RBCDH Revista Brasileira de CINEANTROPOMETRIA e Desempenho Humano

DOI: http://dx.doi.org/10.5007/1980-0037.2014v16n6p629

original article

Rehydration during exercise in the heat reduces physiological strain index in healthy adults

Reidratação durante exercício no calor reduz o índice de esforço fisiológico em adultos saudáveis

Marcelo Gava Pompermayer[1]
Rodrigo Rodrigues[1]
Bruno Manfredini Baroni[2]
Raquel de Oliveira Lupion[1]
Flavia Meyer[1]
Marco Aurélio Vaz[1]

Abstract – Exercise in the heat leads to physiological alterations that reflect mainly on the cardiovascular system. The physiological strain index (PSI) uses heart rate (HR) and rectal temperature (Tre) to evaluate the cardiovascular strain and lately it has been brought up on the literature. However, few studies used the PSI to evaluate its response following dehydration and rehydration protocols. Thus, the aim of the present study was to verify the effect of rehydration proportional to fluid losses during prolonged exercise in the heat on hydration status, PSI and rating of perceived exertion (RPE) in healthy subjects. Ten volunteers performed two sessions of exercise in heat. The first with fluid restriction until subjects reach 2% of body mass (BM) reduction. The second with rehydration proportional to fluid losses of the first. HR and Tre were monitored during the entire exercise protocol in order to calculate PSI. Subjects also reported their RPE. BM, urine specific gravity (USG) and urine color (UC) were measured to evaluate hydration status. Results demonstrated greater PSI in the fluid restricted trial compared to the rehydration trial from 45 minutes of exercise (p<0,05), and that differences remain significant until the end of the protocol. RPE also presented significant differences between trials (p<0,001). Rehydration strategy was effective to maintain hydration status and attenuate the increase on PSI and RPE, which has important implications for sports, especially those with more than 45 minutes.

Key words: Body temperature regulation; Exercise; Hydration; Physiological stress; Water.

Resumo – *O exercício no calor provoca alterações fisiológicas que refletem principalmente no sistema cardiovascular. O índice de esforço fisiológico (IEF), que utiliza o comportamento da temperatura corporal (Tre) e da frequência cardíaca (FC) para avaliar o nível de sobrecarga cardiovascular vem sendo preconizado na literatura. Porém, poucos estudos avaliaram os efeitos da desidratação e reidratação sobre este marcador. Assim, o objetivo foi verificar o efeito de uma estratégia de reidratação proporcional à perda hídrica durante exercício prolongado no calor sobre o estado de hidratação, IEF e taxa de percepção de esforço (TPE) de sujeitos saudáveis. Dez sujeitos realizaram duas sessões de exercício no calor, sendo a primeira sem reidratação (redução de 2% da massa corporal) (MC) e a segunda com reidratação (água mineral) em um volume proporcional à perda da primeira sessão. A FC e a Tre foram monitoradas durante o exercício para o cálculo do IEF. A TPE também foi obtida durante o exercício. A MC, gravidade específica (GEU) e coloração da urina (COR) foram mensuradas antes e após o exercício para avaliação do estado de hidratação. Os resultados demonstraram maior IEF na situação sem reidratação comparada à situação com reidratação a partir de 45 minutos de exercício (p<0,05), mantendo-se significativa até o final do protocolo. A TPE também apresentou diferença significativa entre as situações (p<0,001). A estratégia de reidratação foi efetiva para manter o estado de hidratação, atenuar o IEF e a TPE, trazendo importantes implicações para práticas desportivas, sobretudo àquelas que têm duração superior a 45 minutos.*

Palavras-chave: *Água; Estresse fisiológico; Exercício; Hidratação; Termorregulação.*

1 Federal University of Rio Grande do Sul. School of Physical Education. Laboratory of Exercise Research. Porto Alegre, RS. Brazil.

2 Federal University of Health Sciences of Porto Alegre. Department of Physiotherapy. Porto Alegre, RS. Brazil.

Received: 14 July 2013
Accepted: 30 November 2013

INTRODUCTION

Exercise in the heat causes physiological changes that can affect the functioning of the neuromuscular[1] and cardiovascular[2] systems and impair exercise performance[3]. Loss of body water through sweating can lead to dehydration, which is another aggravating factor in lowered performance, considering that the main form of heat dissipation during exercise is through sweat evaporation[4].

