsmol/kg, and PostC 630 ± 230 mOsmol/kg ($p = .01$; Figure 3). Urine osmolality was similar between EndC and PostC ($p = .10$), with both mean values significantly lower than PreC ($p < .001$). There were no differences between monitoring periods for U_{col}: PreC 6 ± 1, EndC 5 ± 2, and PostC 5 ± 2 ($p = .36$).

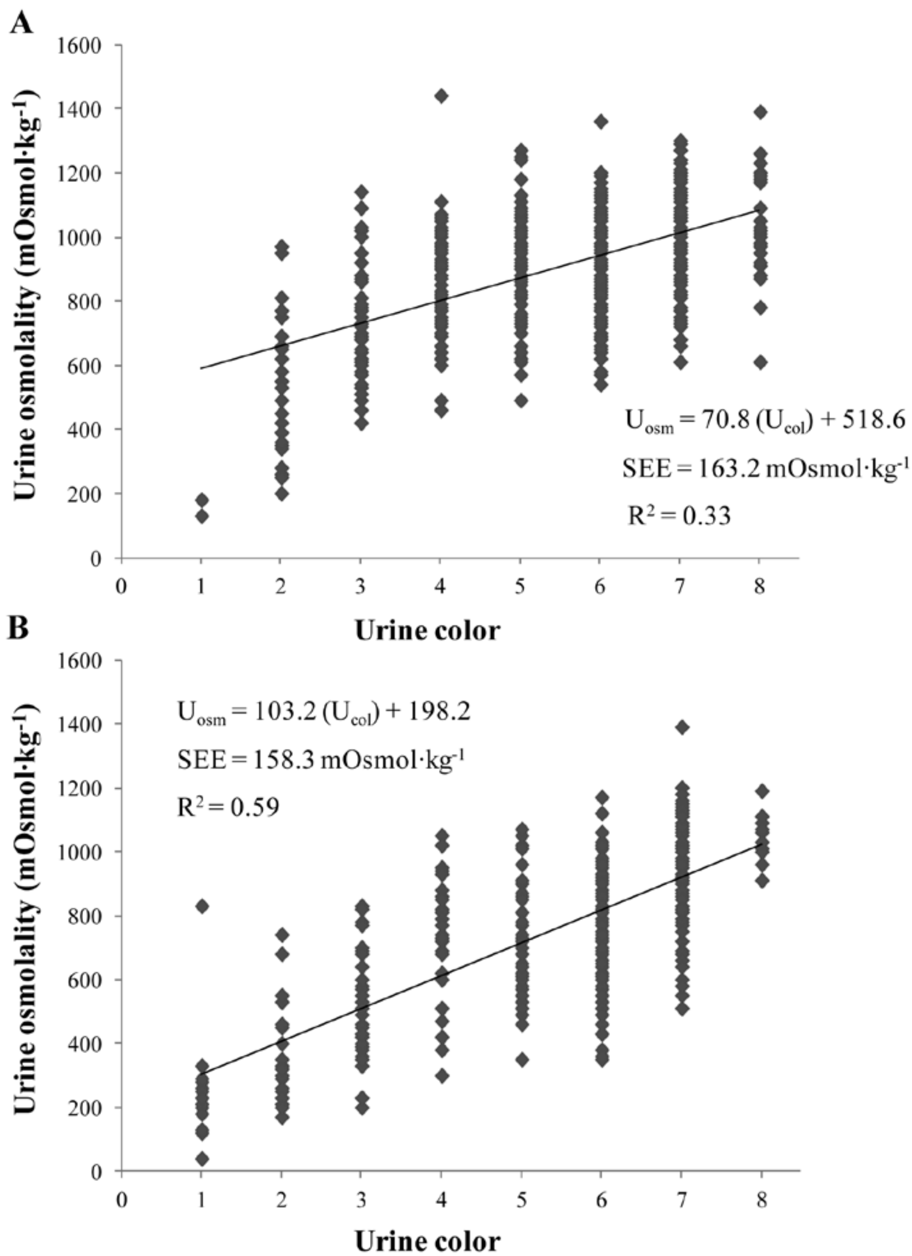

Figure 2 — Relationship between estimated urine osmolality (U_{osm}) and urine color (U_{col}) in (A) young Arabic male adults and (B) Arabic male adolescents. SEE = standard error of the estimate; R^2 = percentage of variation in U_{osm} explained by U_{col}.

