JEPonline
Journal of Exercise Physiologyonline

Official Journal of The American Society of Exercise Physiologists (ASEP)

ISSN 1097-9751
An International Electronic Journal
Volume 7 Number 1 February 2004

Fitness and Training

EFFECT OF HYDRATION STATE ON HEART RATE-BASED ESTIMATES OF VO_2MAX

TERESA L. SOUTHARD AND JOSEPH W. PUGH

United States Air Force Academy, Colorado

ABSTRACT

EFFECT OF HYDRATION STATE ON HEART RATE-BASED ESTIMATES OF VO_2MAX. Teresa L. **Southard And Joseph W. Pugh**. **JEP**online. 2004;7(1):19-25. Submaximal tests of aerobic fitness typically extrapolate oxygen consumption from heart rate. Because heart rate is influenced by hydration level, this study was conducted to investigate the effects of hydration status on the VO_2max scores predicted by a submaximal cycle ergometry assessment. Fifteen male cadets at the U.S. Air Force Academy took the heart rate-based USAF submaximal cycle ergometry fitness test twice over a 3-day period, once following a 12-hour fluid-restriction period (the dehydrated trial) and once following a hydration protocol in which the subjects drank a volume of water equivalent to 2% body weight 10 hours before the test and an additional volume equivalent to 1% body weight at least 30 minutes before the test (the hydrated trial). Prior to testing, subjects were weighed and a urine sample was collected. The urine specific gravity (USG) was measured using a refractometer. Our results indicated that, during the dehydrated trial, subjects' USG was significantly higher and their weight and VO_2max scores were significantly lower than during the hydrated trial. The change in the VO_2max score was significantly correlated to the change in percent body weight between the two trials. These data suggest that hydration status affects heart rate-based, submaximal estimates of VO_2max.

Key Words: Submaximal Cycle Ergometry, Dehydration, USAF Fitness Test

INTRODUCTION

The most accurate test of aerobic fitness is the measurement of peak or maximal rate (VO_2max) of oxygen consumption during exercise at a steadily increasing workload, usually on a treadmill or cycle ergometer. The VO_2max, measured in either mL/min or mL/kg/min, quantifies an individual's maximal ability to utilize oxygen in the aerobic production of ATP. Because a direct measurement of VO_2max requires trained personnel, expensive equipment, and considerable time, indirect methods of estimating VO_2max are often used to assess aerobic fitness. Many of these tests measure heart rate during exercise and rely on a linear relationship between heart rate and oxygen consumption to estimate VO_2max.

In 1954, a nomogram was developed to predict VO_2max based on heart rate during submaximal exercise (2). The U.S. Air Force currently uses a modified version of the Astrand-Rhyming test, the Submaximal Cycle Ergometry (SCE) test, to estimate VO_2max. The validity of the SCE test has been evaluated in several studies. A comparison of SCE VO_2max scores to those obtained on a maximal treadmill test for 22 fit and unfit males reported a correlation coefficient of r=0.94 and a standard error of the estimate of 4.25 mL/kg/min (7). However, the SCE test was found to under-predict true VO_2max by 20%. A cross validation study tested 67 males and 67 females with both the maximal treadmill test and the SCE (13). The results demonstrated the high repeatability of the SCE test and established reliability correlation coefficients of r=0.85 for males and r=0.84 for females. The SCE underestimated the male scores by an average of 2.2 mL/kg/min and overestimated the female scores by the same amount. The USAF subsequently adjusted the algorithms used to calculate VO_2max and the new equations were implemented in 1998.

One disadvantage of a heart rate-based estimate of VO_2max is that factors other than changes in the cellular consumption of oxygen influence changes in heart rate. One such factor is hydration status. Dehydration causes an increase in heart rate, both at rest and during exercise. Resting heart rate increased by 5% in subjects who were dehydrated by 4% of their body weight (5). During exercise at 65% of VO_2max, dehydration by 0.9% caused an elevation of heart rate by 10 ? 2 beats/min while 2.8% dehydration caused an elevation by 18?2 beats/min (8). Blood volume remained constant in this study, suggesting that the tachycardia is not the result of decreased blood pressure and a baroreceptor-mediated reflex. In another study, heart rate changes during dehydration were shown to be significantly correlated with circulating norepinephrine levels, suggesting that dehydration-induced increase in heart rate may be the result of increased norepinephrine action on the beta-1 adrenergic receptors of the heart (6). A study of over-hydration by 0.7% reported no change in heart rate (10).