The effects of dehydration can occur even under light to moderate body mass reductions (1-3%)[5]. According to the guidelines of the Brazilian Society of Sports Medicine[6], severe reductions (4-6%) are even more deleterious to performance and can lead to thermal fatigue, while dehydration levels of 7% show risk of thermal shock, coma and death. Since it is common that athletes finish and even start a training session or competition already dehydrated, the identification of the hydration status is essential to develop appropriate rehydration strategies. Although there are several markers to assess hydration status, non-invasive methods such as change in body mass (BM), urine specific gravity (USG) and urine color (UC) are commonly used in laboratory and field situations due to their low cost and good reproducibility[7].

Seeking to minimize the adverse effects of dehydration, rehydration strategies have been recommended. In field situations, fluid replacement is commonly based on the subjective perception of thirst throughout the exercise section[8]. Although evidence shows that this is a valid strategy for the maintenance of the hydration status[9], there are situations in which dehydration may already be present by the late thirst manifestation[10]. Accordingly, publications of the American College of Sports Medicine[4] and the National Athletic Trainer's Association[11] indicate that fluid intake during exercise should occur at regular intervals and in amounts proportional to losses, which can be easily quantified through changes in BM observed during and after exercise. However, other methodologies such as the physiological strain index (PSI) have been tested to verify the effectiveness of rehydration strategy as well as its effect on the cardiovascular system.

PSI[12] uses heart rate (HR) and temperature in an equation that results in a universal numerical scale (0 - no, 10 - very high) capable of quantifying the physiological overload during exercise. Maxwell et al.[13] and Richardson et al.[7] induced specific dehydration levels in healthy subjects by exercise in the heat under different rehydration strategies and then evaluated the PSI during intermittent exercises in the heat. In both studies, the highest dehydration levels before intermittent exercise resulted in higher PSI values, while the replacement strategy of 150% of the volume of water lost during the dehydration protocol allowed subjects to initiate intermittent exercise rehydrated and reached lower PSI values. On the other hand, while in one study[13], the rate of perceived exertion (RPE) was significantly higher in cases with higher dehydration degrees, in the other[7] no significant differences were observed.

However, the above studies[7,13] used dehydration protocols prior to exercise. Few studies[14-16] have proposed to evaluate the PSI response in a situation of fluid replacement held concurrently with exercise, and these studies have limitations such as lack of instruments and control in assessing the hydration status. Therefore, although the findings of Moran et al.[14] demonstrate association between dehydration level and increased PSI during exercise, there is still a gap on the effect promoted by a corresponding fluid replacement, above all, at 100% of the water volume lost on PSI and RPE. Thus, the aim of this study was to investigate the effect of a rehydration strategy proportional to water loss during prolonged exercise in the heat on the hydration status, PSI and RPE of healthy subjects.

METHODOLOGICAL PROCEDURES

Experimental approach

The volunteers attended the laboratory on two occasions separated by an interval of seven days. On the first visit, subjects performed the exercise protocol without fluid intake (situation without rehydration) and in the second, with fluid replacement corresponding to the loss of body mass (situation with rehydration).

Body mass (BM), urine specific gravity (USG) and urine color (UC) of each subject were measured before and after exercise to assess their body hydration status. In addition, heart rate (HR) and rectal temperature (Tre) were monitored throughout the protocol. Subjects also reported their rate of perceived exertion (RPE).

Sample

The sample consisted of 10 untrained male subjects non-acclimatized to heat (22.5 ± 2.21 years, 75.9 ± 7.35 kg, 176 ± 6.46 cm, 18.85 ± 3.01% body fat). All subjects read and signed the free informed consent form. This study was approved by the Ethics Research Committee of the Federal University of Rio Grande do Sul. Subjects were instructed not to drink alcohol 36h before each assessment, not to perform vigorous physical activity 24 hours before each evaluation and not to consume foods with caffeine 12h before each assessment[17].

