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The Influence of Fluid Replacement Rate on Heart Rate and RPE During Exercise in a Hot, Humid Environment

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Reference Data

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ABSTRACT

This study focused on the effects of 5- and 10-min fluid replacement intervals on heart rate, rating of perceived exertion (RPE), and posttrial oral temperature during a 1-hr bicycle exercise bout in a hot (32 ± 1.5 °C), humid (70 ± 3%) environment. Three experimental conditions were used: no water replacement, 400-ml water prior to and 100 ml every 5 min, and 400-ml water prior to and 200 ml every 10 min. Differences were significant between no-fluid and 5-min fluid replacement conditions for heart rate after 25 min. Mean posttrial recovery heart rates differed significantly during all conditions. Mean RPE differed significantly between no-fluid and 5-min fluid replacement conditions after 30 min. Mean posttrial oral temperatures differed significantly between no-fluid and 5-min fluid replacement conditions. A 5-min fluid replacement interval of 100 ml may be optimal for benefits on heart rate and RPE.

Key Words: dehydration, rehydration, heat

Introduction

When an individual becomes dehydrated, exercise performance is impaired due to slowed heat dissipation, causing an elevation in core body temperature and exacerbating fatigue. Dehydration reduces blood volume, which in turn reduces stroke volume and elicits an increase in heart rate (1, 4, 6, 10–12, 14–16, 19, 20, 23, 24). Dehydration has also been shown to have an adverse effect on the psyche (20). All of these factors reduce endurance.

Research has revealed that drinking fluids before and during exercise attenuates decrements in performance associated with dehydration (1, 4, 12–14, 18, 20, 22, 25, 26). Thus prehydration and continual fluid intake during exercise are needed to replace lost fluids and to improve or maintain performance. Since ad libitum fluid consumption has been found inadequate for maintaining proper hydration during exercise (1), a standard fluid replacement schedule is necessary.

The American College of Sports Medicine (2) in 1984 had recommended that runners drink 100 to 200 ml of fluid every 2 or 3 km run in competition. This means runners could consume anywhere from 200 to over 2,000 ml · h^{-1}, depending on how fast they run and how they interpret the recommendation. For instance, an individual running 15 kph could consume from 500 (100 ml · 3 km^{-1}) to 1,400 ml (200 ml · 2 km^{-1}) of fluid. Therefore this schedule was problematic because it was based on distance rather than time.

In 1988, to minimize the dangers of exercising in the heat, the ACSM (3) further recommended that individuals drink 400 to 500 ml of fluid before and 300 ml · min^{-1} during exercise. This schedule also could be problematic due to the long interval between drinking periods, resulting in a decline in gastric volume between drinks.

To maximize gastric emptying, gastric volume must be maintained (8, 9). Coyle and Montain (9) suggested most individuals could absorb 1,000 ml of fluid an hour during exercise. Costill and Saltin (8) found that colder fluids are absorbed more readily than fluids at body temperature, and that a temperature of 5°C is optimal. Based on these studies, an optimal rate of fluid replacement would be approximately 1,000 ml · h^{-1} at 5°C.

Thus, to help attenuate the increases in heart rate and psychological distress associated with exercise intensity, dehydration, or heat stress, the question arises as to how quickly one should replace fluids lost through sweating while engaged in physical activity. Heart rate and RPE are indicative of the amount of stress endured during exercise. As the stress of exercise becomes greater in intensity or duration, heart rate and RPE increase. Furthermore, this increase is exacerbated under extreme environmental conditions. Hence heart rate and RPE provide valuable information on theeffect of the overall stress one encounters while exercising in a hot, humid environment.

The purpose of this investigation was to study the effects of differing fluid replacement rates on the physiological and psychological determinants of stress during exercise in a hot, humid environment. Specifically examined were the effects of fluid replacement rates on heart rate and RPE while exercising at 65% max HR in an environment of approximately 32 ± 1.5°C and 70 ± 3% RH.

Methods

Subjects

The study was approved by the university's research committee for the protection of human subjects. In all, 18 trained males signed consent forms to participate but 3 later withdrew from the study (see Results). The physical characteristics of the 15 subjects were as follows: age 28.9 ± 1.5 yrs; height 179.0 ± 1.4 cm; weight 77.1 ± 1.8 kg; predicted $\dot{V}O_2max$ 50.0 ± 3.0 ml · kg^{-1} · min^{-1}.

