Comparison of Fluid Balance Between Competitive Swimmers and Less Active Adolescents

Dean G. Higham, Geraldine A. Naughton, Lauren A. Burt, and Xiaocai Shi

The aim of this study was to compare daily hydration profiles of competitive adolescent swimmers and less active maturation- and sex-matched controls. Hydration profiles of 35 competitive adolescent swimmers (male $n = 18$, female $n = 17$) and 41 controls (male $n = 29$, female $n = 12$) were monitored on 4 consecutive days. First morning hydration status was determined independently by urine specific gravity (USG) and urine color. Changes in fluid balance were estimated during the school day and in training sessions after adjusting for self-reported urine losses and fluid intake. Urinalyses revealed consistent fluid deficits (USG $>1.020$, urine color $\geq 5$) independent of activity group, sex, and day of testing (hypohydration in 73–85% of samples, $p > .05$). Fluid balance and intake were observed over typical school days in males and females from the 2 groups. During training, male swimmers lost more fluid relative to initial body mass but drank no more than females. Although both activity groups began each testing day with a similar hydration status, training induced significant variations in fluid balance in the swimmers compared with controls. Despite minimal fluid losses during individual training sessions ($<2\%$ body mass), these deficits significantly increased fluid needs for young swimmers over the school day.

Keywords: hydration, dehydration, sweat, urine specific gravity, swimming

Adequate hydration is important for achieving peak athletic performance and avoiding heat illness. In the human body, hydration fluctuates slightly because of variations in food and fluid intake, sweat and respiratory losses, and the formation and excretion of urine and feces. In adults, euhydration is usually maintained by the balance of normal daily conditions (Cheuvront, Carter, Montain, & Sawka, 2004). With the introduction of physical activity, excess metabolic heat must be eliminated to maintain homeostasis of core body temperature and metabolic function. The disruption of normal body-water status by large sweat losses can have significant adverse effects on performance and health (Casa, Clarkson, & Roberts, 2005). Body-water deficits from sweat production must therefore be replaced to maintain euhydration.
Competitive swimming involves prolonged, high-intensity activity in relatively stable water temperatures. Aquatic athletes have distinctive thermoregulatory stresses because of increased opportunities to dissipate heat through forced convection and conduction (Nielsen & Davies, 1976). The low thermal stresses of exercise in water might be insufficient to incur significant sweat losses in adolescents. Therefore, adolescent swimmers might not require more fluid to maintain euhydration than their less active peers. The limited existing hydration literature on aquatic sports is predominantly restricted to studies of adult samples (Cox et al., 2002; Lemon et al., 1989). Adolescents have different thermoregulatory and fluid requirements than children and adults (Armstrong & Maresh, 1995; Falk et al., 1992). Leiper and Maughan (2004) reported greater water turnover rates in a small sample of young swimmers than in age-matched controls. However, no previous study of adolescent swimmers has concurrently assessed fluid-balance changes and hydration status. Furthermore, no previous study has examined sex differences in fluid balance associated with high-volume training in adolescents. Investigation of the synergy between thermoregulatory and training factors is required to generate data to strengthen the current scientific evidence base for hydration guidelines for active and less active adolescents (“Climatic Heat Stress,” 2000).

The primary aim of this study was to compare daily hydration profiles of competitive adolescent swimmers and less active maturation- and sex-matched controls. The secondary aim was to assess the validity of using urine color to assess hydration status in adolescents.