Table 2 Estimated Urine Osmolality (mOsmol/kg) From Urine Color in Arabic Adolescents and Young Adults

Urine color	Adolescents	Adults
1	301	589
2	405	660
3	508	731
4	611	802
5	714	873
6	818	944
7	921	1,014
8	1,024	1,085

According to McNemar's chi-square test, the proportion of students correctly identifying the color of hydrated urine (i.e., clear/pale yellow) did not change as a result of the hydration-education campaign ($p = .180$). However, a larger proportion of students correctly identified the color of hydrated urine at EndC (70%) than at PreC (52%), with a small positive relationship between pre- and postcampaign responses (phi coefficient $\varphi = .349$).

Discussion

In this article, we have presented three studies that explored hydration thresholds for two distinct Arabic populations in the GCC: male adolescents at a military preparatory school and young male adults engaged in basic military training. In addition, the relationship between two easy-to-measure urinary hydration variables (estimated U_{osm} and U_{col}) was detailed, as was the efficacy of a school-based hydration campaign to improve hydration status. Despite the importance of adequate hydration for health, cognition, academic success, and physical performance (Popkin et al., 2010), there has been a lack of similarly focused research carried out previously in the Arab world. This is somewhat surprising considering the high environmental temperatures that are common for much of the year in these locales.

Study 1

Compared with previously published norms for euhydration (≤700 mOsmol/kg; Sawka et al., 2007), the mean U_{osm} values reported in Study 1 suggest that participants in both cohorts were, on average, in a state of hypohydration (811–910 mOsmol/kg). This assertion is strengthened with the knowledge that 119 of the 160 adolescent U_{osm} samples (74%) and 378 of the 440 young adult U_{osm} samples (86%) were in excess of 700 mOsmol/kg. However, it is widely accepted that there is no gold standard for hydration (Shirreffs, 2000); rather, euhydration represents a state that fluctuates over a 24-hr period (Greenleaf, 1992). In agreement with this theory are the findings of Armstrong et al. (1994), who argued that the normal range of U_{osm} could be as broad as 442–1,052 mOsmol/kg, based on two cohorts of young adult males with a varying level of fitness, while Popowski et al. (2001) investigated young adult males with a high level of aerobic fitness (VO_{2max} 71 ± 6 ml · kg^{-1} · min^{-1}) exercising in the heat and reported this same range to be 325–858 mOsmol/kg. More recently, Armstrong et al. (2010) revised their U_{osm} range for euhydration using a cohort of physically active, free-living, young male adults: initial morning U_{osm} sample 805–867 mOsmol/kg; 24-hr U_{osm} 637–720 mOsmol/kg. As such, it may be more appropriate to state that the adolescent cohort in the current study were, on average (and compared with Western populations), in a state approaching hypohydration, while the young adults were slightly hypohydrated. However, comparing the data in Study 1 with hydration thresholds published in studies involving participants from different cultures and climates may not be appropriate. Although some of the previous study designs involved free-living young adults (Armstrong et al., 2010), many involved measurement of, or reference to, moderately to well-trained athletes and soldiers engaging in a variety of physical activities in a range of environmental conditions (Armstrong et al., 1994; Popowski et al., 2001; Sawka et al., 2007). It is plausible that these participants were engaged in strenuous activities that resulted in their day-to-day hydration status extending beyond the range that would be considered normal in their local populations. Therefore, we followed the approach of Armstrong et al. (2010) and produced hydration thresholds using the percentiles from our two Arabic cohorts. The 95% confidence intervals for U_{osm} were also presented, and any individual from a similar cohort who exhibits a value outside these limits may be considered at risk for severe hypohydration or hyperhydration (Armstrong et al., 2010).