Procedures

During a preliminary evaluation the subjects were tested for predicted $\dot{V}O_2max$ using the Åstrand Ryhming submaximal bicycle ergometer test for descriptive purposes. The test was used to determine each subject's workload for the exercise trials as follows: Subjects pedaled at a cadence they could comfortably maintain for 1 hr, and resistance was increased until a 65% max heart rate, approximately 50% $\dot{V}O_2max$ (21), was achieved for a steady-state period of 10 min.

All trials were conducted in a sauna; subjects wore cycling shorts and shoes. Each subject completed three exercise trials on a Monark bicycle ergometer equipped with an electronic measuring device (Cateye Micro cyclocomputer) that recorded cadence and kilometers completed. Heart rate was obtained via a heart rate monitor (Polar Vantage, XL). Ambient and oral temperatures were measured by a telethermometer (Yellow Springs Instrument Co.). RPE data were obtained using the Borg 15-point scale (5).

Water, the replacement drink for the 5- and 10-min fluid replacement trials, was administered at approximately 5°C. Subjects completed three 60-min exercise trials in an environment of approximately 32 ± 1.5°C and 70 ± 3% relative humidity, produced by the use of a sauna and vaporizers. One trial involved no fluid replacement. A second trial included a preexercise drink of 400 ml of water administered 5 min prior to the start, then 100 ml of water every 5 min during the trial. A third trial involved the preexercise drink, then 200 ml of water every 10 min. Assigned randomly, the trials were conducted at the same time of day and were completed within a 2-week interval of each other.

Each trial followed a 2- to 3-hr fast. When each subject arrived at the sauna, his weight, resting heart rate, and oral temperature were recorded. If he was to receive fluid during the trial, he was given a preexercise 400-ml drink. After a 5-min rest he entered the sauna and began the exercise trial. Heart rate, ambient temperature, and relative humidity were monitored continuously during each trial. Heart rate was recorded every minute; RPE and kilometers completed were recorded at 5-min intervals.

At the conclusion of the trial, oral temperature was taken, a 5-min standing recovery heart rate was recorded, and the subject was weighed and excused.

A two-factor (condition by time) repeated measures ANOVA was used to determine statistical differences. A Tukey post hoc test was used to probe any significant main effects. The 0.05 level of probability was used to determine significance.

Results

Two subjects withdrew because of volitional exhaustion and a third because of a sudden drop in heart rate of 20 beats · min^{-1}. These data were excluded from the statistical analyses. Means and standard deviations for kilometers completed did not vary significantly among trials.

Testing Profile

Heart Rate. Mean pretrial heart rates did not differ significantly (see Table 1). Mean exercise heart rates, shown in Figure 1, increased over time for all three conditions and differed significantly between the no-fluid and the 5-min fluid replacement trials. There were significant differences between no-fluid and the 5-min fluid replacement conditions at Minutes 25, 30, 35, 40, 45, 50, 55, and 60. No significant differences were observed for exercise heart rate between the no-fluid and the 10-min fluid replacement trials. Posttrial heart rates (see Table 1) were significantly different among conditions.

RPE. Mean RPE values are presented in Figure 2. Differences between RPE in the no-fluid and the 5-min fluid replacement trials were significant. Post hoc data revealed significance at Minutes 30, 35, 40, 45, 50, 55, and 60 between the no-fluid and the 5-min fluid replacement trials. Mean RPE values in the 10-min fluid replacement trial were between those of the no-fluid and the 5-min fluid replacement trials and not significantly different from the former.

Oral Temperature. Pre- and posttrial oral temperatures (see Table 1) reveal a significant difference between the no-fluid and the 5-min fluid replacement conditions for posttrial oral temperatures.

Body Weight. Mean pretrial body weights did not differ significantly (see Table 1). The change in weight

Table 1
Pre- and Posttrial Values for 15 Subjects

Condition	Pretrial *M*	Pretrial *SE*	Posttrial *M*	Posttrial *SE*
Heart rate (beats · min^{-1})				
No fluid	64	3.10	1.58[b,c]	3.26
5-min	65	3.42	137[a,c]	5.64
10-min	64	3.11	145[a,b]	5.36
Oral temperature (°C)				
No fluid	35.18	0.31	37.78[b]	0.41
5-min	35.41	0.13	36.78[a]	0.28
10-min	35.17	0.15	37.22	0.31
Body weight				
No fluid	76.97	1.84	75.66	1.80
5-min	77.29	1.75	77.18	1.78
10-min	77.05	1.73	76.94	1.72

Signif. diff., $p < 0.05$, from: [a]no fluid; [b]5-min; [c]10-min.