Exercise protocol

The exercise protocol was conducted in an environmental chamber at an average temperature of 37°C and relative humidity of 45%. To control excessive rise in core temperature, a fan was placed in front of the volunteers with wind speed maintained at 6 $m.s^{-1}$. On the first day (situation without rehydration), subjects cycled on a cycle ergometer (ERGOFIT 167, Spain) at a pace of 80-90rpm and constant load of 100 W. Every 20 minutes, subjects interrupted the exercise, urinated when possible, dried sweat and were weighed (digital scale Uranus PS-180). The procedure was repeated until loss of BM reached 2% or Tre exceeded 39.5°C. On the second day (situation with rehydration), the same protocol was performed, differing only by the intake of commercial mineral water (Na, 76.83 mgnl-1; Ca, 3,81 mgnl-1, Mg, 1,79 mgnl-1; K, 0,40 mgnl-1, HCO3-, 184,74 mgnl-1, SO4-, 4,06 mgnl-1) proportional to the situation without hydration every 20 minutes to maintain hydration status.

Evaluation protocols

To determine the hydration status, USG was used by a digital refractometer (Atago 2722-E04, Tokyo, Japan) and the COR scale[18], given that USG values > 1.020g.ml-^{1} and COR values > 5 indicated dehydration[11]. The core temperature was measured by a flexible rectal thermometer (Physitemp Instruments, USA) with disposable cover inserted approximately 10 cm beyond the anal sphincter. HR was measured using a frequency counter (POLAR RS 100, Polar Electro OY - Finland). The rate of perceived exertion (RPE) was also assessed[19].

PSI calculation

PSI was calculated by monitoring variables Tre and HR throughout the exercise protocol in both situations. Values related to the above variables were computed at intervals of 5 minutes and then applied into the following equation:

$$PSI = 5\,[Tret - Tre0] \times [39.5 - Tre0]^{-1} + 5\,[HRt - HR0] \times [180 - HR0]^{-1}$$

Where: Tre0 and HR0 correspond to Tre and HR values measured before the beginning of the exercise protocol, and Tret and HRt corresponded to simultaneous measurements of these variables at any time interval.

Statistical Analysis

Two-Way ANOVA (condition x time) was used to compare the absolute PSI values. In case of interaction, the difference between condition with rehydration and without rehydration at every moment of analysis was verified through a One-Way ANOVA. For comparison of RPE between conditions, the paired t test was used. For variables BM, UC, USG, HR and Tre, descriptive statistics was used (mean ± standard deviation). The SPSS software (version 17.0, Chicago, USA) was used for analysis. The significance level was p = 0.05.

RESULTS

Table 1 shows that before exercise, and in both conditions, the subjects showed adequate hydration status. In the condition without fluid replacement, subjects showed dehydration (2.002 ± 0.103%) while in condition with rehydration, water deficit was negligible (- 0.201 ± 0.389%).

Subjects began the two exercise sessions with RPE value equal to six. At the end of the exercise, the average RPE was significantly higher (p <0.001) in condition without rehydration (16.5 ± 2.0) compared to condition with rehydration (11.1 ± 3.0).

Table 1. Hydration status and physiological variables in conditions without rehydration and with rehydration in pre and post-exercise moments (mean ± standard deviation).

	Without rehydration		With rehydration	
	Pre	Post	Pre	Post
USG	1.007 ± 0.006	1.024 ± 0.005	1.012 ± 0.011	1.013 ± 0.010
UC	1.7 ± 1.25	6.7 ± 0.94	2.1 ± 1.72	3.1 ± 1.44
HR (bpm)	105 ± 20.02	168.1 ± 9.76	96.9 ± 18.41	149.1 ± 17.01
Tre (ºC)	37.1 ± 0.26	38.7 ± 0.32	37.0 ± 0.29	38.1 ± 0.26
BM (Kg)	77.31 ± 7.35	75.79 ± 7.18	77.53 ± 7.68	77.35 ± 7.45

USG = urine specific gravity; UC = urine color; HR = heart rate; Tre = rectal temperature; BM = body mass.

PSI showed significant condition x time interaction ($p = 0.01$). The development of the chosen statistical procedure showed that subjects showed significantly higher PSI responses ($p < 0.05$) from 45 minutes until the end of the exercise protocol in the heat in condition without rehydration (Figure 1).