**Methods**

**Participants**

A convenience sample of 35 adolescent swimmers competing at state or national level (male $n = 18$, female $n = 17$) was recruited from three accredited swim-training facilities, and 41 maturation- and sex-matched less active controls (male $n = 29$, female $n = 12$) age 13–18 years volunteered from two secondary schools in the same demographic area as the swim squads. Swimmers trained twice daily either 5 or 6 days/week, covering a minimum of 4.5 km in each session. The control group participated in no more than 5 hr of organized physical activity per week outside of school. Participants had no specific education on methods to monitor hydration and gauge individual fluid requirements. Variability in puberty makes the stage of sexual maturation a more appropriate basis for comparison of differences between peripubertal individuals than chronological age (Roemmich & Rogol, 1995; Tanner, 1968). To ensure that the groups were well matched for pubertal development, participants estimated their maturation status via a self-assessment protocol using Tanner’s five-stage model of pubertal maturation (Schmitz et al., 2004). In the 4 weeks before the commencement of the study, participants needed to be injury free and not consuming any fluid-retaining or diuretic medications or supplements. They completed a baseline survey to profile training background and physical activity history, injury status, medication and supplement use, typical nutrition behaviors, and current hydration strategies. The survey was used to verify eligibility to participate and to profile perceived hydra-
tion practices of participants from the two groups. Written parental or guardian consent and participant assent were obtained after approval from the University Human Research Ethics Committee and the school district central office.

**Experimental Design**

This study was a field-based, case-controlled, observational study with repeated measures over 4 consecutive days. Body-mass measurements were taken before and after training sessions for the athlete group and before and after school for the control group. Testing was offered over a 4-week period. In an attempt to minimize fluctuations in body water associated with hormonal changes during the menstrual cycle, female participants were asked to select the week that best represented their follicular phase (Bunt, Lohman, & Boileau, 1989). Participants were also asked to refrain from intense physical activity and training for 24 hr before beginning initial testing. No further intervention was made, and maintenance of usual fluid-intake practices was encouraged. Coaches of the swim group agreed to maintain typical routines to ensure a true representation of hydration practices and profiles.

**Protocol**

Diurnal wet-bulb-globe temperature (WBGT) was estimated based on Bureau of Meteorology observations of maximum ambient (dry-bulb) temperature in the 24 hr from 9 a.m. and relative humidity at 9 a.m. at a location central to testing.

Participants were asked to arrive at school or morning swim training in an overnight fasted state, and body mass was recorded after they voided. Swimmers were weighed towel dried immediately before and after each training session of the 4 days, wearing their usual training attire without taping. Controls wore their usual school uniforms during body-mass measurements. A “typical” breakfast consisting of an ad libitum selection of toast, cereal, juice, and milk was provided by researchers to the control group. Although it was not ideal, breakfast was not provided to the athlete group. Remaining at training for breakfast would have interrupted routines for transport to school. Athletes ate a self-selected breakfast after morning training similar to that provided to controls. Body mass was recorded again at the end of the school day at school for controls and before and after afternoon training sessions for the swimmers. Swimmers’ individual drink bottles were also weighed immediately before and after each training session. During the session, when drink bottles were refilled by either the athlete or the coach, the empty weight and refill weight were recorded. If the swimmers needed to urinate during the session, they were towel dried and weighed before and after voiding.

The mass of participants and drink bottles were recorded using medical-grade UC-321 digital scales (A&D Company Ltd., Tokyo, Japan) accurate to ±0.05 kg. Measurements were assessed in triplicate, and mean values were reported. Net change in fluid balance relative to initial body mass was calculated for each school day using the following formula: Net change in fluid balance (%) = \{(\text{post mass (kg)} - \text{pre mass (kg)})/\text{pre mass (kg)}\} × 100.

Water temperature of the pool was recorded (Center 300 thermometer and TP-K02 immersion probe, Center Technology Corp., Taipei, Taiwan). Relative
training load was calculated for each swimmer after every training session using the session rating of perceived exertion multiplied by duration in minutes (Foster et al., 1995).