Several factors, in addition to cohort characteristics and study design, may account for the higher U_{osm} values per hydration threshold in our data than those of Armstrong et al. (2010), including differences in environmental conditions, daily fluid intake and turnover, and energy expenditure. Considering the discrepancy in hydration status between the two cohorts of the current study, variability in physical activity was likely to have been a contributing factor. Unpublished energy-expenditure data using the doubly labeled water technique in both cohorts revealed physical activity levels were higher in the young adults (1.81) than in the adolescents (1.67; unpublished observations, although data from our group using similar cohorts and the same methodology are available: Blacker et al., 2011; Carter, Richmond, Wilkinson, & Rayson, 2008). In addition, differences in total osmolar load of the diet (Ebner & Manz, 2002) and in renal solute excretion caused by variations in dietary intake of sodium (Manz & Wentz, 2003) would influence U_{osm}. Although a higher sodium intake, which would contribute to a raised U_{osm}, is thought commonplace in diets of the Arab Middle East (Musaiger, 2002), there is a distinct lack of studies exploring the dietary salt content in the GCC (Ng et al., 2011). However, the sodium content of meals available to participants in Study 3 provides some support for this

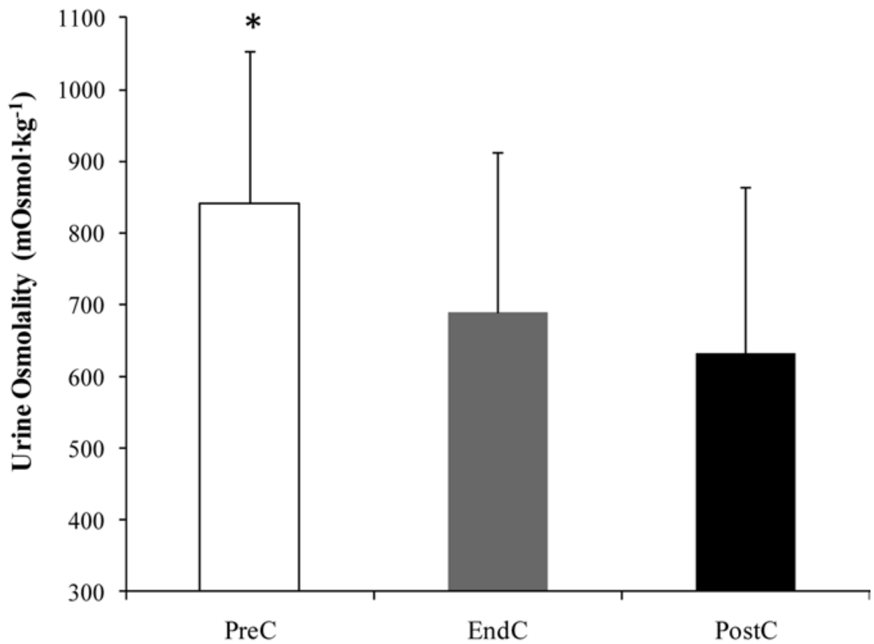

Figure 3 — Mean urine osmolality before (PreC), at the end of (EndC), and 2 weeks after (PostC) the hydration campaign, *M* + *SD*, *n* = 21. *Difference between PreC and EndC and between PreC and PostC ($p < .05$).

supposition, with estimated daily values of 3,600 mg/day, exceeding the U.S. Institute of Medicine's Food and Nutrition Board's (2004) recommended daily adequate intake and tolerable upper intake level for sodium for adolescent males age 14–18 years (1,500 mg/day and 2,300 mg/day, respectively). Such dietary differences account, in part, for the wide-ranging intercultural U_{osm} values collected previously by numerous research groups and collated in one volume by Manz and Wentz . In that publication, U_{osm} data range from <400 to >1,000 mOsmol/kg in adults and adolescents. Additional contributory factors for the international disparity include advice from medical practitioners, ethnicity, geographic location, and choice of sporting pursuit (Manz & Wentz, 2003).

