ORIGINAL

Assessment of water balance in high school athletes and non-athletes

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Abstract : Water is the main component of cells, tissues, and organs, and plays vital roles in macronutrient hydrolysis and overall cell function regulation. While low water intake may be sufficient for hydration, several studies suggest that most children fail to meet water intake guidelines, leading to underhydration as indicated by elevated hydration biomarkers. We conducted a cross-sectional observational study to examine water intake and output among high school students, comparing non-athletes and athletes. We enrolled 26 non-athletes and 28 athletes in this study. Water balance was assessed by water intake from foods and beverages, metabolic water production, and non-renal water loss (NRWL). Moreover, urine was compared. Increases of total water intake from food and beverage consumption in athletes were significantly higher than those in non-athletes. Furthermore, urinary output was lower and NRWL was 2-3 times higher in athletes than non-athletes. These findings suggest that large NRWL induces hypohydration in athletes. J. Med. Invest. 72 : 42-46, February, 2025

***Keywords* :** *water balance, athlete, sweat, non-renal water loss*

INTRODUCTION

Water is the main constituent of cells, tissues, and organs. Adequate hydration of body tissues is necessary for health and life (1, 2), because water is essential for metabolism, substrate transport across membranes, cellular homeostasis, temperature regulation, and circulatory function. Net body water balance is regulated by the processes of thirst and hunger coupled with ad libitum access to food and beverages to offset water losses (3).

Sedentary individuals living in a temperate climate typically lose about 5%-10% of total body water, which is replaced on a daily basis (4). Large increases in water intake require substantial behavioral changes. A body water deficit is a common occurrence in athletes following the completion of an exercise session. It is important to replace water losses to avoid beginning the next exercise hypohydrated, which may cause detrimental effects on performance. Detailed and representative data on water intake and hydration status of Japanese high school athletes are required to derive intake recommendations.

Water balance can be assessed by water intake from foods and beverages, metabolic water production, water loss from urine, and non-renal water loss (NRWL) and constitutes clear evidence of how much water we really need. The aim of the present study was to quantify the total fluid balance with the total water intake and with the total water output over a 24-h period in healthy high school student non-athletes and athletes under moderate ambient temperature (20-25 C) conditions.

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SUBJECTS AND METHODS

We performed a cross-sectional observational study to investigate the amounts of water intake and water output in high school student non-athletes and athletes. Ethics approval was obtained from the Clinical Research Ethics Committee at Tokushima University Hospital (approval number 384). Informed consent to participate in the study was also received from the participants or from an authorized surrogate. This trial was registered as UMIN000038105.

We enrolled 31 male non-athletes and athletes (n = 13 and 18, respectively) and 23 female non-athletes and athletes (n = 13 and 10, respectively) (Table 1). The subjects were living at home or in a dormitory. The athletes trained at their self-selected pace with most of their training at a light to moderate intensity for 90-120 min. All measurements were made on two days of practice sessions. None of the non-athletes were engaged in high levels of exercise training or were taking any medications just before or during the study. Height and weight measurements were performed with the participants wearing light clothing and no shoes. BMI was calculated as weight (kg) divided by the square of height (m).

Subjects were instructed by registered dietitians on how to weigh each food and drink item and were asked to record and weigh all foods and drinks consumed on each recording day. They consumed plain water ad libitum from individual water bottles. Water bottles were weighed to record the volume of fluid intake. Total water intake corresponds to the sum of beverages (including tea, coffee, milk, and soup), metabolic water, and water in food consumed, which was taken from the dietary record of the day of urine collection. All foods and beverages consumed were recorded using food scales for weighing or standardized containers and templates for estimating the amounts consumed. Dietary data were converted into water using the Standard Tables of Food Composition in Japan (5). Water is also produced by the oxidative metabolism of hydrogen-containing substrates in the body. Total water intake was calculated by addition of 250 ml of metabolic water.