First morning midstream urine samples were obtained on the 4 days of testing. Samples were brought to training or school, placed on ice, and analyzed within 3 hr of collection. Hydration profiles were assessed by variations in first morning urine specific gravity (USG) and urine color. The appraisal of USG was chosen because it is a noninvasive, valid, and reliable measure of hydration status (Armstrong et al., 1994; Casa et al., 2000; Oppliger & Bartok, 2002; American College of Sports Medicine [ACSM] et al., 2007). Before the measurement of USG, urine color was categorized using an eight-color scale (Armstrong et al., 1994). Participants who consumed vitamin supplements in the 24 hr before testing were excluded from the analysis of urine color. The same investigator determined all USG and urine-color values to eliminate intertester variability. The investigator was not blind to sample group because of logistical constraints, but strict controls were maintained to minimize potential bias.

USG was measured using a handheld optical refractometer (URC-NE, Atago, Tokyo, Japan) accurate to 0.001 with a measurement range of 1.000–1.050. The refractometer was calibrated daily using distilled water before analysis of the first sample and again after every tenth sample. Calibration was verified using two control standards (quantitative urine control normal and abnormal levels, Bio-Rad Laboratories Inc., Irvine, CA, USA) before analysis of the first daily sample, after every tenth sample, and after the final daily sample to ensure that readings were within the acceptable range. The coefficient of variation was calculated for both control standards. Urinalyses were conducted in duplicate under standardized laboratory conditions.

Hydration status was classified independently based on daily USG and urine-color values. Classification criteria were based on recommended euhydration thresholds (Casa et al., 2005; ACSM et al., 2007). Participants were classified as euhydrated if their daily USG value was \( \leq 1.020 \). They were classified as euhydrated based on urine color if their categorical score was \( \leq 4 \). Having a USG value in excess of 1.020 or a urine color value \( \geq 5 \) was classified as being in fluid deficit (hypohydration).

Before data collection, participants were given two containers of known volume. They were asked to use the 250- and 70-ml containers to help estimate urine losses. Participants completed a daily questionnaire on fluid and nutritional intake; the type, duration, and intensity of physical activity participation; and estimates of urine losses. Estimates of daily school-day water turnover were used to account for school-day body-mass fluctuations. Total school-day water intake (fluid from food and beverages) was estimated based on participant-reported daily nutrition records using FoodWorks Professional 2007, release 5.0.1353, (dietary-analysis software Xyris Software Pty. Ltd., Highgate Hill, Qld., Australia). The validity of self-reports of dietary intake in young participants has been documented (Emmons & Hayes, 1973; Greger & Etnyre, 1978). Estimates of water intake were calculated to the nearest milliliter. Fluid intake was reported relative to initial body mass. No correction was made for respiratory water loss or metabolic fluid changes. Respiratory water losses were assumed to be offset by parallel metabolic water production (Mitchell, Nadel, & Stolwijk, 1972).
Change in fluid balance adjusted for water turnover was calculated for each school day and training session and expressed relative to initial body mass using the following formula: Change in fluid balance (%) = ([post mass (kg) – pre mass (kg) – water intake (L) + urinary output (L)]/pre mass (kg)) × 100. First morning measurements were used as the pre-school-day body mass for both groups. To ensure that the time between measurements was equal between groups, school-day changes were calculated using body-mass measurements at the end of the school day, before afternoon training, for the swim group. Calculations of fluid-balance changes adjusted for fluid intake and urine losses assumed that 1 L of water was equivalent to 1 kg of body mass.

Statistical Analyses

After tests for normal distribution, independent t tests were conducted to detect baseline group differences in descriptive and lifestyle characteristics. The Hedges’s g effect size of the difference in means was calculated. Mann–Whitney U tests were conducted on the categorical data of self-reported Tanner stage for sexual maturation and any variable failing tests for normal distribution. Intraclass correlations were calculated to assess the reliability of USG, school-day estimated urine losses, and school-day fluid intake measures. Intraclass correlations were used to account for consistency of measurement error and diurnal variations. To assess differences over consecutive testing days between activity groups and sexes, linear mixed-model ANOVAs with four repeated measures were employed. If baseline differences between groups were observed, these variables were added to the model as covariates at the mean value. The relationship between USG and the ordinal urine-color variable was evaluated using Spearman’s rank correlation coefficient. Pearson’s correlation-coefficient analyses were used to assess the relationship between training load and hydration parameters. Pearson’s chi-square analyses were used to test for distribution differences between groups in hydration practices and classifications of hydration status determined by USG and urine color.