The effects of dehydration on VO_2max depend on the extent of the dehydration. Dehydration of 2.6% body weight achieved by previous exercise had no effect on VO_2max in a group of seven moderately trained women (11). Similarly, diuretic-induced dehydration of 1.6-2.1% body weight, which resulted in a significant decrease in 5,000 and 10,000-meter race performance, did not change VO_2max (1). However, dehydration by 4% body weight did significantly decrease VO_2max in six endurance-trained cyclists (12).

The effects of hydration state on heart rate-based estimates of VO_2max have not previously been tested. The 12-hour fluid restriction used in this study was not expected to cause severe dehydration or to impact VO_2max. However, we hypothesized that the effects of mild dehydration on heart rate during exercise would significantly decrease a heart rate-based estimate of VO_2max.

METHODS

Fifteen male cadets at the U.S. Air Force Academy, all between the ages of 18 and 22, volunteered to participate in this study. A power analysis (a<0.05, ß<0.50) revealed that 10 subjects would be sufficient to detect a reduction of approximately 10% in VO_{2max} expected for subjects dehydrated by 0.9% (8). We chose to use 15 subjects in case some tests were invalid or some subjects were excluded during the study due to unforeseen injury or illness. The subjects were all healthy non-smokers who were not taking any medication. The experimental protocol was approved by the U.S. Air Force Academy's Institutional Review Board, and each subject signed a written informed consent document prior to participation in the study. Only males were used in this study because the difference in total body water between males and females represents a potential confounding variable in a study involving the physiological effects of hydration.

The subjects each took the SCE test twice during a 3-day period; once following a 12-hour fluid restriction period (the dehydrated or DE trial) and once following a prescribed hydration protocol (the hydrated or HY trial). The HY trial required the subjects to consume a volume of water equivalent to 2% body weight 10 hours before the SCE test and an additional volume of water equivalent to 1% body weight at least 30 minutes prior to

the test. These quantities were chosen to correct for any pre-existing dehydration (up to 2% body weight) and to replace all fluid lost during the night. By using a constant amount of fluid, regardless of baseline hydration level, we hoped to observe a wide range of differences in hydration state across our subjects and possibly be able to correlate the magnitude of the difference to the degree of change in the SCE score. Ideally, fluids would be consumed approximately 2 hours before exercise to allow for complete absorption and excretion of excess water; however, this was impossible due to time constraints of the subjects' daily schedules. Tests were always administered at 7:00 am with the 12-hour fluid control period starting at 7:00 pm the previous evening. The order of the two trials was randomized.

On the morning of the test, the subjects' height and weight were measured, and each subject provided a mid-stream, clean-catch urine sample. The urine specific gravity (USG) was measured using a refractometer. During the entire SCE test, the subject pedaled a Monarch cycle ergometer at 50 rpms. The test consisted of a 2-minute warm-up period followed by 0-8 minutes of workload adjustment and 6 minutes at a steady workload. Heart rate data were collected every minute throughout the test. During the workload-adjustment period, the resistance on the cycle ergometer was adjusted according to a pre-defined protocol every 2 minutes as needed until the heart rate was greater than 125 beats/min but not more than 75% of the predicted maximum (220 - age).

Once the heart rate was within the target zone, the 6-minute steady-state period began. Heart rate data from 2 of the last 3 minutes of this period were used in the calculation of the VO_2max score. The two heart rates that were used in the calculation were required to be within 5 beats/min, otherwise, the test was deemed to be invalid. The VO_2max score was calculated from three factors: an oxygen consumption factor, a heart rate factor, and an age factor. The equations used in the calculation of the VO_2max score are shown in Appendix A. All these equations, as well as the testing protocol, are imbedded in the Fitsoft® software program. The test administrator enters height, weight, and age data prior to the start of the test and then follows instructions regarding workload adjustments. The program calculates VO_2max in mL/kg/min. Because body weight was expected to change between the two trials in this study, VO_2max scores were converted into mL/min so that changes in oxygen consumption could be evaluated independently of weight change.