Table 1. Water balance in high school student non-athletes and athletes

	Male			Female		
	non - athletes (n=13)	athletes (n=18)	P value**	non - athletes (n=13)	athletes (n=10)	P value
Age (years)	17* (16-17)	17 (16-17)	0.363	17 (16-17)	16 (16-17)	0.121
BMI (kg/m^2)	25.8 (21.0-27.4)	20.7 (19.4-23.1)	0.003	21.8 (18.8-22.5)	18.9 (18.6-19.4)	0.051
Water intake						
total (ml/day)	2869 (2272-3299)	4820 (3663-5453)	<0.001	2431 (2017-2842)	3398 (2858-3738)	0.004
(ml/kg/day)	38.6 (32.8-42.7)	80.1 (55.7-104.1)	<0.001	46.0 (39.8-54.0)	70.6 (60.0-79.4)	0.001
from food (ml/day)	988 (854-1177)	2278 (2119-3428)	<0.001	821 (686-1006)	1654 (1110-1932)	<0.001
(%)	39.0 (32.4-44.0)	61.5 (40.4-64.3)	0.005	34.3 (30.2-44.7)	46.5 (37.9-58.9)	0.032
from bevarages (ml/day)	1384 (1134-1690)	1960 (1120-2851)	0.284	1310 (960-1650)	1426 (1100-1645)	0.475
(%)	49.7 (47.6-58.2)	31.5 (29.9-56.1)	0.032	54.4 (41.1-60.2)	46.5 (33.5-52.8)	0.088
Water output						
Urine (ml/day)	1200 (870-1625)	780 (640-1200)	0.034	1240 (780-1820)	760 (410-955)	0.022
(ml/kg/day)	19.0 (10.2-27.2)	12.0 (10.0-19.8)	0.289	28.9 (15.6-31.7)	16.1 (8.8-19.9)	0.032
(%)	51.4 (30.5-66.5)	19.5 (9.4-23.9)	<0.001	51.4 (38.6-62.9)	23.8 (10.8-26.1)	<0.001
NRWL (ml/day)	1231 (781-2210)	3401 (2936-4267)	<0.001	1182 (813-1685)	2576 (2266-2956)	<0.001
(ml/kg/day)	18.8 (13.0-24.9)	60.4 (46.5-78.8)	<0.001	24.8 (14.0-33.2)	53.1 (49.9-60.7)	<0.001
(%)	48.6 (33.5-69.5)	80.5 (76.1-90.6)	<0.001	48.6 (37.1-61.4)	76.2 (73.9-89.2)	<0.001
Na^++K^+/145	1.0 (0.7-1.4)	1.4 (1.0-1.6)	0.089	0.8 (0.7-1.2)	1.5 (1.2-1.6)	0.004

NRWL : non-renal water losses

* : interquartile range
** : wilcoxon rank sum U test

In water balance, total water intake corresponds to total water losses, which was defined as the sum of NRWL and 24-h urine volume. Each subject provided two 24-h urine samples on two consecutive days. Thus, NRWL corresponded to the difference of calculated total water intake and measured 24-h urine volume :

NRWL (ml/day) = total water intake (ml/day) – 24-h urine volume (ml/day).

The ratio of urinary (Na^+ + K^+) concentrations (mEq/L) to plasma 145 (mEq/L) (U (Na^+ + K^+)/145) was obtained to assess 24-h hydration status (6). A ratio showing more or less than 1.0 suggested insufficient or sufficient water intake, respectively.

STATISTICAL ANALYSIS

Continuous data are presented as medians (interquartile range [IQR]), and categorical data are presented as counts (%). Comparisons were conducted using Wilcoxon rank sum U test. All p-values were two tailed and p-values < 0.05 were considered significant. JMP version 13.1.0 (SAS Institute Inc., NC, USA) and R version 3.1.1 (R Foundation for Statistical Computing, Vienna, Austria) were used for statistical analysis.