Statistical significance was set at p ≤ .05. Statistical analyses were two-tailed and calculated using SPSS 15.0 for Windows, release 15.0.0 (SPSS Inc., Chicago, IL, USA). Descriptive parametric data are presented as M and SD.

Results

Descriptive characteristics and t-test results of the two groups are summarized in Table 1. Mann–Whitney U tests were conducted on data for Tanner stage of sexual maturation and nonnormally distributed measures of hours of organized physical activity per week. Reported median values were not different between males of each group for genital (median = Tanner Stage 4, U = 198.0, p = .107) or pubic-hair (median = Tanner Stage 4, U = 220.5, p = .244) development or between females for breast (median = Tanner Stage 4, U = 93.0, p = .654) or pubic-hair (median = Tanner Stage 4, U = 67.0, p = .098) development. Differences were observed between groups for hours of physical activity per week (males U = 0.0, p < .001; females U = 0.0, p < .001).
<table>
<thead>
<tr>
<th></th>
<th>Swimmers, $n = 35$, 18 male, 17 female, $M (SD)$</th>
<th>Controls, $n = 41$, 29 male, 12 female, $M (SD)$</th>
<th>Effect size (Hedges’s $g$)</th>
<th>Lower</th>
<th>Upper</th>
<th>$p$</th>
</tr>
</thead>
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<tr>
<td>Age (years)</td>
<td></td>
<td></td>
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<td>male</td>
<td>15.4 (1.5)</td>
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<td>0.89</td>
<td>0.13</td>
<td>1.67</td>
<td>.024</td>
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<td>13.7 (0.9)</td>
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<td>male</td>
<td>174.6 (8.5)</td>
<td>168.6 (7.9)</td>
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<td>160.4 (7.0)</td>
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<td>68.57 (10.23)</td>
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<td>59.09 (12.96)</td>
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<td>−10.57</td>
<td>6.21</td>
<td>.583</td>
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<td>−0.36</td>
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<td>22.91 (4.26)</td>
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<td>−5.16</td>
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<td>Body-surface area: mass (cm$^2$/kg)</td>
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<tr>
<td>male</td>
<td>267.60 (15.18)</td>
<td>261.65 (25.62)</td>
<td>0.26</td>
<td>−6.05</td>
<td>17.93</td>
<td>.323</td>
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<tr>
<td>female</td>
<td>285.59 (8.19)</td>
<td>278.56 (27.32)</td>
<td>0.37</td>
<td>−10.63</td>
<td>24.69</td>
<td>.404</td>
</tr>
<tr>
<td>Physical activity (hr/week)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>male</td>
<td>15.9 (2.1)</td>
<td>2.2 (1.8)</td>
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<td>N/A</td>
<td>N/A</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>female</td>
<td>15.2 (2.9)</td>
<td>1.8 (1.8)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Table 1  Descriptive Characteristics
The survey administered to participants at baseline included a series of questions used to identify their perceived hydration practices. Analyses demonstrated no group differences for males or females in responses to questions assessing their behavior in maintaining adequate hydration and self-monitoring hydration status ($p > .05$). Results also indicated that although many participants suggested they took steps to ensure adequate hydration (45%), very few actively monitored their hydration status (7%).

Daily estimates of WBGT were different between activity groups, $F(1, 74) = 220.364, p < .001$. Mean maximum 24-hr WBGT for the control group fell within the low-risk range for exertional heat illness on each day ($17.5 \pm 1.1 \, ^\circ C$, range 15.2–19.3 °C). Mean WBGT for the swim group ranged from low to high risk ($24.5 \pm 3.4 \, ^\circ C$, range 18.8–30.9 °C; Armstrong et al., 2007). Water temperatures during swim training remained relatively consistent between morning and afternoon measurements and between days (morning $28.2 \pm 0.9 \, ^\circ C$, afternoon $28.7 \pm 1.2 \, ^\circ C$).