An Excel spreadsheet and the SPSS statistical software package were used for data analysis. Differences in USG, weight, and VO_2max between the HY and DE trials were analyzed using student's paired t-tests, and relationships between the magnitude of change in each of the variables were analyzed using Pearson Product Moment correlation. Significance was set at $p=0.05$. Data are presented as mean?standard deviation.

Ideally, actual VO_2max would have also been measured for each trial. However, because previous studies have established that mild dehydration (<4% body weight) does not significantly alter VO_2max (1, 11), and because of time constraints of the subject population, these measurements were not done.

RESULTS

All 15 subjects completed both SCE trials. VO_2max, USG, and weight data for both trials are shown in Table 1. Urine specific gravity was significantly higher and weight was significantly lower ($p<0.01$ for both) in the DE trial than the HY trial. The 12-hour water restriction period was associated with a decrease in weight and an increase in USG in all 15 subjects. The change in weight from the HY to the DE trial averaged 1.2?0.05%, while the USG decreased by an average of 0.017?0.008%. The National Athletic Trainers' Association (4) define "well hydrated" as having a USG < 1.010, "minimally dehydrated" as having a USG between 1.010 and 1.020, "significantly dehydrated" as having a USG between 1.020 and 1.030, and "seriously dehydrated" as having a USG>1.030. Based on these criteria, 1 subject was well hydrated, 8 were minimally dehydrated, and 6 were significantly dehydrated in the HY trial while 3 subjects were significantly dehydrated and 12 were seriously dehydrated in the DE trial.

Table 1. Data Summary (mean? SD; N=15)

	*USG**	*Weight* (kg)*	*VO_2max* (mL/min)*
Dehydrated Trial	1.037?0.008	78.5?13.6	3398.3?795.5
Hydrated Trial	1.020?0.006	79.5?13.8	3763 .8?840.3

* Difference is statistically significant (P < 0.01)

The VO_2max scores for all 15 subjects are shown in Figure 1. Compared to the HY trials, VO_2max scores were significantly lower ($p<0.01$) in the DE trials. All 15 subjects scored lower in the DE trial, with the difference ranging from 24 to 705 mL/min (mean difference=365?173 mL/min). VO_2max scores from the DE trial were also significantly lower than the HY scores when the data were expressed in mL/kg/min ($p<0.01$), despite the decrease in body weight associated with the water restriction.

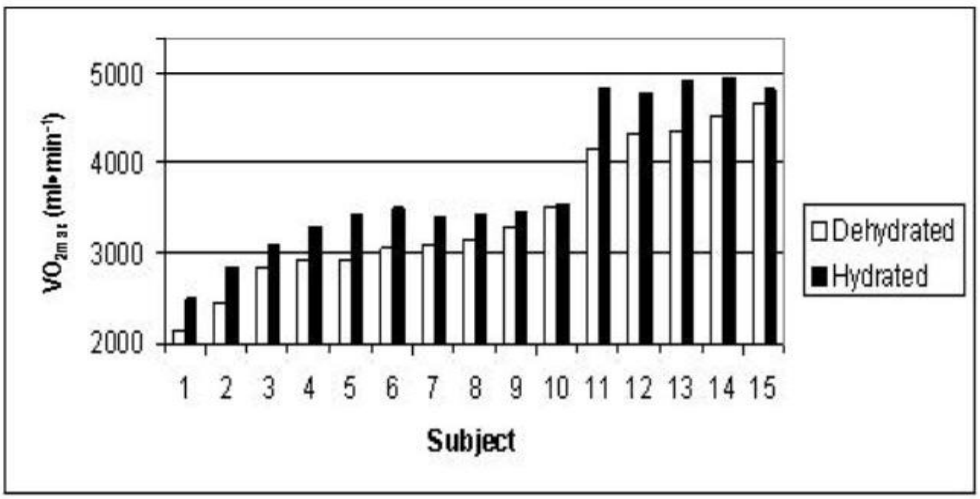

Figure 1. Submaximal Cycle Ergometer test estimates of VO_2max in 15 subjects during dehydrated and hydrated trials. Scores from the hydrated trials were significantly higher than those from the dehydrated trials.