There is need for caution when interpreting the percentile hydration thresholds reported in this article. Unlike previous work, including that of Armstrong et al. (2010), who used the freezing-point-depression technique, a handheld digital refractometer rather than a criterion measure of U_{osm} was used in the current study. Although the same device has previously been used to measure hydration status in athletic populations (Kilding et al., 2009; Tam et al., 2011), published validation or precision data comparing the Osmocheck with a criterion measure do not seem to be available. The Osmocheck manufacturers, Vitech Scientific Ltd., cite the work of Godfrey in their claim that urine specific gravity and U_{osm} share a close relationship (for an example, refer to Pollock, Godfrey, & Reilly, 1997). In support of this claim, Armstrong et al. (1998) conducted a study involving 34 healthy males and demonstrated that urine specific gravity (as measured with a handheld refractometer) and U_{osm} (measured with a freezing-point-depression osmometer) may be used interchangeably. The coefficient of determination (R^2) of these measurements, and that provided in a later but similar study (Hamouti, Del Coso, Avila, & Mora-Rodriguez, 2010), was .96. However, the lack of validation studies pertaining to the handheld refractometer used in the current study is a recognized limitation and one that future research would do well to rectify.

In addition, and similar to Armstrong et al. (2010), we assumed that the mean U_{osm} values represented a state of euhydration in our cohorts. Several previous studies have taken measures to help ensure this, namely preloading participants with fluid (Armstrong et al., 1994; Armstrong et al., 1998). However, this approach was not adopted in the current study because deviations from the participants' normal drinking behavior were likely. Priming the participants with fluid may have guaranteed adequate body-water stores, but it may also have shifted the subsequently presented thresholds for hydration falsely to the left. It is plausible to suggest that evolutionary changes resulted in these former Bedouin populations becoming less reliant on water or perhaps developing more efficient water-conservation mechanisms, and this would be reflected in urinary hydration variables that could be misinterpreted as indicative of hypohydration. While evolutionary adaptations may explain some of the findings in the current study, we do not currently have and are not aware of any longitudinal empirical evidence to support this theory. There appears a scarcity of published research on Bedouin hydration norms, although U_{osm} data collected from Tunisian Muslims before (881 mOsmol/kg) and after (898 mOsmol/kg) Ramadan suggests that a restricted daily fluid intake may be commonplace in such communities (Zebidi et al., 1990). During Ramadan, U_{osm} was even higher before and after breaking the daylight fast (1,023 and 923 mOsmol/kg).

Additional caution is urged if extrapolating the findings of the current article to other Arabic cohorts. The differences in mean U_{osm} and percentile thresholds between the young adults and the adolescents provide evidence that a one-size-fits-all approach is not valid for the wider population. However, the U_{osm} of participants in the current study is in keeping with values for healthy cohorts from three countries with climates and/or cultures comparable with those of the GCC: Israel (1,028 mOsmol/kg; Manz & Wentz, 2003), Libya (830 mOsmol/kg; Waterhouse, Alkib, & Reilly, 2008), and Tunisia (881–898 mOsmol/kg; Zebidi et al., 1990). Finally, the timing of the urine sample is worthy of consideration. In the current study, a morning sample was collected, which was typically the second void of the day. However, Armstrong et al. (2010) presented hydration thresholds for both initial morning sample and 24-hr urine collection, with the former being significantly more concentrated. Although comparisons with the second void of the day are not known, it is likely that the hydration thresholds presented in this study are slightly higher than would be expected if 24-hr urine had been collected and analyzed.

