Athletic Performance and Serial Weight Changes During 12- and 24-Hour Ultra-Marathons

Wei-Fong Kao, MD,†‡§ Chih-Ling Shyu, BS,§ Xiu-Wu Yang, MD,¶‖ Teh-Fu Hsu, MD,*‡ Jin-Jong Chen, PhD,§** Wei-Chun Kao, MS, DDS,§ Polun-Chang, PhD,¶ Yi-Jen Huang, MS,†† Fon-Chu Kuo, MS,‡‡ Chun-I Huang, MD,*‡ and Chen-Hsen Lee, MD*‡*

Objective: The principal objective of this study was to evaluate serial weight changes in athletes during 12- and 24-hour ultra-marathons and to correlate these changes with athletic performance, namely the distance covered.

Design: This was a prospective study.

Setting: The 2003 Soochow University international ultra-marathon.

Participants: Fifty-two race participants.

Interventions: 12- or 24-hour ultra-marathon.

Main Outcome Measurements: Body weight changes were measured before, at 4-hour intervals during, and immediately after the 12- and 24-hour races.

Results: Significant overall decreases in body weight were apparent at the conclusion of both races. The mean relative body weight change after the 12-hour race was $-2.89 \pm 1.56\%$, ranging from 0 to 6.5%. The mean relative body weight change after the 24-hour race was $-5.05 \pm 2.28\%$, ranging from -0.77% to -11.40%. Of runners in the 24-hour race, 26% lost greater than 7% of baseline body weight during the race. During both the 12- and 24-hour races, the greatest weight change (decrease) occurred during the first 4 hours. Weight remained relatively stable after 8 hours, although a further decrease was apparent between 16 and 20 hours in the 24-hour participants. Weight change had no bearing on performance in the 12-hour race, whereas weight loss was positively associated with performance in the 24-hour race.

Conclusions: Our findings demonstrate that the majority of weight decrease/dehydration in both the 12- and 24-hour races occurred during the first 8 hours. Hence, to maintain body weight, fluid intake should be optimized in the first 8 hours for both 12- and 24-hour runners and in 16 to 20 hours for 24-hour marathon runners.

Key Words: ultra-marathon, athletic performance, dehydration, body weight, endurance

(*Clin J Sport Med* 2008;18:155–158)

Submitted for publication March 9, 2007; accepted September 14, 2007.

From the *Section of Emergency Medicine; †The Institute of Bioinformatics, National Yang-Ming University, Taipei, Taiwan; ‡Department of Emergency Medicine, Taipei Veterans General Hospital, Taipei, Taiwan; §Taipei City Hospital, Taipei, Taiwan; ¶The Institute of Health Informatics and Decision Making, National Yang-Ming University, Taipei, Taiwan; ‖Department of Emergency Medicine, Cheng Hsin Rehabilitation Medical Center, Taipei, Taiwan; **Institute of Physical Therapy, National Yang-Ming University, Taipei, Taiwan; ††Department of Physical Education; and ‡‡Department of Computer Science, Soochow University, Taipei, Taiwan.

Reprints: Wei-Fong Kao, MD, Department of Emergency Medicine, Veterans General Hospital-Taipei, 201 Shih-Pai Road, Section 2, Taipei, Taiwan, R.O.C. (e-mail: wfkao@vghtpe.gov.tw).

INTRODUCTION

The majority of studies regarding symptomatic hyponatremia secondary to exercise[1–5] and dehydration[6,7] have focused on the measurement of serum sodium levels, predictive mathematic models, and/or self-retrospective questionnaires. Few, if any, studies have conclusively established a time-based strategy for prevention of these physiologic disturbances, optimal performance as determined by quantification of serial fluid intake,[6] and serial body weight change during prolonged exercise.

According to the literature, a 1%–2% dehydration-related decrease in body weight readily compromises physiologic function and negatively affects athletic performance.[8] Similar levels of dehydration have also been demonstrated to impair cardiovascular and thermoregulatory responses and reduce exercise capacity.[9] Conventional exercise hydration techniques have attempted to combat inadequate fluid intake during endurance events through the excessive intake of plain water and nonelectrolyte-containing fluids; however, such strategies periodically result in varying degrees of hyponatremia or water intoxication.[10,11] Indeed, it has been reported that 18% to 27% of ironman triathletes are hyponatremic following race completion.[10,12] The current recommendation is that thirst should dictate self-hydration, with a mean liquid intake of 400 to 800 mL/h (greater volumes for ultra-marathoners and longer endurance performance athletes, and lower volumes for amateurs competing in traditional marathons).[13,14] Thirst-driven intake, however, has been demonstrated to replace only approximately 1/2 of the fluid lost via the sweating process.[15]