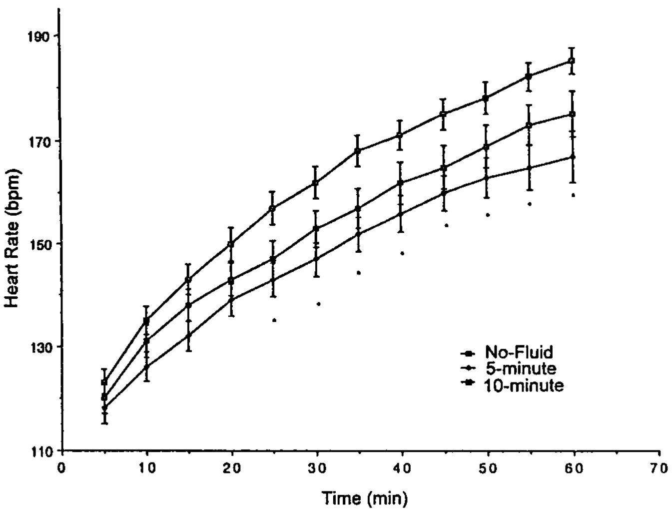

Figure 1. Mean exercise heart rates by condition. *Significant differences, $p < 0.05$, between no-fluid and 5-min trials.

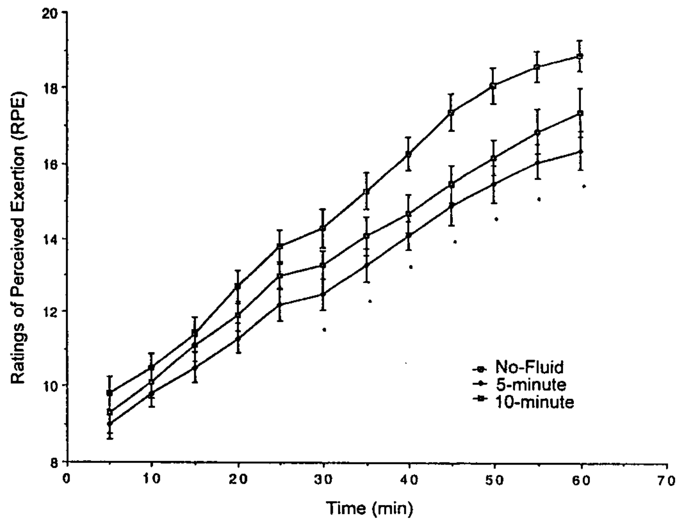

Figure 2. Mean ratings of perceived exertion by condition. *Significant differences, $p < 0.05$, between no-fluid and 5-min trials.

was −1.31 kg in the no-fluid trial, −0.11 kg in the 5-min fluid replacement trial, and −0.11 kg in the 10-min trial. These values represent a dehydration level of 1.7, 0.1, and 0.1% in the no-fluid, 5-, and 10-min fluid replacement trials, respectively.

Discussion

In the no-fluid trial, subjects exhibited a larger increase in heart rate and RPE than in the fluid replacement trials. This once again demonstrates the pernicious effects of dehydration (1, 4, 6, 10, 11, 22). Heart rate increased by roughly 65, 45, and 55 beats · min^{-1} during the no-fluid, 5-, and 10-min fluid replacement trials, respectively. Ryan et al. (22) reported similar findings: an increase of 70 beats · min^{-1} for a fluid replacement schedule of 350 ml · 20 min^{-1} of water and various other drinks.

Results of the current study contradict the conclusion of Costill et al. (7) that fluid intake had little influence on heart rate. Our subjects had heart rates of 185, 167, and 175 beats · min^{-1} for no-fluid, 5-, and 10-min fluid replacement regimens, respectively. In contrast, Costill et al. reported heart rate values of 154 and 150 beats · min^{-1} at 60 min for no-fluid and water trials, respectively.

The difference in heart rate response could be related to the dissimilar environment, mode of exercise, work level, or a combination of these. Costill et al.'s environmental conditions, at 24.8 to 25.6°C and 49 to 55% relative humidity, were less severe than those in the current study. Also, their subjects exercised by running at 70% $\dot{V}O_2max$ whereas our subjects cycled at approximately 50% $\dot{V}O_2max$. Similar to the current study, Barr et al. (4) also reported significantly higher heart rates over time in a no-fluid trial compared to a water replacement trial. But their subjects exercised for several hours at 55% $\dot{V}O_2max$ in environmental conditions of 30°C and 50% relative humidity.