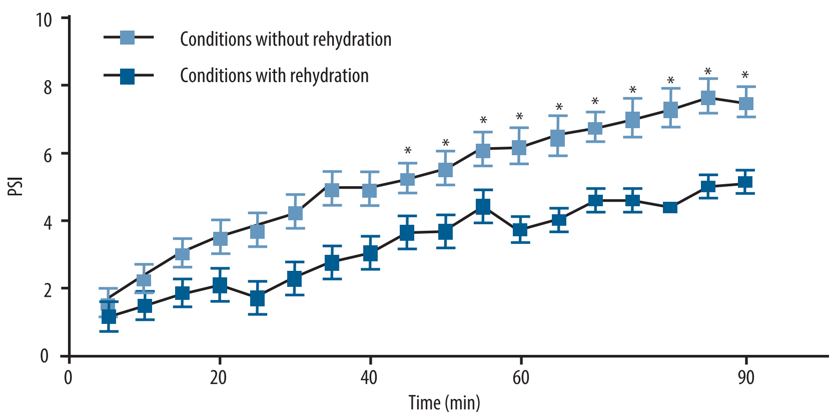

Figure 1. Responses (mean ± standard error) of the Physiological Stress Index (PSI) in both conditions over time. * Significant difference between conditions ($p < 0.05$).

DISCUSSION

The main finding of this study was that the maintenance of the hydration status minimized the physiological overload assessed by PSI during prolonged exercise in the heat from 45 minutes. Among the various hydration strategies available in literature[7,20,21], fluid replacement at regular intervals and in accordance with the mass loss is recommended by the American College of Sports Medicine[4]. However, when dehydration condition is already established, the intake of 150% the volume of fluid lost can be more effective[22].

Regarding the physiological overload, Tre and HR responses throughout the exercise protocol, reflect, respectively, heat storage and the response to the cardio circulatory demand during exercise and environmental conditions[23]. Thus, changes in the exercise intensity and volume, heat acclimatization, fitness level, weather conditions and pathological conditions can interfere with the cardiovascular overload as they modify heat dissipation and heart rate. Although monitoring core temperature and HR is widely used in studies involving exercise in the heat and dehydration[24], few studies have combined these variables to calculate and discuss the PSI behavior to assess the physiological overload[7,13-16]. However, the results of these previous studies corroborate our findings to suggest PSI as a sensitive tool to denote differences between hydration statuses and determine the effectiveness of rehydration strategies.

Richardson et al.[7] evaluated the PSI of subjects exposed to intermittent exercise submitted to four different hydration status (euhydrated and dehydrated at 1, 2 and 3%). PSI was significantly higher in conditions 2 and 3% when compared to euhydration condition and 1%; and in the two latter conditions, previous hydration strategy consisted of 150% and 50% the volume of water lost, respectively. Importantly, the subjects were submitted to a previous dehydration protocol and, only after 15h, they performed the exercise at the predetermined conditions, resulting in dehydration since the beginning of the exercise (except for euhydration condition). This fact justifies the higher PSI values in conditions of greater dehydration, since the decrease in plasma volume as a result of dehydration increases cardiovascular overload [2].

With a similar experimental design, Maxwell et al.[13] submitted subjects to a dehydration protocol seeking to reduce BM by 2% and to intermittent sprint tests on the subsequent day. Three hydration strategies were compared (without replacement, 100 and 150% the lost volume), leading subjects to perform intermittent exercise under a dehydration condition of 4% and 2% and euhydration (0%), respectively. Condition 4% showed higher PSI compared to conditions 2% and 0%. Unlike the present study, there was no difference in PSI between conditions 2% and 0%, showing no benefits in replacing more than the amount lost in situations of mild dehydration. However, the study by Richardson et al.[7], Maxwell et al.[13] also adopted a methodology of prior dehydration in which subjects did not ingest fluid during the test, making it difficult to establish comparisons with the present study.

With similar experimental design, Moran et al.[14], Grego et al.[15] and Bergeron et al.[16] evaluated the influence of fluid replacement during exercise. However, Grego et al.[15] did not use an individualized fluid replacement strategy and Bergeron et al.[16], as reported by the authors, did not control the pre-exercise hydration state, which may have interfered in the interpretation of results. The study of Moran et al.[14], in turn, even not making used of other instruments to measure hydration status, was more methodologically rigorous. Eight trained young individuals cycled for 120 minutes on a cycle ergometer at four conditions, receiving in each of them replacement of 80, 50 and 20% the lost BM according to condition without rehydration, resulting in dehydration of 1, 2, 3 and 4%, respectively. PSI showed behavior proportional to dehydration, so that the more the subjects were dehydrated, the higher the PSI values. In the time interval of 90 minutes, PSI in conditions 1 and 2% were, respectively, 6 and 7, which corroborates the findings of the condition without rehydration of the present study.