Such recommendations are typically derived from controlled observations of elite athletes, well aware of their personal requirements, while excluding recreational and amateur runners. Furthermore, the majority of such studies have tended to focus on the impact of nutritional and fluid intake with respect to outcome.[16–18] To our knowledge, there have been no studies to date concerning changes in body weight and its relationship to exercise performance during 12- and 24-hour marathons. This is surprising given that rapid body weight reduction is a crucial index of hydration.[14] With these considerations in mind, the principal objective of this study was to evaluate serial weight changes in athletes during endurance events (12- and 24-hour ultra-marathons) and to assess any correlation between serial weight change and athletic performance.

METHODS

This study was conducted during the 2003 Soochow University international ultra-marathon event, which consisted of 12- and 24-hour ultra-marathons. A total of 23 individuals (21 males and 2 females) registered for the 12-hour race, and 33 (26 males and 7 females) registered for the 24-hour race. Four of the 56 registered athletes (1 for the 12-hour and 3 for the 24-hour race) did not participate in the event.

The event was held on a 400-m oval track, with the 24-hour and 12-hour races commencing at 10 AM and 9 PM, respectively. Runners were permitted to rest and ingest water and food freely. Running direction changed every 4 hours. Runners were weighed (wearing only a single layer of clothing and shoes as worn during the races) on a calibrated weigh scale located at the medical station 1 hour before the race, at 4-hour intervals (when the runner changed direction) during the race, and immediately on completion of the race. Runners who rested more than 4 hours during the 12-hour race and 8 hours during the 24-hour race were excluded from our data analysis.

Participant demographics are presented as the mean (range) ± standard deviation (SD). Weight changes in athletes who completed their respective races are shown as the percentage change from baseline at each 4-hour interval. Baseline and 4-hour interval weights were compared by Student's (paired) *t*-test. The relationship between the percentage change in body weight and performance (distance counted in kilometers) was analyzed by scatter plots and corresponding linear regression. Differences were considered to be significant when $P < 0.05$.

RESULTS

On race day, the temperature ranged from 11.5° to 14.6°C, the humidity was 55%–60%, and wind speed ranged from 2.5 to 5.1 m/s.

Two runners in the 12-hour race and 3 runners in the 24-hour race were excluded from analysis after dropping out or resting excessively (more than 4 hours in the 12-hour race and 8 hours in the 24-hour race). Two 12-hour ultra-marathon runners were not weighed at race completion and were excluded from analysis. Data (including demographic) pertaining to the 18 athletes who successfully completed the 12-hour ultra-marathon are presented in Table 1. Four 24-hour marathon runners were not weighed at race completion and were excluded from analysis. Data (including demographic) pertaining to the 23 athletes who successfully completed the 24-hour marathon are presented in Table 2.

TABLE 1. Twelve-Hour Ultra-Marathon Participant Demographics, Race-Related Body Weight Changes, and Performance (n = 18)

Variable	Mean (Range) ± SD/Number (%)
Age (years)	45.3 (35 to 61) ± 6.4
Gender	
Female	1 (5.6%)
Male	17 (94.4%)
Body weight at race start (kg)	64.2 (49 to 76) ± 7.7
Absolute weight change (kg)*	−1.86 (−4 to 0) ± 1.01
Relative weight change (%)*	−2.89 (0.00 to -6.56) ± 1.56
Maximum weight change during the race (kg)	−2.32 (−1 to −4) ± 0.85
Total kilometers completed (km)	89.7 (66.1 to 107.0) ± 11.7
Time to minimum body weight (hours)	7.6 (4 to 12) ± 2.6

*The difference between prerace and postrace weight.

A total of 4 runners collapsed during the 24-hour marathon. Three of these collapsed immediately after the race, whereas the other collapsed at 20 hours. Two of the 3 runners who collapsed after the race had lost greater than 7% of basal body weight (only 1 of the 2 runners was weighed at race completion).

The greatest relative weight change (−11.4%) was observed in 1 of the 24-hour runners at the 20-h mark. This runner subsequently collapsed shortly after the race and received intravenous hydration. No athlete in the 12-hour race had a relative weight change of greater than 7%. In the 24-hour race, 7 runners (5 male, 2 female) had a body weight loss greater than 7% and 3 runners had a body weight loss greater than 7% during the first 8 hours. No athlete had gained weight at completion of the 12-hour race, whereas 1 24-hour athlete gained 1 kg.