In the present study, heart rate increased progressively in each trial, the largest increase occurring in the no-fluid trial. These findings—the recorded loss of 1.31 kg (1.7%) in body weight and an 18 and 10 beats · min^{-1} increase during the no-fluid trial compared to the 5- and 10-min fluid replacement trials—are in agreement with the conclusions of Buskirk et al. (6) and Saltin (23) that dehydration increases heart rate.

The increase in heart rate for our subjects was attenuated during the fluid replacement trials, especially during the 5-min one. Mean exercise heart rates were significantly lower in the 5-min fluid replacement trial than in the no-fluid trial; however, no significant differences were found for the 10-min fluid replacement and no-fluid trials. Therefore a 5-min fluid replacement interval was better than a 10-min one for attenuating the increase in heart rate resulting from exercise in a hot, humid environment. This supports the linear relationship Montain and Coyle (17) established between the magnitude of increase in heart rate and percent body weight lost.

Since our subjects became progressively more dehydrated in the no-fluid trial (evident by a 1.31-kg loss in weight), the increase in heart rate that was observed may be linked to dehydration. However, given that a 5-min fluid replacement trial attenuated heart rate further than a 10-min one, the attenuation in heart rate is not only linked to a decrease in weight (the amount of weight loss was the same in both fluid replacement trials) but also to the rate of fluid replacement.

Our findings on recovery heart rates correspond with those of Greenleaf et al. (15) that dehydrated individuals have a higher recovery heart rate. Thus the fact that fluid replacement at 5-min intervals results in a lower recovery heart rate displays the worth of the 5-min fluid replacement interval during exercise.

RPE increased progressively during each trial. At Minute 60 the largest increase was found in the no-fluid trial (18.9), followed by the 10-min fluid replacement trial

(17.4) and the 5-min one (16.4). Montain and Coyle (17) reported similar findings after their subjects exercised at approximately 65% $\dot{V}O_2max$ in 33°C temperature and 50% relative humidity. RPE increased progressively during exercise; without fluid replacement it reached a level of 17.6, compared to 15.8, 14.0, and 13.4 for small, moderate, and large fluid consumption trials, respectively.

The values in the present study were higher, however, and could be related to two factors: (a) Montain and Coyle (17) employed lower relative humidity than in our study; (b) we did not use a fan to circulate the air to correct for convective heat loss. Our findings are also in agreement with those of Barr et al. (4), who concluded that RPE increases over time and is significantly higher in a no-fluid trial than in a fluid replacement trial.

Noakes (20) stressed the importance of fluid replacement to combat the psychological disturbance of dehydration that results in "a low morale [and a] don't-give-a-damn-for-anything attitude" (p. 301). Montain and Coyle (17) concluded that the constant increase in RPE is attenuated by fluid replacement. Moreover, they found that the more closely fluid replacement matches fluids lost through sweating, the lower the RPE. Our results reiterate these findings. The RPE in the 5-min fluid replacement trial differed significantly from that in the no-fluid trial, whereas the values for the 10-min fluid replacement trial were intermediate and not significantly different.

The current study agrees with previous investigations (4, 6, 7, 10, 20, 24) in that fluid intake attenuates the increase in body temperature during exercise. Post-trial oral temperatures were highest in the no-fluid trial, followed by the 10- and 5-min fluid replacement trials, each being significantly different. Hortsman and Horvath (16) reported there was a "failure of temperature regulation during dehydration" (p. 446) and that subjects will gain heat when dehydrated. This finding was confirmed by the current study, as evidenced by the higher oral temperatures in the no-fluid trial. Moreover, the 5-min fluid replacement trial produced lower values than the 10-min one, again proving the effectiveness of 5-min fluid replacement intervals at attenuating the increase in body temperature.

Practical Applications

The results illustrate that fluid should be made available every 5 min for participants engaged in physical activity in hot, humid environments. Specifically, individuals exercising in such environments should prehydrate (400–500 ml) and drink 100 ml of fluid at 5-min intervals to reduce the effects of dehydration and heat stress. In regard to summer events conducted in the heat and humidity, event sponsors, race directors, and coaches should educate participants about the deleterious effects of dehydration and the need to rehydrate.