RESULTS

Water intake in high school student non-athletes and athletes

Daily total water intake (median [IQR]) in non-athletes and athletes were 38.6 (32.8-42.7) ml/kg and 80.1 (55.7-104.1) ml/kg in the males, and 46.0 (39.8-54.0) ml/kg and 70.6 (60.0-79.4) ml/kg in the females, respectively (Table 1). Daily total water intake in the athletes was more than the non-athletes in both the males and females.

The percentage of water intake derived from foods and beverages were 39.0 (32.4-44.0) % and 49.7 (47.6-58.2) % in male non-athletes, 61.5 (40.4-64.3) % and 31.5 (29.9-56.1) % in male athletes, 34.3 (30.2-44.70) % and 54.4 (41.1-60.2) % in female non-athletes, and 46.5 (37.9-58.9) % and 46.5 (33.5-52.8) % in female athletes, respectively. Daily total water intake and water intake from foods in athletes were more than those in non-athletes for both sexes. The increased water intake in athletes was predominately from food rather than from beverages.

Water output in high school student non-athletes and athletes

Daily water output from urine and NRWL were 19.0 (10.2-27.2) ml/kg and 18.8 (13.0-24.9) ml/kg in male non-athletes, 12.0 (10.0-19.8) ml/kg and 60.4 (46.5-78.8) ml/kg in male athletes, 28.9 (15.6-31.7) ml/kg and 24.8 (14.0-33.2) ml/kg in female non-athletes, and 16.1 (8.8-19.9) ml/kg and 53.1 (49.9-60.7) ml/kg in female athletes, respectively (Table 1).

The percentage of water output from urine and NRWL were 51.4 (30.5-66.5) % and 48.6 (33.5-69.5) % in male non-athletes, 19.5 (9.4-23.9) % and 80.5 (76.1-90.6) % in male athletes, 51.4 (38.6-62.9) % and 48.6 (37.1-61.4) % in female non-athletes, and 23.8 (10.8-26.1) % and 76.2 (73.9-89.2) % in female athletes, respectively.

The daily total water outputs from NRWL in the athletes were higher than those of non-athletes in both sexes. In contrast, the amount of urine (mg/kg, %) in the athletes was lower than that of the non-athletes in both sexes. Furthermore, U ($Na^+ + K^+$)/145 in the athletes was higher than that in the non-athletes, indicating hyperosmotic urine in both the male and female athletes.

DISCUSSION

Fluid intake, driven by a combination of thirst and habitual consumption of beverages at meals and on other occasions throughout the day, normally allows maintenance of hydration status and total body water at appropriate levels. Over a 24-h period, a sedentary adult produces l-2 L of urine. About 450 ml of water per day is lost as NRWL by evaporation through the skin in a temperate environment and about 250-350 ml per day from the respiratory tract. The adequate total water intakes for sedentary adults are an average of about 2 and 2.5 L per day in women and men, respectively (7). Therefore, the total water inputs for sedentary adults are an average of between 2 and 3 L. Leiper *et al*. measured total body water and water turnover (WT) rates of six male cyclists (cycling group) who trained and competed on a recreational basis and six age-matched sedentary men (sedentary group) using deuterium oxide dilution and elimination (8). The average median daily urinary loss (mL/kg/d) was similar (cycling group 27 [22-33] ; sedentary group 29 [24-31]) ; however, calculated daily NRWL (mL/kg/d), presumably mostly in the form of sweat, was faster in the cycling group (19 [13-35]) than in the sedentary group (6 [5-22]). The total movement of water through the body, both intake and loss, is called WT. The study demonstrated that WT was faster in individuals undertaking prolonged exercise than in sedentary men and that the difference was due to the almost 3 times greater NRWL incurred by the exercising group. This suggests that exercise induced increases in respiratory water loss and sweat rate, which are major factors in water loss.