Serial weight changes during the 12- and 24-hour races are presented in Figures 1 and 2, respectively. Seventeen and 19 participants were weighed at every time point in the 12- and 24-hour races, respectively. During the 12-hour race, relative

TABLE 2. Twenty-Four-Hour Ultra-Marathon Participant Demographics, Race-Related Body Weight Changes, and Performance (n = 23)

Variable	Mean (Range) ± SD/Number (%)
Age (years)	45.7 (36 to 67) ± 8.5
Gender	
Female	4 (17.4%)
Male	19 (82.6%)
Body weight at race start (kg)	60.96 (45 to 76) ± 8.3
Absolute weight change (kg)*	−2.48 (−6 to −1) ± 1.8
Relative weight change (%)*	−5.07 (−11.40 to 2.64) ± 2.6
Maximum weight change during the race (kg)	−3.11 (−6.5 to 0.5) ± 1.4
Total kilometers completed (km)	199.44 (127.0 to 261.4) ± 37.0
Time to minimum body weight (hours)	13.22 (4 to 24) ± 7.6

*The difference between prerace and postrace weight.

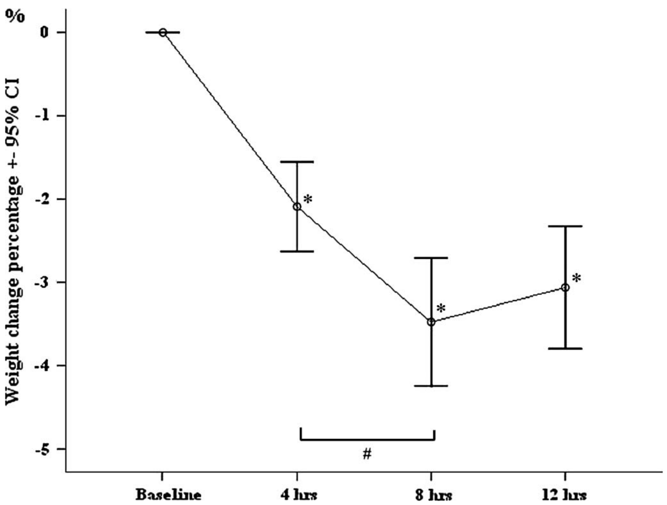

FIGURE 1. The average relative weight change for athletes in the 12-hour ultra-marathon (n = 17). Data were included only for athletes who were weighed at every time point. *Statistically significant difference from baseline ($P < 0.001$). #Statistically significant between time point difference ($P < 0.001$).

weight was significantly decreased from baseline at 4, 8, and 12 hours (Fig. 1; $P < 0.01$ for all comparisons). Furthermore, relative weight significantly decreased between 4 and 8 hours ($P < 0.01$) but did not change between 8 and 12 hours.

During the 24-hour ultra-marathon, relative weight was significantly decreased from baseline at 4, 8, 12, 16, 20, and 24 hours (Fig. 2; $P < 0.01$ for all comparisons). Although there was no further decrease in relative weight between 4 and 16 hours, there was a significant decrease apparent between 16 and 20 hours ($P < 0.05$). There was no further change between 20 and 24 hours. The most rapid decrease (steepest slope) in relative weight change for both the 12- and 24-hour runners was in the first 4 hours.

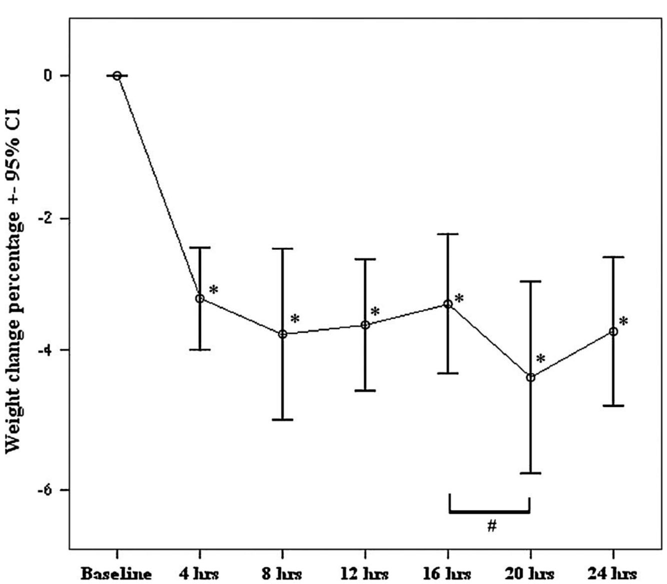

FIGURE 2. The average relative weight change for athletes in the 24-hour ultra-marathon (n = 19). Data were included only for athletes who were weighed at every time point. *Statistically significant difference from baseline ($P < 0.001$). #Statistically significant between time point difference ($P < 0.001$).