Baseline differences between activity groups for age, height, and daily estimated WBGT were added to analyses of USG values as covariates. No covariate was correlated with USG ($p > .05$). Results demonstrated no effect of participants’ group, $F(1, 70) = 0.331, p = .567$; sex, $F(1, 70) = 0.024, p = .876$; or day of testing, $F(3, 75) = 0.920, p = .436$, on USG. Mean USG values on each testing occasion are presented in Table 2. The intraclass correlation for USG values was .76 (95% CI: .66–.84). Furthermore, the coefficients of variation were 0.03% and 0.06% for measured normal- and abnormal-level control standards, respectively.

Classifications of daily hydration status determined by first morning midstream sample USG showed a prevailing consistency of fluid deficit across both sexes and activity groups. Hypohydration was present in 85% of samples analyzed from the athlete group and 78% of samples from the control group. No differences in the hydration status between groups were detected on any day of testing independent of sex ($p > .05$). Consistent with the categorization of daily hydration status determined by USG, urine-color classification also confirmed a pattern of fluid deficit across both sexes and activity groups. Hypohydration was present in 73% of samples analyzed from both activity groups, indicating higher euhydration than USG classification. Sixty samples (19.7%) proportionately distributed across all groups were excluded from analysis because of the potential confounding effect of participants’ vitamin supplement ingestion (Institute of Medicine, 2005). A moderate correlation was present between the two hydration markers, $r_s(242) = .62, p < .001$ (Figure 1). Figure 1 demonstrates the relatively high incidence of false positive and false negative urine-color hydration classifications using USG as the criterion measure.

Net changes in fluid balance over the school day showed no effect of sex, $F(1, 48) = 0.861, p = .358$, or day of testing, $F(3, 54) = 1.207, p = .316$. The main effect

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Daily Urine Specific Gravity, $M$ (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 1</td>
</tr>
<tr>
<td>Swimmers</td>
<td>1.025 (0.004)</td>
</tr>
<tr>
<td>Controls</td>
<td>1.025 (0.006)</td>
</tr>
</tbody>
</table>
of activity group also failed to reach significance, \( F(1, 90) = 3.883, p = .052. \) Mean net changes demonstrated that participants of both groups were able to closely match water intake through food and fluids with fluid losses over each observed school day (swimmers = 0.34% ± 0.85%, controls = 0.36% ± 0.68%).

When adjusted for water turnover, changes in fluid balance were different between groups, \( F(1, 71) = 7.216, p = .009. \) An interaction effect was also present for group by sex, \( F(1, 77) = 9.618, p = .003. \) No main effect of sex was observed, however, \( F(1, 37) = 0.209, p = .650. \) Female swimmers demonstrated the greatest change in fluid balance after adjustment for water turnover (–2.57% ± 1.11%), whereas female controls displayed the least variation (–0.25% ± 0.46%). Overall, swimmers had significantly greater school-day fluid losses than controls. The mean adjusted relative school-day body-mass change of swimmers was –2.37% (± 1.11%). In contrast, the control group averaged –0.32% (± 0.63%) over the 4 days of testing. Figure 2 shows the mean adjusted change in fluid balance for both groups on each day of testing.