The present study used a combination of dietary weighed records and concomitantly utilizable 24-h urine samples (n = 54) to estimate individual 24-h hydration status in high school student non-athletes and athletes aged 16-17 years old. In male and female student non-athletes, daily total water intake was 2869 ml (38.6 ml/kg) and 2431 ml (46.0 ml/kg), of which intake from foods accounted for 39.0% and 49.7%, and beverages for 34.3% and 54.4%, respectively. Moreover, water losses from kidneys in the form of urine were 51.4% and 51.4%, and those from the skin and respiratory tract (NRWL) were 48.6% and 48.6%, respectively. In male and female student athletes, daily total water intake was 4820 ml (80.1 ml/kg) and 3398 ml (70.6 ml/kg), of which intake from foods accounted for 61.5% and 46.5%, and beverages accounted for 31.5% and 46.5%, respectively. The water loss from kidneys in the form of urine was 19.5% and 23.8%, and that from the skin and respiratory tract (NRWL) was 80.5% and 76.2%, respectively. These parameters of water balance were not significantly different between the males and females. These findings of more water intake and NRWL in athletes than non-athletes suggest that WT in athlete students is faster. We also found a shift from beverage to food consumption as the source of water in athletes. This finding suggests that as athletes consumed a lower energy density diet with higher water and sodium contents, they needed less water from drinks and beverages. In the present study, the amount of water intake in male and female athletes was 80.1 ml/kg/day and 70.6 ml/kg/day to recover euhydration, which are 2- and 1.5-fold those of non-athletes, respectively. Our findings do not show that daily water intake was sufficient for high school athlete students because U ($Na^+ + K^+$)/145 in athletes was higher than that in non-athletes. Further intervention studies with 100 ml/kg/day of total water intake are needed to establish the amount of water intake needed to recover euhydration in athletes.

During sedentary daily activities in a mild environment, renal responses and thirst are the primary homeostatic regulators. During continuous-intermittent labor or prolonged exercise at low intensities (5-18 h duration), renal responses and thirst have minor-to-large effects on water regulation, whereas sweat loss presents the foremost challenge to homeostasis (9). Sweat evaporation is important for the dissipation of metabolic heat production, which may increase 10- to 20-fold during exercise (10). The rate of sweat loss is directly related to exercise intensity (metabolic heat production) (11). Since evaporation of sweat is the primary means of heat loss during exercise, fluid losses and the risk of hypohydration in athletes can be significant. Hypohydration (> 2% body mass loss) can impair endurance performance, particularly in hot/humid environments (12, 13).

The majority of the dehydration/exercise performance literature suggests that during exercise dehydration increases physiological strain, as measured by elevations in core temperature, heart rate, and perceived exertion responses (14). Moreover, the greater the body water deficit, the greater the increase in physiological strain (15-18). The extent of hypohydration is large (> 5% body mass). The prevalence of urine hyperosmolality at the start of exercise sessions in athletes training on a daily basis (19-22) suggests that many athletes begin exercise in a hypohydrated state. It is generally accepted that commencing exercise in a hypohydrated state will impair exercise performance, particularly if the exercise task is prolonged and/or is undertaken in a hot environment (23-25).

The present study had several limitations. First, the subjects were high school students during the growth period and had different BMIs. A recent study reported that age, body size, and composition during the growth period were significantly associated with WT (26). Second, our analysis represents a cross-section of data from subjects that was self-reported. Third, this study did not investigate qualitative aspects, particularly sodium, of WT. A previous study reported that daily water (4-10 L) and sodium (3500-7000 mg) losses in active athletes could induce water and electrolyte deficits. Both water and sodium need to be replaced to re-establish “normal” total body water (euhydration) (27). In this study, there was a shift from beverages to food items as the source of water in athletes. This finding suggests that athletes who consume a lower energy density diet with higher water and sodium content may need less water from drinks and beverages. However, it is important to understand the different roles of water homeostasis between non-athletes and athletes. Both renal responses and thirst are the primary homeostatic regulators in non-athletes. On the other hand, sweat losses become a major factor in whole-body water balance in athletes. Because evaporative sweat cooling is the main means of heat loss, preventing rapid rises of core body temperature is necessary.