There was no significant correlation between weight loss and performance in the 12-hour race participants (Fig. 3). In the 24-hour race, however, weight loss was found to be associated with performance (Fig. 4; $P < 0.01$).

DISCUSSION

In this study, we found in both the 12- and 24-hour races that body weight declined markedly over the initial 8 hours, with the most rapid decreases apparent over the first 4 hours. It is interesting that, for runners in the 24-hour race, better performance was correlated with greater body weight loss.

As already noted, body weight decreased most dramatically in both groups over the initial 8 hours. According to previously published criteria,[19] at completion participants in the 12-hour race were on average minimally dehydrated, whereas those in the 24-hour race were significantly dehydrated. Seven runners in the 24-hour race experienced body weight loss greater than 7%, a change consistent with serious dehydration. The mean percentages of weight loss are comparable with those reported in previous studies.[11,20]

We found that weight loss was actually correlated with performance in the 24-hour group of participants. All runners with body weight loss of greater than 7% ran more than 200 km in the 24 hours. This is a somewhat puzzling finding and not in keeping with the general dogma regarding athletic performance and weight change. It does, however, agree with the study of Sharwood and colleagues who reported that athletes exhibiting the most dramatic changes in body weight during an ironman triathlon were among the fastest to finish.[11] In a later study (also pertaining to ironman triathlon athletes), the same researchers found that there was a positive correlation between percent body weight decrease and performance/

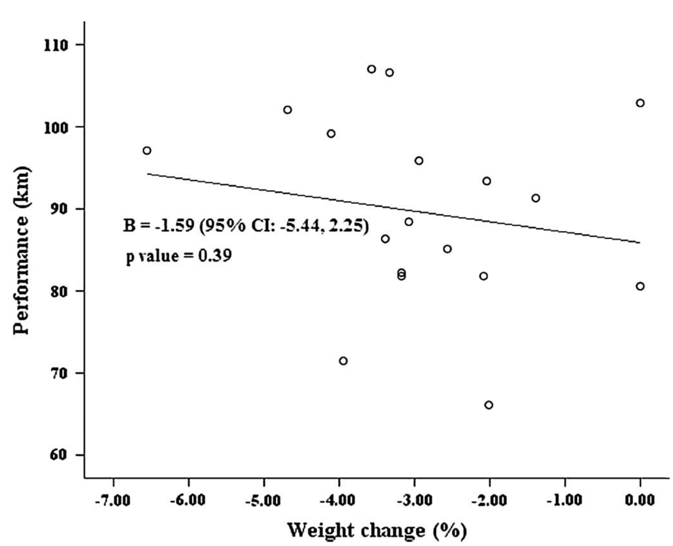

FIGURE 3. Relationship between the percentage change in relative body weight and performance (kilometers) for athletes who successfully completed the 12-hour ultra-marathon (n = 18). B = the regression coefficient of the slope.

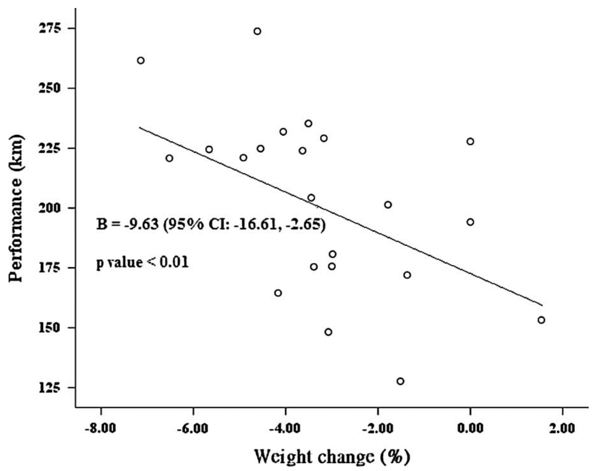

FIGURE 4. Relationship between the percentage change in relative body weight and performance (kilometers) for athletes who successfully completed the 24-hour ultra-marathon (n = 23). B = the regression coefficient of the slope.

finishing time.[20] Both these and our findings suggest, at the very least, that maintenance of body weight is not critical to performance in extreme endurance events. As noted by Sharwood et al,[11] these findings, if conclusively confirmed, have important practical implications with regard to hydration recommendations.