Independent \( t \)-test results showed no differences (\( p > .05 \)) between relative training loads of male and female swimmers, making sex comparisons during training sessions appropriate. Variations in fluid balance adjusted for water turnover were analyzed independently for morning and afternoon swim-training sessions. Between-sex differences were present in morning sessions, \( F(1, 34) = 5.568, p = .024, \) and afternoon sessions, \( F(1, 8) = 49.666, p < .001. \) No effect of

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**Figure 1** — Moderate correlation between urine specific gravity and urine color. Dashed lines represent hydration classification thresholds. Results in the top left corner and bottom right corner of the graph represent false positive and false negative urine-color values, respectively.
testing day was observed, however, for morning, $F(3, 29) = 0.979$, $p = .416$, or afternoon, $F(3, 9) = 3.419$, $p = .068$. During both sessions, male and female swimmers averaged adjusted body-mass losses of less than 2% of initial body mass. Compared with females and relative to body mass, however, males exhibited greater fluid loss during both morning (males = $-1.04\% \pm 0.64\%$, females = $-0.66\% \pm 0.63\%$) and afternoon (males = $-1.48\% \pm 0.71\%$, females = $-0.74\% \pm 0.62\%$) training (Figure 3).

Results of similar analysis for differences in fluid intake between athlete and control groups revealed a main effect of group, $F(1, 47) = 50.487$, $p < .001$, and an interaction effect of group by sex, $F(1, 47) = 5.653$, $p = .022$. A large degree of individual variation in fluid intake was also observed. Absolute school-day intake through food and beverages ranged from 0.067 to 4.152 L. Mean fluid intake was 0.919 L ($\pm 0.605$ L) per school day. Estimated mean WBGT had no effect on fluid intake, $F(1, 55) = 3.336$, $p = .073$. Over the 4 days of testing, on average, swimmers ingested 3.18% ($\pm 0.99\%$) of their body mass in water per school day. In contrast, the control group averaged 0.90% ($\pm 0.44\%$) per school day. Consistent with results for school-day-adjusted change in fluid balance, female swimmers demonstrated the greatest school-day fluid intake (3.22% $\pm 1.02\%$) and female controls displayed the least intake (0.84% $\pm 0.40\%$). Intraclass correlations were .82 (95% CI: .73–.89) and .87 (95% CI: .80–.92) for school-day fluid intake and urine losses, respectively. Mean relative school-day water intakes through food and beverage sources for both groups on each day of testing are illustrated in Figure 4.

Swimmers’ relative fluid intake during training sessions demonstrated no differences between male and female athletes, $F(1, 32) = 0.021$, $p = .887$, or testing days, $F(3, 30) = 2.232$, $p = .105$, during morning training sessions. Similarly, no sex, $F(1, 76) = 0.029$, $p = .866$, or day, $F(3, 32) = 2.147$, $p = .113$, effects were

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Figure 2 — Daily adjusted changes in fluid balance relative to initial body mass ($M \pm SD$). A negative value represents fluid deficit. *Main effect for group ($p = .009$).
observed for afternoon training. Absolute fluid intake ranged from 0 to 1.5 L per session. Mean relative fluid intake for morning and afternoon swim sessions on each day of testing is presented in Table 3.

Correlation analyses revealed no relationship between daily training load (944 ± 354 arbitrary units, range = 300–1840 arbitrary units) and USG values of the following day. Similarly, analyses revealed no correlation between training-session fluid intake and training loads or changes in fluid balance and training loads.

Discussion

The current study is novel in its implementation of existing methodology to assess hydration profiles of adolescent swimmers in high-volume training and compare these findings with less active sex- and maturation-matched controls over 4 consecutive days. The major finding was the consistent status of fluid deficit in both adolescent swimmers and control students during school days. This finding suggests that the level of physical activity alone is insufficient as a predictor of daily hydration status and that participants’ fluid intake over the testing period was inadequate to achieve and maintain euhydration.