Although dehydration conditions of 2% are common in athletes [25], even small changes in the hydration status can compromise performance in aerobic activities due to increased temperature, cardiovascular overload and use of glycogen, as well as functional changes in metabolism and in the central nervous system[26]. Together, these physiological responses potentiate the increase in RPE[27], leading to a condition of early fatigue. As demonstrated in this study, adequate rehydration is able to hold the growth of RPE during exercise, a factor of high practical applicability to athletes of different competitive levels and non-athletes who practice physical exercises. In this context, Presland et al.[28] observed an inverse correlation between time to exhaustion and RPE at the specific time of 15 minutes, so that subjects who took longer to reach exhaustion showed the lowest RPE values during exercise. Pires et al.[29], in a similar line of investigation, submitted subjects to tests at three different intensities until exhaustion. Regardless of intensity in which the exercise was conducted, RPE showed a strong correlation with the exhaustion time, demonstrating that the increase in RPE is a limiting factor of performance.

Although some studies[21] have reported that fluid replacement with high sodium concentration can be more effective, our findings corroborate previous evidence[30] that suggests simple water intake to maintain hydration status. Although the replacement strategy at regular intervals and corresponding to the loss of BM cannot be applied in many sports, similar rehydration methods may provide the individual with lower physiological overload, lower perceived exertion, increased security in the performance of the exercise and possible increase in total exercise time.

According to the reviewed literature, our study seems to be the first to evaluate PSI using fluid replacement proportional to 100% BM lost during exercise. In this sense, the main finding is that the fluid replacement strategy used was able to significantly attenuate the PSI from 45 minutes compared to condition without fluid replacement. Given that many sports (such as soccer, basketball, handball, rugby and endurance running) have duration greater than 45 minutes, adequate fluid replacement strategy is critical to decrease physiological overload and ensure athletic performance.

CONCLUSION

The results indicate that fluid replacement at regular intervals and in amounts proportional to the loss of body mass is able to maintain hydration status, mitigate the significant increase in PSI from 45 minutes of exercise in the heat and hold the increase in RPE values.

REFERENCES

1. Hayes LD, Morse CI. The effect of progressive dehydration on strength and power: is there a dose-response? Eur J App Physiol 2009;108(4):701-707.
2. Casa DJ. Exercise in the heat I. Fundamentals of thermal physiology, performance implications, and dehydration. J Athl Train 1999;34(3):246-252.
3. González-Alonso J, Crandall CG, Johnson JM. The cardiovascular challenge of exercising in the heat. J Physiol 2008;586(1) 45–53.
4. American College of Sports Medicine (ACSM). Exercise and fluid replacement. Med Sci Sports Exerc 2007;39(2):377-90.

