Influence of Hydration Status and Fluid Replacement on Cardiovascular Response During Uncompensable Heat Stress

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INTRODUCTION

The purpose of the present study was to investigate the influence of manipulating hydration status both before and during heat exposure on cardiovascular responses in an environment of uncompensable heat stress. Subjects exercised in a hot environment while wearing the Canadian Forces nuclear, biological, and chemical (NBC) protective clothing ensemble at either a light or a heavy intensity and in either a euhydrated or a hypohydrated (~2.5%) state. To investigate the effects of rehydration during exercise in an uncompensable heat stress environment, subjects exercising in the euhydrated state either underwent a rehydration program or refrained from drinking. It was hypothesized that hypohydration will significantly impair the cardiovascular response to exercise in an uncompensable heat stress environment by decreasing the blood volume and cardiac output. Fluid ingestion during exercise was expected to attenuate decreases in cardiac output only during the later stages of light exercise, when tolerance time is long enough for the ingested fluid to empty from the digestive system and have an effect on the body fluid compartments.

METHODS

Eight healthy and active males participated. Descriptive characteristics were: age 29.3 ± 6.4 y, $\dot{V}O_2$ max 56.5 ± 4.4 $ml \cdot kg^{-1} \cdot min^{-1}$, and body fatness 12.4 ± 2.8 %. On seven separate occasions, each subject performed a heat stress test (HST) exercise session on a motorized treadmill in a hot (40 °C, 30% relative humidity) environment while wearing the Canadian Forces NBC protective clothing ensemble. The first session was used as a familiarization trial and the results were discarded. A minimum of 72 h separated experimental trials.

Responses to the HST's were tested while manipulating the subjects' level of hydration. On the afternoons before the HST's, subjects exercised in the heat until they dehydrated by 2.5-3% of body weight. Following this protocol, subjects were either rehydrated to baseline body weight overnight (EU) or maintained the 2.5% decrease in body weight overnight (H). A minimum of 15 h elapsed between the end of the dehydration protocol and the HST. During EU sessions, the effects of rehydration during exercise in the NBC clothing were tested by the presence (F, 200 and 250 mL each 15 min for light and heavy exercise, respectively) or absence (NF) of water. Subjects undergoing H trials were tested only in the F condition. Subjects were tested at EU/F, EU/NF, and H/F conditions while exercising at light ($3.5\,km \cdot h^{-1}$, 0% grade, $\dot{V}O_2 = 0.9\ L \cdot min^{-1}$) and heavy ($4.8\,km \cdot h^{-1}$, 4% grade, $\dot{V}O_2 = 1.4\ L \cdot min^{-1}$) intensities. The order in which the different conditions were presented were randomized. Stroke volume and cardiac output were obtained by impedance cardiography every 15 min during the HST using the methods outlined by Kubicek *et al.* (1). 6-8 s samples were obtained during an end-expiratory breath hold with the subjects straddling the treadmill in order to minimize motion and respiratory artifacts.

RESULTS

Subjects undergoing H/F trials maintained an average overnight weight loss of 2.2% body weight prior to both light and heavy exercise. During light exercise, heart rate was significantly higher for H/F ($118.8 \pm 14.2\ b \cdot min^{-1}$) compared with EU/F trials ($107.8 \pm 10.6\ b \cdot min^{-1}$) after 30 minutes and remained elevated for the remainder of the exercise. Rehydration during exercise did not elicit a significantly lower heart rate in the EU trials. During heavy exercise, higher heart rates were found after 10 minutes of walking for H/F ($122.0 \pm 10.6\ b \cdot min^{-1}$) compared with either EU/F ($116.9 \pm 11.6\ b \cdot min^{-1}$) or EU/NF ($118.1 \pm 11.2\ b \cdot min^{-1}$) and remained higher for the duration of the exercise. After 30 minutes, heart rates for EU/NF ($142.8 \pm 12.8\ b \cdot min^{-1}$) were significantly higher compared to EU/F ($137.0 \pm 12.2\ b \cdot min^{-1}$). Stroke volume decreased over the course of exercise for all hydration conditions and exercise intensities. During light exercise, stroke volumes were lower for H/F (average of 55.0 mL) compared to both EU/F and EU/NF (averages of 64.2 and 63.0 mL, respectively). At heavy work rates, EU/F stroke volumes (average of 72.7 mL) were higher than EU/NF and H/F (averages of 64.9 and 60.6 mL, respectively). The decrease in stroke volume during H/F was compensated by the increase in heart rate, such that cardiac output was not different among the trials for either light or heavy exercise (Fig. 1).