Study 2

Several studies have investigated the use of U_{col} as a tool to determine hydration status (Armstrong et al., 1994; Armstrong et al., 1998). Subsequently, U_{col} has become accepted as a simple method for individuals to self-monitor their level of hydration, especially when precision or sensitivity is not required (Armstrong, 2007; Oppliger & Bartok, 2002; Shirreffs, 2003). Previously published U_{osm} and U_{col} relationships have reported coefficients of determination (R^2) ranging from .38 to .98 (Armstrong et al., 1994; Armstrong et al., 1998; Pollock et al., 1997). Until now, this relationship has not been described in Arabic populations, despite the usefulness of such a test for active individuals trying to maintain euhydration in the harsh environmental conditions in this part of the world. The proportion of variance in U_{osm} explained by U_{col} in Study 2 was 33% in the young adult cohort and 59% in the adolescent cohort, although the range in the adult cohort was 19–52% depending on the training establishment. The error associated with these predictions was similar between cohorts (SEE 158–163 mOsmol/kg) and should be taken into consideration when using U_{col}. Consequently, the use of U_{col} as a measure of hydration status is justified in male Arabic adolescents and young Arabic male adults attending basic military training, although the wide variability associated with the prediction of U_{osm} should be acknowledged.

Factors responsible for the variability in error and for the disparities between the coefficients of determination reported herein and those reported previously (Armstrong et al., 1994; Armstrong et al., 1998; Pollock et al., 1997) cannot be determined. Those previous studies imposed greater participant (i.e., enforcing constraints on physical activity and tobacco use) and dietary control and used a criterion measure of U_{osm} (freezing-point-depression osmometry—see earlier discussion on Study 1). Furthermore, it is possible that investigator error was, in part, responsible; determination of U_{col} is largely a subjective process, and different investigators were used to carry out the urine analysis. The wide range in the proportion of variance of U_{osm} explained by U_{col} between the different adult military training establishments (R^2 = .19–.52) may provide evidence of this. Alternatively, differences in dietary supplement intake, illness, or medication between the study participants cannot be ruled out (Shirreffs, 2000).

In summary, the coefficient of determination and SEE data reported in this article reemphasize previous assertions that U_{col} remains a useful guide rather than a precise tool for determining hydration. The data in Table 1 show that a urine color of 5–6 would be indicative of euhydration in these Arab populations. The original recommendations that athletes should seek to produce a U_{col} of 1–3 to indicate being well hydrated (Armstrong et al., 1994) should not be encouraged as a target color in these populations, as it may encourage excessive fluid consumption and hyperhydration. In support of this contention, Armstrong et al. (2010), in their recent study, state that achievement of a U_{col} of 1 is not desirable, and such advice from health and sport practitioners should be avoided.

Study 3

The series of studies was completed with an investigation into the effectiveness of a school-based education campaign to improve adolescent hydration status. The mean U_{osm} at the end of the campaign and in the following 2 weeks was significantly reduced compared with precampaign levels. In addition, the number of participants in the euhydrated to hyperhydrated zones (i.e., <901 mOsmol/kg) increased at each stage of the campaign (PreC n = 12, EndC n = 17, and PostC n = 19). Collectively, these data suggest that the 4-week campaign was effective in modifying drinking behavior, resulting in decreased urine concentrations. These findings support those of Loughridge and Barratt (2005), who demonstrated an increase in water consumption by high school adolescent students with an active promotion campaign that involved improved drinking-water access, hydration education, and encouragement from a local sporting celebrity. In Study 3, the change in hydration status was not verified by the U_{col} data. This provides further evidence that color is useful as a simple field technique to indicate hydration status but should not be used when greater precision and sensitivity are required (Shirreffs, 2003).

It has been previously discussed that an increased sodium intake would contribute to U_{osm} (Ebner & Manz, 2002; Manz & Wentz, 2003). It is therefore plausible that alterations in the total daily dietary intake as a result of enrollment in the healthy eating group may have influenced U_{osm} and U_{col} in Study 3. However, the initiative had been running for 12 weeks before the hydration study commenced, and the daily sodium content of the meals was kept constant throughout Study 3. Consequently, any changes in urinary indices resulting from modifications in the dietary intake of the cohort participating in the healthy-eating initiative were likely to have occurred before the start of Study 3. Despite this, additional and uncontrolled dietary intake on the weekends, when participants were not at the school, may have influenced the results and contributed to the lack of difference in U_{col}. Therefore, future hydration studies investigating similar cohorts would benefit from more precise measures of dietary sodium intake, as well as the total osmolar load of the diet, rather than relying on estimations from recipe analysis.