It is important to replace fluid deficits after a preceding bout of activity. It is accepted that any deficit incurred prior to the next bout of exercise could lead to impairment in endurance performance (28, 29). When exercise commences in a well-hydrated state, accumulated fluid loss and the subsequent development of sensations of thirst can take time. Our findings suggest that increased awareness of the importance of increased daily water intake in athlete high school students because of their significantly large NRWL is necessary.

ETHICAL CONSIDERATIONS

Ethics approval was obtained from the Clinical Research Ethics Committee at Tokushima University Hospital (approval number 3593-1). Informed consent to participate in the study was received from participants or from an authorized surrogate. This trial was registered as UMIN000038105.

CONFLICTOFINTERESTANDACKNOWLEDGEMENT

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REFERENCES

1. European Food Safety Authority (EFSA) : Scientific opinion on dietary reference values for water. EFSA J 8 : 1459, 2010
2. Kleiner SM : Water : an essential but overlooked nutrient. J Am Diet Assoc 99 : 200-206, 1999
3. Hoffman MD, Cotter JD, Goulet ED, Laursen PB : VIEW : is drinking to thirst adequate to appropriately maintain hydration status during prolonged endurance exercise? Yes. Wilderness Environ Med 27 : 192-195, 2016
4. Raman A, Schoeller DA, Subar AF, Troiano RP, Schatzkin A, Harris T, Bauer D, Bingham SA, Everhart JE, Newman AB, Tylavsky FA : Water turnover in 458 American adults 40-79 yr of age. Am J Physiol Renal Physiol 286(2) : F394-401, 2004
5. Science and Technology Agency : Standard Tables of Food Composition in Japan, 2010. Ministry of Education, Culture, Sports, Science and Technology : Tokyo, 2010
6. Manz F, Wentz A, Sichert-Hellert W : The most essential nutrient : defining the adequate intake of water. J Pediatr 141 : 587-592, 2002
7. EFSA : Draft dietary reference values for water. Scientific Opinion of the Panel on Dietetic Products, Nutrition and Allergies, 2008 (agreed on 11 April 2008 for release for public consultation)
8. Leiper JB, Pitsiladis Y, Maughan RJ : Comparison of water turnover rates in men undertaking prolonged cycling exercise and sedentary men. Int J Sports Med 22(3) : 181-185, 2001
9. Armstrong, L.E : Assessing hydration status : The elusive gold standard. J Am Coll Nutr 26 : 575s-584s, 2007
10. Cunha F, Midgley A, Monteiro W, Farinatti P : Influence of cardiopulmonary exercise testing protocol and resting VO2 assessment on %HRmax, %HRR, %VO2max and %VO2R relationships. Int. J. Sports Med 31 : 319-326, 2010
11. Gagnon D, Jay O, Kenny GP : The evaporative requirement for heat balance determines whole-body sweat rate during exercise under conditions permitting full evaporation. J Physiol 591(Pt 11) : 2925-2935, 2013
12. Sawka MN, Burke LM, Eichner ER, Maughan RJ, Montain S, Stachenfeld NS : American College of Sports Medicine position stand. Exercise and fluid replacement. Med Sci Sports Exerc 39(2) : 377-390, 2007
13. Cheuvront SN, Kenefick RW : Dehydration : physiology, assessment, and performance effects. Compr Physiol 4(1) : 257-285, 2014
14. Sawka MN, Coyle EF : Influence of body water and blood volume on thermoregulation and exercise performance in the heat. Exercise Sport Sci Rev 27 : 167-218, 1999
15. Adolph EF : Physiology of man in the desert. New York, Interscience Publishers Inc., 1947
16. Montain SJ, Coyle EF : Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise. J Appl Physiol 73 : 1340-50, 1992
17. Montain SJ, Latzka WA, Sawka MN : Control of thermoregulatory sweating is altered by hydration level and exercise intensity. J Appl Physiol 79 : 1434-1439, 1995
18. Sawka MN, Young AJ, Francesconi RP, Muza SR, Pandolf KB : Thermo regulatory and blood responses during exercise at graded hypohydration levels. J Appl Physiol 59 : 1394-1401, 1985
19. Maughan RJ, Merson SJ, Broad NP, Shirreffs SM : Fluid and electrolyte intake and loss in elite soccer players during training. Int J Sport Nutr Exerc Metab 14 : 333-346, 2004
20. Maughan RJ, Shirreffs SM, Merson SJ, Horswill CA : Fluid and electrolyte balance in elite male football (soccer) players training in a cool environment. J Sports Sci 23 : 73-79, 2005
21. Maughan RJ, Watson P, Evans GH, Broad N, Shirreffs SM : Water balance and salt losses in competitive football. Int J Sport Nutr Exerc Metab 17 : 583-594, 2007
22. Volpe SL, Poule KA, Bland EG : Estimation of prepractice hydration status of national collegiate athletic association division I athletes. J Athl Train 44 : 624-629, 2009
23. Cheuvront SN, Kenefick RW : Dehydration : physiology, assessment, and performance effects. Compr Physio l4 : 257-285, 2014
24. Sawka MN, Burke LM, Eichner ER, Maughan RJ, Montain SJ, Stachen-feld NS ; American College of Sports Medicine : American College of Sports Medicine position stand. Exercise and fluid replacement. Med Sci Sports Exerc 39 : 377-390, 2007
25. Sawka MN, Cheuvront SN, Kenefick RW : Hypohydration and human performance : Impact of environmental and physiological mechanisms. Sports Med 45, Suppl1 : S51-S60, 2015
26. Yamada Y, Zhang X, Henderson MET, Sagayama H, Pontzer H, Watanabe D, Yoshida T, Kimura M, Ainslie PN, Andersen LF, Anderson LJ, Arab L, Baddou I, Bedu-Addo K, Blaak EE, Blanc S, Bonomi AG, Bouten CVC, Bovet P, Buchowski MS, Butte NF, Camps SG, Close GL, Cooper JA, Cooper R, Das SK, Dugas LR, Eaton S, Ekelund U, Entringer S, Forrester T, Fudge BW, Goris AH, Gurven M, Halsey LG, Hambly C, Hamdouchi AE, Hoos MB, Hu S, Joonas N, Joosen AM, Katzmarzyk P, Kempen KP, Kraus WE, Kriengsinyos W, Kushner RF, Lambert EV, Leonard WR, Lessan N, Martin CK, Medin AC, Meijer EP, Morehen