5. Armstrong LE, Costill DL, Fink WJ. Influence of diuretic-induced dehydration on competitive running performance. Med Sci Sports Exerc 1985;17(4):456–461.
6. Sociedade Brasileira de Medicina do Esporte (SBME). Modificações dietéticas, reposição hídrica, suplementos alimentares e drogas: comprovação de ação ergogênica e potenciais riscos para a saúde. Rev Bras Med Esp 2009;15(3):3-12.
7. Richardson A, Watt P, Maxwell N. The effect of hypohydration severity on the physiological, psychological, and renal hormonal responses to hypoxic exercise. Eur J App Physiol 2009;106(1):123-130.
8. Noakes TD. Hydration in the marathon: using thirst to gauge safe fluid replacement. Sports Med 2007;37(4-5):463-466.
9. Machado-Moreira CA, Vimieiro-Gomes AC, Silami-Garcia E, Rodrigues LOC. Hidratação durante o exercício: a sede é suficiente? Rev Bras Med Esp 2006;12(6):361-364.
10. Mack GW, Weseman CA, Langhans GW, Scherzer H, Gillen CM, Nadel ER. Body fluid balance in dehydrated healthy older men: thirst and renal osmoregulation. J App Physiol 1994;76(4):1615-1623.
11. Casa DJ, Armstrong LE, Hilman SK, Montain SJ, Reiff RV, Rich BSE. National Athletic Trainer's Association Position Statement: fluid replacement for athletes. J Athl Train 2000;35(2):212-224.
12. Moran DS, Shitzer A, Pandolf KB. A physiological strain index to evaluate heat stress. Am J Physiol 1998(a);275(44):129-134.
13. Maxwell NS, Mackenzie RWA, Bishop D. Influence of hypohydration on intermittent sprint performance in the heat. Int J Sports Physiol Perform 2009;4(1):54-67.
14. Moran DS, Montain SJ, Pandolf KB. Evaluation of different levels of hydration using a new physiological strain index. Am J Physiol 1998(b);275(44):854-860.
15. Grego F, Vallier JM, Collardeau M, Rousseu C, Cremieux C, Brisswalter J. Influence of exercise duration and hydration status on cognitive function during prolonged cycling exercise. Int J Sports Med 2005;26(1):27-33.
16. Bergeron MF, Laird MD, Marinik EL, Brenner JS, Waller JL. Repeated-bout exercise in the heat in young athletes: physiological strain and perceptual responses. J App Physiol 2009;106(2):476-485.
17. Evetovich TK, Boyd JC, Drake SM. Effect of moderate dehydration on torque, electromyography, and mechanomyography. Muscle Nerve 2002;26 (2):225-231.
18. Armstrong LE, Maresh CM, Castellani JW, Bergeron MF, Kenefick RW, Lagasse KE, et al. Urinary indices of hydration status. Int J Sports Nutr 1994;4(3):265-79.
19. Borg G. Perceived exertion as an indicator of somatic stress. Scand J Rehabil Med 1970;2(2):92-98.
20. Shirreffs SM, Taylor AJ, Leiper JB, Maughan RJ. Post-exercise rehydration in man: effects of volume consumed and sodium content of ingested fluids. Med Sci Sports Exerc 1996;28(10):1260-1271.
21. Nielsen B, Sjogaard G, Uqelviq J, Knudsen B, Dohlmann B. Fluid balance in exercise dehydration and rehydration with different glucose-electrolyte drinks. Eur J App Physiol Occup Physiol 1986;55(3):318-25.
22. Shirreffs SM, Maughan RJ. Volume repletion after exercise-induced volume depletion in humans: replacement of water and sodium losses. Am J Physiol 1998;274(5):868–875.
23. Moran D, Epstein Y, Laor A, Vitalis A, Shapiro Y. Predicting heart rate response to various metabolic rates, environments, and clothing. J App Physiol 1995;78(1):318–322.
24. Armstrong LE, Maresh CM, Gabaree CV, Hoffman JR, Kavouras SA, Kenefick RW, et al. Thermal and circulatory responses during exercise: effects of hypohydration, dehydration, and water intake. J App Physiol 1997;82(6):2028-2035.
25. Shirreffs SM, Ragon-Vargas LF, Chamorro M, Maughan RJ, Serratosa L, Zachwieja JJ. The sweating response of elite professional soccer players to training in the heat. Int J Sports Med 2005;26(2):90–95.
26. Nybo L, Nielsen B. Hyperthermia and central fatigue during prolonged exercise in humans. J App Physiol 2001;91(3):1055–1060.

27. Sawka MN, Coyle EF. Influence of body water and blood volume on thermoregulation and exercise performance in the heat. Exerc Sport Sci Rev 1999;27(1):167-218.
28. Presland JD, Downson MN, Cairns SP. Changes of motor drive, cortical arousal and perceived exertion following prolonged cycling to exhaustion. Eur J App Physiol 2005;95(1):42-51.
29. Pires FP, Noakes TP, Lima-Silva AE, Bertuzzi R, Ugrinowitsch C, Lira FS, et al. Cardiopulmonary, blood metabolite and rating of perceived exertion responses to constant exercises performed at different intensities until exhaustion. Brit J Sports Med 2011;45(14):1119-1125.
30. Cohen D. The truth about sports drinks. BMJ 2012;345:e4737.

Corresponding author

Marcelo Gava Pompermayer
Rua Felizardo, 750/sala 109.
Jardim Botânico, CEP: 90690-200
Porto Alegre – RS, Brasil.
Email: marcelog.p@hotmail.com