The concomitant benefits of improved hydration include both short-term and long-term enhancements in health, well-being, and performance. Short-term changes can include improved attention and memory, reduced tiredness, and enhanced exercise capacity and performance (Bar-David et al., 2005; Sawka et al., 2007; Wilson & Morley, 2003). Longer term benefits are less clear, but indirect evidence suggests that maintaining adequate body water may help prevent diseases such as hypertension, stroke, heart disease, and urinary tract infections (Manz, 2007; Popkin et al., 2010). Of particular relevance to the cohort in this study, though, are the indirect associations between improved body-water content and reductions in overweight and obesity (Lappalainen, Mennen, van Weert, & Mykkanen, 1993; Muckelbauer et al., 2009). This is likely to be a consequence of increased water intake at the expense of caloric alternatives (e.g., soda) but may also be associated with improvements in metabolism and resting energy expenditure (Dubnov-Raz et al., 2011). Whether the changes in estimated U_{osm} in Study 3 resulted in any of the health benefits described here was unknown and beyond the scope of this article. However, we recommend that future research focus on investigating the health benefits associated with improvements in body-water content in Arabic populations. Changing the focus of future hydration campaigns in these populations, away from achieving U_{col} in the range of 1–3 (Armstrong et al., 1994) and toward avoiding dark-colored urine in the range of 6–8, may be more appropriate and effective at promoting euhydration.

In conclusion, Arabic adolescents and young adults attending basic military training generated daily U_{osm} and U_{col} values that were higher than the previously published thresholds in groups living in Western temperate climates. More concentrated and darker colored urine in Arabic cohorts may be indicative of hypohydration, potentially caused by a reduced fluid intake and/or increased fluid loss in response to exposure to the thermally demanding environment. Alternatively, differences in dietary intake, through either an increased osmolar load or an evolutionary adaptation to living in an arid climate, may have contributed to normal hydration reflected by augmented U_{osm} and U_{col}. In addition, U_{col} was shown to be an adequate and easy-to-use marker of hydration status in Arabic adolescents and adults, although there was large individual variability at each color level. Finally, a 4-week school-based hydration campaign was effective in modifying Arabic adolescent drinking behavior and lowering estimated U_{osm}.

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References

Armstrong, L.E. (2007). Assessing hydration status: The elusive gold standard. *Journal of the American College of Nutrition, 26,* 575S–584S. PubMed

Armstrong, L.E., Maresh, C.M., Castellani, J.W., Bergeron, M.F., Kenefick, R.W., LaGasse, K.E., & Riebe, D. (1994). Urinary indices of hydration status. *International Journal of Sport Nutrition, 4,* 265–279. PubMed

Armstrong, L.E., Pumerantz, A.C., Fiala, K.A., Roti, M.W., Kavouras, S.A., Casa, D.J., & Maresh, C.M. (2010). Human hydration indices: Acute and longitudinal reference values. *International Journal of Sport Nutrition and Exercise Metabolism, 20,* 145–153. PubMed

Armstrong, L.E., Soto, J.A., Hacker, F.T., Jr., Casa, D.J., Kavouras, S.A., & Maresh, C.M. (1998). Urinary indices during dehydration, exercise, and rehydration. *International Journal of Sport Nutrition, 8,* 345–355. PubMed

Bar-David, Y., Urkin, J., & Kozminsky, E. (2005). The effect of voluntary dehydration on cognitive functions of elementary school children. *Acta Paediatrica, 94,* 1667–1673. PubMed doi:10.1080/08035250500254670

Bar-David, Y., Urkin, J., Landau, D., Bar-David, Z., & Pilpel, D. (2009). Voluntary dehydration among elementary school children residing in a hot arid environment. *Journal of Human Nutrition and Dietetics, 22,* 455–460. PubMed doi:10.1111/j.1365-277X.2009.00960.x