References

1. Adolph, E.F. *Physiology of Man in the Desert*. New York: Interscience, 1947.
2. American College of Sports Medicine. Position stand on prevention of thermal injuries during distance running. *Med. Sci. Sports Exerc.* 16: ix-xiv. 1984.
3. American College of Sports Medicine. *Resource Manual for Guidelines for Exercise Testing and Prescription* (4th ed.). Philadelphia: Lea & Febiger, 1988.
4. Barr, S.I., D.L. Costill, and W.J. Fink. Fluid replacement during prolonged exercise: Effects of water, saline, or no fluid. *Med. Sci. Sports Exerc.* 23:811-817. 1991.
5. Borg, G.A. Psychophysical bases of perceived exertion. *Med. Sci. Sports Exerc.* 14:377-381. 1982.
6. Buskirk, E.R., P.F., Iampietro, and D.E. Bass. Work performance after dehydration: Effects of physical conditioning and heat acclimation. *J. Appl. Physiol.* 12:189-194. 1958.
7. Costill, D.L., W.F. Kammer, and A. Fisher. Fluid ingestion during distance running. *Arch. Environ. Health* 21:520-525. 1970.
8. Costill, D.L., and B. Saltin. Factors limiting gastric emptying during rest and exercise. *J. Appl. Physiol.* 37:679-683. 1974.
9. Coyle, E.F., and S.J. Montain. Carbohydrate and fluid ingestion during exercise: Are there trade-offs? *Med. Sci. Sports Exerc.* 24:671-678. 1992.
10. Craig, F.N., and E.G. Cummings. Dehydration and muscular work. *J. Appl. Physiol.* 21:670-674. 1966.
11. Craig, F.N., and H.L. Froehlich. Endurance of preheated men in exhausting work. *J. Appl. Physiol.* 24:636-639. 1968.
12. Greenleaf, J.E. Problem: Thirst, drinking behavior, and involuntary dehydration. *Med. Sci. Sports Exerc.* 24:645-656. 1992.
13. Greenleaf, J.E., P.J. Brock, L.C. Keil, and J.T. Morse. Drinking and water balance during exercise and heat acclimation. *J. Appl. Physiol.* 54:414-419. 1983.
14. Greenleaf, J.E., and B.L. Castle. Exercise temperature regulation in man during hypohydration and hyperhydration. *J. Appl. Physiol.* 30:847-853. 1971.
15. Greenleaf, J.E., E.M. Prance, and E.G. Averkin. Physical performance of women following heat-exercise hypohydration. *J. Appl. Physiol.* 22:55-60. 1967.
16. Hortsman, D.H., and S.M. Horvath. Cardiovascular and temperature regulatory changes during progressive dehydration and euhydration. *J. Appl. Physiol.* 33:446-450. 1972.
17. Montain, S.J., and E.F. Coyle. Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise. *Med. Sci. Sports Exerc.* 73:1340-1350. 1992.
18. Moroff, S.V. and D.E. Bass. Effects of overhydration on man's physiological responses to work in the heat. *J. Appl. Physiol.* 20:267-270. 1967.
19. Neufer, P.D., A.J. Young, and M.N. Sawka. Gastric emptying during exercise: Effects of heat stress and hypohydration. *Eur. J. Appl. Physiol.* 58:433-439. 1989.
20. Noakes, T.D. Fluid replacement during exercise. *Exerc. Sport Sci. Rev.* 297-332. 1993.
21. Powers, S.K., and E.T. Howley. Exercise physiology, theory and application to fitness and performance. Dubuque, IA: Wm. C. Brown. 1990.
22. Ryan, A.J., T.L. Bleiler, F.E. Carter, and C.V. Gisolfi. Gastric emptying during prolonged cycling exercise in the heat. *Med. Sci. Sports Exerc.* 21:51-58. 1989.
23. Saltin, B. Aerobic and anaerobic work capacity after dehydration. *J. Appl. Physiol.* 19:1114-1118. 1964.
24. Sawka, M.N. Physiological consequences of hypohydration: Exercise performance and thermoregulation. *Med. Sci. Sports Exerc.* 24:657-670. 1992.
25. Sawka, M.N., R.P. Francesconi, A.J. Young, and K.B. Pandolf. Influence of hydration level and body fluids on exercise performance in the heat. *J. Am. Med. Assoc.* 252:1165-1169. 1984.
26. Sawka, M.N., and J.E. Greenleaf. Current concepts concerning thirst, dehydration, and fluid replacement: Overview. *Med. Sci. Sports Exerc.* 24:643-644. 1992.