A number of mitigating factors may have compromised the validity and verifiability of our study findings. Because we did not assess fluid intake, serum sodium levels, or rectal temperature, we were not able to definitively examine the relationship between body weight change with osmoregulation, temperature regulation, or plasma volume changes. Future studies should aim to assess these variables in the context of serial weight change during extreme endurance events.

In conclusion, we have reported for the first time serial body weight changes in athletes competing in 12- and 24-hour ultra-marathon events. In both groups of runners, weight decreases occurred primarily over the first 8 hours, with the most rapid decline taking place between 0 and 4 hours. In the 24-hour ultra-marathon, a further weight loss occurred between 16 and 20 hours. In addition, greater weight loss is associated with better performance in the 24-hour race.

ACKNOWLEDGMENTS

We would like to thank all the doctors, nurses, and emergency medical technicians who provided professional care at this ultra-marathon race. We also express gratitude to our colleagues at Soochow University, the International Association of Ultra Runners, and the Chinese Taipei Road Running Association, all of whom assisted at the ultra-marathon event. We would like also to thank all the ultra-runners who participated in this study.

REFERENCES

1. Almond CS, Shin AY, Fortescue EB, et al. Hyponatremia among runners in the Boston Marathon. *N Engl J Med*. 2005;352:1550–1556.
2. Siegel AJ. Exercise-associated hyponatremia: role of cytokines. *Am J Med*. 2006;119:S74–S78.
3. Montain SJ, Sawka MN, Wenger CB. Hyponatremia associated with exercise: risk factors and pathogenesis. *Exerc Sport Sci Rev.* 2001;29: 113–117.
4. Noakes TD, Sharwood K, Collins M. et al. The dipsomania of great distance: water intoxication in an Ironman triathlete. *Br J Sports Med*. 2004;38:E16.
5. Hew TD, Chorley JN, Cianca JC. et al. The incidence, risk factors, and clinical manifestations of hyponatremia in marathon runners. *Clin J Sport Med*. 2003;13:41–47.
6. Kruseman M, Bucher S, Bovard M. et al. Nutrient intake and performance during a mountain marathon: an observational study. *Eur J Appl Physiol*. 2005;94:151–157.
7. Fogelholm M. Effects of bodyweight reduction on sports performance. *Sports Med*. 1994;18:249–67.
8. Von Duvillard SP, Braun WA, Markofski M. et al. Fluids and hydration in prolonged endurance performance. *Nutrition*. 2004;20:651–656.
9. Murray R. Dehydration, hyperthermia, and athletes: science and practice. *J Athl Train*. 1996;31:248–252.
10. Speedy DB, Noakes TD, Rogers IR, et al. Hyponatremia in ultradistance triathletes. *Med Sci Sports Exerc*. 1999;31:809–815.
11. Sharwood K, Collins M, Goedecke J, et al. Weight changes, sodium levels, and performance in the South African Ironman Triathlon. *Clin J Sport Med*. 2002;12:391–399.
12. Hiller WD, O'Toole ML, Fortess EE, et al. Medical and physiological considerations in triathlons. *Am J Sports Med*. 1987;15:164–167.
13. Noakes T. Fluid replacement during marathon running. *Clin J Sport Med*. 2003;13:309–318.
14. Casa D. Proper hydration for distance running: identifying individual fluid needs. *Track Coach*. 2004:5321–5328.
15. Coyle EF. Physiological determinants of endurance exercise performance. *J Sci Med Sport*. 1999;2:181–189.
16. Fallon KE, Broad E, Thompson MW, et al. Nutritional and fluid intake in a 100-km ultramarathon. *Int J Sport Nutr*. 1998;8:24–35.
17. Rehrer NJ. Fluid and electrolyte balance in ultra-endurance sport. *Sports Med*. 2001;31:701–715.
18. Speedy DB, Noakes TD, Kimber NE, et al. Fluid balance during and after an Ironman triathlon. *Clin J Sport Med*. 2001;11:44–50.
19. Casa DJ, Armstrong LE, Hillman SK, et al. National Athletic Trainers' Association Position Statement: Fluid Replacement for Athletes. *J Athl Train*. 2000;35:212–224.
20. Sharwood KA, Collins M, Goedecke JH, et al. Weight changes, medical complications, and performance during an Ironman triathlon. *Br J Sports Med*. 2004;38:718–724.