Bates, G.P., Miller, V.S., & Joubert, D.M. (2010). Hydration status of expatriate manual workers during summer in the Middle East. *The Annals of Occupational Hygiene, 54,* 137–143. PubMed doi:10.1093/annhyg/mep076

Blacker, S.D., Horner, F.L., Brown, P.E., Linnane, D.M., Wilkinson, D.M., Wright, A., . . . Rayson, M.P. (2011). Health, fitness and responses to military training of officer cadets in a Gulf Cooperation Council country. *Military Medicine, 176,* 1376–1381. PubMed

Carter, J.M., Richmond, V.L., Wilkinson, D.M., & Rayson, M.P. (2008). Health, fitness and nutritional status at the Military High School in the United Arab Emirates. *Medicine and Science in Sports and Exercise, 40,* S238.

Dubnov-Raz, G., Constantini, N.W., Yariv, H., Nice, S., & Shapira, N. (2011). Influence of water drinking on resting energy expenditure in overweight children. *International*

Journal of Obesity, 35,* 1295–1300. PubMed doi:10.1038/ijo.2011.130

Ebner, A., & Manz, F. (2002). Sex difference of urinary osmolality in German children. *American Journal of Nephrology, 22,* 352–355. PubMed doi:10.1159/000065226

Gonzalez-Alonso, J., Calbet, J.A.L., & Nielsen, B. (1999). Metabolic and thermodynamic responses to dehydration-induced reductions in muscle blood flow in exercising humans. *The Journal of Physiology, 520,* 577–589. PubMed doi:10.1111/j.1469-7793.1999.00577.x

Gopinathan, P.M., Pichan, G., & Sharma, V.M. (1988). Role of dehydration in heat stress-induced variations in mental performance. *Archives of Environmental Health, 43,* 15–17. PubMed doi:10.1080/00039896.1988.9934367

Greenleaf, J.E. (1992). Problem: Thirst, drinking behaviour, and involuntary dehydration. *Medicine and Science in Sports and Exercise, 24,* 645–656. PubMed

Hamouti, N., Del Coso, J., Avila, A., & Mora-Rodriguez, R. (2010). Effects of athletes' muscle mass on urinary markers of hydration status. *European Journal of Applied Physiology, 109,* 213–219. PubMed doi:10.1007/s00421-009-1333-x

Hargreaves, M., Dillo, P., Angus, D., & Febbraio, M. (1996). Effect of fluid ingestion on muscle metabolism during prolonged exercise. *Journal of Applied Physiology, 80,* 363–366. PubMed

Kilding, A.E., Tunstall, H., Wraith, E., Good, M., Gammon, C., & Smith, C. (2009). Sweat rate and sweat electrolyte composition in international female soccer players during game specific training. *International Journal of Sports Medicine, 30,* 443–447. PubMed doi:10.1055/s-0028-1105945

Lappalainen, R., Mennen, L., van Weert, L., & Mykkanen, H. (1993). Drinking water with a meal: A simple method of coping with feelings of hunger, satiety and desire to eat. *European Journal of Clinical Nutrition, 47,* 815–819. PubMed

Loughridge, J.L., & Barratt, J. (2005). Does the provision of cooled filtered water in secondary school cafeterias increase water drinking and decrease the purchase of soft drinks? *Journal of Human Nutrition and Dietetics, 18,* 281–286. PubMed doi:10.1111/j.1365-277X.2005.00622.x

Manz, F. (2007). Hydration and disease. *Journal of the American College of Nutrition, 26,* 535S–541S. PubMed

Manz, F., & Wentz, A. (2003). 24-h hydration status: Parameters, epidemiology and recommendations. *European Journal of Clinical Nutrition, 57,* S10–S18. PubMed doi:10.1038/sj.ejcn.1601896