JC, Morton JP, Neuhouser ML, Nicklas TA, Ojiambo RM, Pietiläinen KH, Pitsiladis YP, Plange-Rhule J, Plasqui G, Prentice RL, Rabinovich RA, Racette SB, Raichlen DA, Ravussin E, Redman LM, Reilly JJ, Reynolds RM, Roberts SB, Schuit AJ, Sardinha LB, Silva AM, Sjödin AM, Stice E, Urlacher SS, Valenti G, Etten LMV, Mil EAV, Wells JCK, Wilson G, Wood BM, Yanovski JA, Murphy-Alford AJ, Loechl CU, Luke AH, J Rood J, Westerterp KR, Wong WW, Miyachi M, Schoeller DA, Speakman JR ; International Atomic Energy Agency (IAEA) Doubly Labeled Water (DLW) Database Consortium : Variation in human water turnover associated with environmental and lifestyle factors. Science 378(6622) : 909-915, 2022

27. Shirreffs SM, Sawka MN : Fluid and electrolyte needs for training, competition, and recovery. J Sports Sci 29 Suppl 1 : S39-46, 2011
28. Maughan, R : Fluid and electrolyte loss and replacement in exercise. J Sports Sci 9 : 117-142, 1991
29. Maughan, R : Effects of CHO-electrolyte solution on prolonged exercise. Perspect Exerc. Sci Sports Med 4 : 35-85, 1991