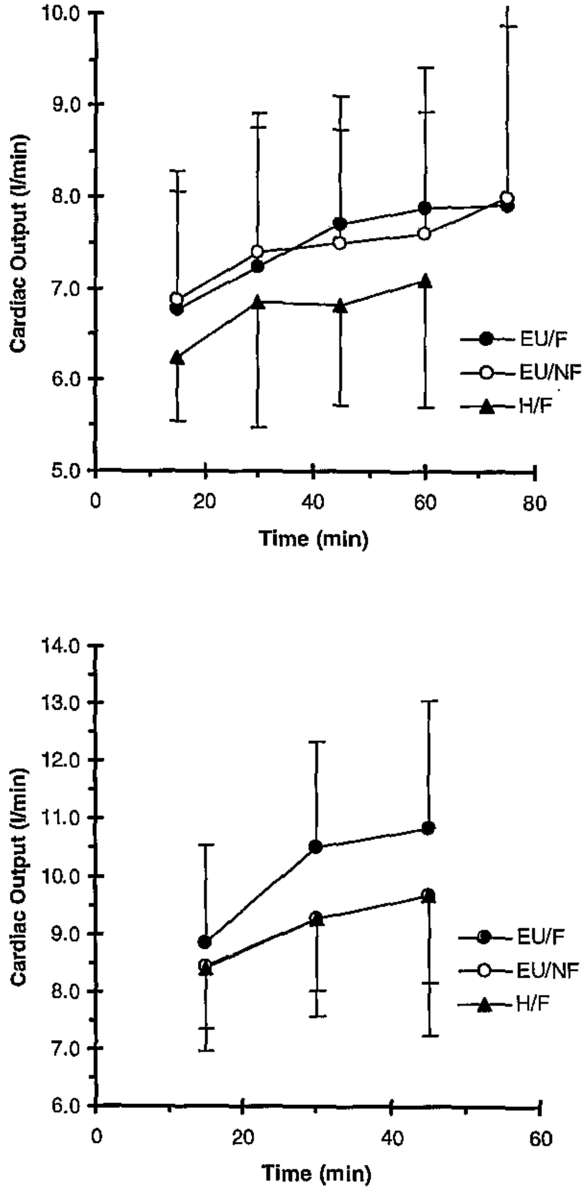

Figure 1: Changes in cardiac output during light (top) and heavy (bottom) exercise.

DISCUSSION

Hypohydration placed an additional strain on the cardiovascular system during exercise in the NBC clothing. During both light and heavy exercise, HR was significantly higher while hypohydrated than while euhydrated and given fluid replacement over the course of the HST. Heart rate was increased during hypohydration in order to compensate for the decreased stroke volume which reflected, presumably, a decreased blood volume and end-diastolic ventricular volume (2). During exercise in the heat, Sawka *et al.* (3) has reported an increase in heart rate of 4 $\text{beats} \cdot \text{min}^{-1}$ for each percentage increase in hypohydration. In the present experiment, stroke volume was significantly decreased by hypohydration during both light and heavy exercise. However, the elevated HR response was successful in maintaining a similar cardiac output during both EU/F and H/F conditions. The decreased stroke volume during hypohydration may lead to peripheral vasoconstriction and a decreased sweating response, due to competition between metabolic and thermoregulatory demands for blood flow and the need to maintain central blood volume (4). During exercise without adequate fluid replacement, progressive dehydration decreased blood volume and cardiac output. This was accompanied by increased systemic and cutaneous vascular resistance despite significant hyperthermia, demonstrating that peripheral blood flow participated in systemic vasoconstriction during exercise and heat stress (2). In summary, hypohydration resulted in a decrease in stroke volume while exercising in an environment of uncompensable heat stress. Heart rate increased with hypohydration, and the increase was sufficient to maintain a similar cardiac output during exercise.

REFERENCES

1. Kubicek, W.G., From, A.H.L., Patterson, R.P., Witsoe, D.A., Castaneda, A., Lillehei, R.C., and Ersek, R. 1970, Impedance cardiography as a noninvasive means to monitor cardiac function. *J. Assn. Advan. Med. Instrum.* **4**, 79-84.
2. Gonzalez-Alonzo, J., Mora-Rodriguez, R., Below, P.R., and Coyle, E.F. 1995. Dehydration reduces cardiac output and increases systematic and cutaneous vascular resistance during exercise *J. Appl. Physiol.* **79**, 1487-1496.
3. Sawka, M.N., Young, A.J., Francesconi, R.P., Muza, S.R., and Pandolf, K.B. 1985, Thermoregulatory and blood responses during exercise at graded hypohydration levels. *J. Appl. Physiol.* **59**, 1394-1401.
4. Tankersley, C.G., Zappe, D.H., Meister, T.G., and Kenney, W.L. 1992, Hypohydration affects forearm vascular conductance independent of heart rate during exercise. *J. Appl. Physiol.* **73**, 1232-1237.