Muckelbauer, R., Libuda, L., Clausen, K., Toschke, A.M., Reinehr, T., & Kersting, M. (2009). Promotion and provision of drinking water in schools for overweight prevention: Randomized, controlled cluster trial. *Pediatrics, 123,* e661–e667. PubMed doi:10.1542/peds.2008-2186

Musaiger, A.O. (2002). Diet and prevention of coronary heart disease in the Arab Middle East countries. *Medical Principles and Practice, 11,* 9–16. PubMed doi:10.1159/000066415

Ng, S.W., Zaghloul, S., Ali, H.I., Harrison, G., & Popkin, B.M. (2011). The prevalence and trends of overweight, obesity and nutrition-related non-communicable diseases in the Arabian Gulf States. *Obesity Reviews, 12,* 1–13. PubMed doi:10.1111/j.1467-789X.2010.00750.x

Oppliger, R.A., & Bartok, C. (2002). Hydration testing of athletes. *Sports Medicine (Auckland, N.Z.), 32,* 959–971. PubMed doi:10.2165/00007256-200232150-00001

Pollock, N.W., Godfrey, R.J., & Reilly, T. (1997). Evaluation of field measures of urine concentration. *Medicine and Science in Sports and Exercise, 29,* S261.

Popkin, B.M., D'Anci, K.E., & Rosenberg, I.H. (2010). Water, hydration, and health. *Nutrition Reviews, 68,* 439–458. PubMed doi:10.1111/j.1753-4887.2010.00304.x

Popowski, L.A., Oppliger, R.A., Lambert, G.P., Johnson, R.F., Johnson, A.K., & Gisolfi, C.V. (2001). Blood and urinary measures of hydration status during progressive acute dehydration. *Medicine and Science in Sports and Exercise, 33,* 747–753. PubMed doi:10.1097/00005768-200105000-00011

Sawka, M.N., Burke, L.M., Eichner, E.R., Maughan, R.J., Montain, S.J., & Stachenfeld, N.S. (2007). American College of Sports Medicine position stand. Exercise and fluid replacement. *Medicine and Science in Sports and Exercise, 39,* 377–390. PubMed doi:10.1249/mss.0b013e31802ca597

Sawka, M.N., Montain, S.J., & Latzka, W.A. (2001). Hydration effects on thermoregulation and performance in the heat. *Comparative Biochemistry and Physiology. Part A, Molecular & Integrative Physiology, 128,* 679–690. PubMed doi:10.1016/S1095-6433(01)00274-4

Shirreffs, S.M. (2000). Markers of hydration status. *The Journal of Sports Medicine and Physical Fitness, 40,* 80–84. PubMed

Shirreffs, S.M. (2003). Markers of hydration status. *European Journal of Clinical Nutrition, 57,* S6–S9. PubMed doi:10.1038/sj.ejcn.1601895

Tam, N., Nolte, H.W., & Noakes, T.D. (2011). Changes in total body water content during running races of 21.1 km and 56 km in athletes drinking ad libitum. *Clinical Journal of Sport Medicine, 21,* 218–225. PubMed doi:10.1097/JSM.0b013e31820eb8d7

U.S. Institute of Medicine. Food and Nutrition Board. (2004). *Dietary reference intakes for water, sodium, potassium, chloride and sulphate*. Washington, DC: National Academic Press.

Waterhouse, J., Alkib, L., & Reilly, T. (2008). Effects of Ramadan upon fluid and food intake, fatigue, and physical, mental, and social activities: A comparison between the UK and Libya. *Chronobiology International, 25,* 697–724. PubMed doi:10.1080/07420520802397301

Wilson, M.M., & Morley, J.E. (2003). Impaired cognitive function and mental performance in mild dehydration. *European Journal of Clinical Nutrition, 57,* S24–S29. PubMed doi:10.1038/sj.ejcn.1601898

Zebidi, A., Rached, S., Dhidah, M., Sadraoui, M., Tabka, Z., Dogui, M., . . . Chaieb, A. (1990). The effect of Ramadan fasting on some plasmatic and urinary parameters. *La Tunisie Medicale, 68,* 367–372. PubMed