Results from daily classifications of hydration status demonstrated hypohydration in 73% of samples determined by urine color and up to 85% of samples determined by USG. No differences were observed in the frequency of fluid defi-
cits determined by urinary markers between activity-level groups in males or females. Mean USG values were greater than the accepted euhydration threshold on every day of testing in both groups. Consistently elevated observations of USG are congruous with previous findings of significant hypohydration before activity in adolescents of other sports (Bergeron, Waller, & Marinik, 2006; Dougherty, Baker, Chow, & Kenney, 2006; Stover, Zachwieja, Stofan, Murray, & Horswill, 2006). In contrast, similarity in USG values between adolescent athletes and controls and the lack of evidence of any significant deleterious effects might provide opportunity for debate on the thresholds representing euhydration and hypohydration. When based on the more liberal range of Armstrong et al. (1994; USG of 1.013–1.029), mean USG values for both activity groups on each day of testing are classified as indicating euhydration. If the accepted euhydration cutoff is an accurate representation of fluid deficit (ACSM et al., 2007), hydration education strategies for adolescents participating in all levels of physical activity might be necessary to encourage adequate fluid intake even in the mild environmental conditions described in the current study. The short-term efficacy of implementing an education and drinking strategy with athletes training in high volumes has been reported (Dabinett, Reid, & James, 2001; Stover et al.).

Figure 4 — Daily school-day fluid intake relative to initial body mass ($M \pm SD$). *Main effect for group ($p < .001$).

Table 3 Fluid Intake during Morning and Afternoon Training Relative to Initial Body Mass, $M (SD)$

<table>
<thead>
<tr>
<th></th>
<th>Day 1 (%)</th>
<th>Day 2 (%)</th>
<th>Day 3 (%)</th>
<th>Day 4 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning training</td>
<td>0.95 (0.49)</td>
<td>0.76 (0.35)</td>
<td>0.74 (0.40)</td>
<td>0.68 (0.40)</td>
</tr>
<tr>
<td>Afternoon training</td>
<td>0.92 (0.53)</td>
<td>1.11 (0.45)</td>
<td>0.80 (0.57)</td>
<td>0.80 (0.40)</td>
</tr>
</tbody>
</table>
Analyses of urine color supported trends of hydration classification determined by USG. Previous studies have shown moderate to strong correlations between measures of USG and urine color (Armstrong et al., 1994, 1998; Kutlu & Guler, 2006). A moderate association in the current study supports previous findings. Despite the correlation between urinalysis measures, urine color indicated a higher proportion of euhydration than did USG (false positive). Although urine color is a simple, inexpensive, and immediate method of monitoring hydration status in adolescents, it is subjective and lacks the accuracy and precision offered by other hydration markers (ACSM et al., 2007). Results of the current study indicate that use of urine color might lead to the misclassification of hydration status. Furthermore, the potential influence of confounding factors on urine color must be acknowledged (DiPalma, 1977; Institute of Medicine, 2005; Pearcy, Mitchell, & Smith, 1992).

Substantial differences in adjusted fluid-balance changes between swimmers and controls demonstrated the significant demand placed on swimmers to maintain body mass over the school day. Net changes in fluid balance closely matched fluid intake and were not different between groups. However, water intake through food and beverages was greater for athletes than controls. After adjusting for fluid intake and urinary output, mean school-day fluid-balance losses were consistently in excess of 2% of morning body mass for swimmers. Conversely, the less active group averaged losses below 0.5% of body mass. School-day fluid-balance differences resulted from the addition of a single (morning) swim-training session. Based on trends observed over the school day, it is likely that had full-day (24-hr) fluid-balance changes been monitored, results would compare favorably with previous findings of daily nonrenal water losses 3 times greater in adolescent swimmers than nonathletic controls of the same age (Leiper & Maughan, 2004).

Participants were largely able to recover fluid losses over the duration of a typical school day. Nevertheless, when first morning hydration status is considered in combination with fluid-balance changes, it appears that daily fluid intake was inadequate to restore euhydration. Fluid intake at levels insufficient to achieve euhydration supports suggestions of an underlying behavioral effect of involuntary dehydration in adolescents (Greenleaf, 1992).

Although local estimated WBGT was different between groups over the testing period, fluid-balance measures were compared over the school day, when participants largely remained indoors. Furthermore, mean WGBT was added to all between-groups analyses as a covariate to standardize this measure by assessing dependent variables with WBGT at the mean value for all participants. School-day relative fluid intake was not affected by estimated WBGT. Although we acknowledge the limitations, given the consistency of hydration and fluid-balance measures over the 4 days in both groups and by accounting for between-group disparities statistically, differences in fluid balance between swimmers and controls can be confidently associated with training outcomes.

The greater estimated fluid losses observed in male swimmers during training are explained by the higher sweating rates of males than of females (Bar-Or, 1996; Meyer, Bar-Or, MacDougall, & Heigenhauser, 1992). Higher sweat losses in male swimmers suggest that the larger muscle mass of adolescent males generated more metabolic heat than females under comparable relative training loads. Analyses of training fluid intake demonstrated no sex differences, signifying that the
increased demand for fluid in males was not met. Results of the current study are in contrast to those of a previous investigation of sweating rates of elite male and female swimmers during training (Cox et al., 2002). In pool-water temperatures similar to those in the current study, males showed consistently greater mean sweating rates than female swimmers. After controlling for body mass and type of training session, however, no sex differences in sweating rate were present, yet fluid intake rate was greater for males than females. The mechanisms behind sex differences in adolescent sweating patterns remain understudied.

Despite sex differences in acute fluid deficits during training, mean fluid losses for male and female swimmers did not exceed 2%. Fluid losses of less than 2% demonstrate hypohydration below the level that typically compromises performance in adults and adolescents (Dougherty et al., 2006; Sawka & Coyle, 1999). The minimal fluid losses observed in swimmers might be a result of different thermoregulatory conditions from those typically experienced by athletes training and competing in land-based sports. Fluid losses during swim training in the current study support previous reports of sweat losses in senior elite-level swimmers and water polo players considerably lower than in nonaquatic team sports (Cox et al., 2002). Facilitated body-heat losses through convection reduce aquatic athletes’ reliance on sweating mechanisms, allowing them to retain a greater proportion of fluid during exercise (Nielsen & Davies, 1976). Despite minimal fluid losses during individual training sessions, these deficits significantly increased fluid needs for swimmers over the school day.

Swimmers in this study commenced training sessions in fluid deficit, as measured by urinalyses. Given that athletes started training in a state of hypohydration, true fluid deficits would be greater than reported, and training performance might have been compromised. In spite of minimal training fluid losses, high USG values emphasize the need to maintain hydration practices during periods of inactivity or recovery such as during the school day for adolescent athletes.

Observations of body-mass changes and fluid intake in the current study were based on protocols devised to minimize or standardize potential sources of error often prevalent in field-based studies. However, several potentially confounding factors remained difficult to eliminate or control. Failure to account for potential sources of error might lead to either underestimation or overestimation of true changes in fluid balance. The current study was limited by several factors including failure to measure water absorbed through the skin (Buettner, 1959) and water accidentally ingested from the pool during swim training. We also acknowledge that limitations in methodology based on participants’ self-reported food intake and estimates of urine losses were not ideal.

Changes in fluid balance were limited to the school day. In contrast, classification of hydration status was based on first morning USG and was therefore likely to be influenced by accounting for food and fluid consumption outside of observation times. It was not possible to determine whether differences between groups during the day continued into the evening.

The current study advances the knowledge of hydration practices and fluid requirements in active and less active adolescents. Within the acknowledged limitations of the field-based study design, there was a large degree of individual variation in habitual hydration practices. Although sex differences were present in training fluid losses and group-by-sex effects were observed over the school day.
for fluid intake and changes in adjusted fluid balance, individual intake practices and level of physical activity remain important considerations in fluid-balance outcomes of adolescents. Fluid intake guidelines for adolescents should reflect the multitude of complex factors affecting fluid balance, including sex, type and level of physical activity, environment, and individual needs and preferences. The findings of this study highlight the need for individually customized hydration strategies for adolescents.

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References