Correlation coefficients were calculated to establish the relationships between the changes in weight, USG and VO_2max. The r-values are presented in Table 2. The only significant correlation was between percent change in body weight and VO_2max score ($r=0.54$; $p<0.05$). Figure 2 shows the scatter plot and regression line for these two variables.

Table 2. Correlation Coefficients for ? USG, %? Weight, and ? VO_2max

	? USG	*%? Weight*	*? VO_2max*
? USG	__	0.11	0.28
%? Weight	0.11	__	0.52*
? VO_2max (mL/min)	0.28	0.52*	__

* = Statistically significant ($p<0.05$)

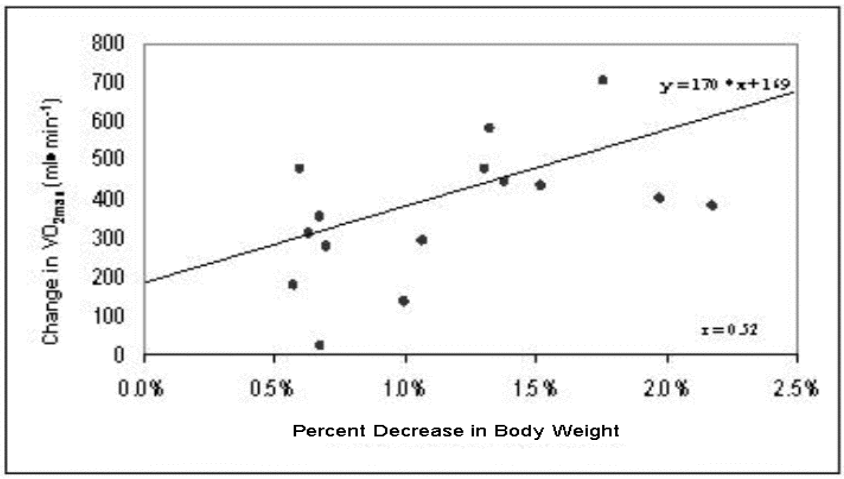

Figure 2. Scatter plot demonstrating the relationship between the percent change in body weight and change in estimated maximal oxygen consumption between hydrated and dehydrated trials (N=15).

DISCUSSION

Dehydration is known to increase heart rate, both at rest and during exercise. However, most studies have not found a significant effect of mild dehydration (<4% body weight) on VO_2max (1, 11). This study revealed that a 12-hour period of fluid restriction, resulting in 1.2 ? 0.05 % dehydration when compared to a specific hydration protocol, was associated with a significant decrease in a heart rate-based estimates of VO_2max. The results were similar regardless of whether VO_2max was expressed in mL/min or mL/kg/min. The change in VO_2max score (mL/min) was significantly correlated with percent change in body weight.

Although the percent change in body weight was correlated to the change in VO_2max, no correlation was found between change in VO_2max score and the other measure of hydration, USG. This lack of correlation could be due to a methodological problem. Some subjects were unable to produce a urine sample when they arrived at the test location. For these subjects, the sample was collected after SCE test. Urinary indices have been shown to be poor indicators of hydration status after exercise is completed (9). Also, for some (but not all) subjects, the sample collected was the first morning urine, which is generally the most concentrated urine produced throughout the day. Standardization of the urine sample may result in a better correlation between USG and change in VO_2max.

Previous studies have shown that mild dehydration (0.9-2.8%) caused an elevation in exercising heart rate of, on average, 10-18 beats/min (8). Using the SCE equations, a change in average exercising heart rate from 135 beats/min to 145 beats/min (values that would typically be seen for a 20 year old, male subject) would result in a 10.5% decrease in predicted VO_2max. This value is in line with the 9.6% decrease observed in our subjects. Other studies have concluded that similar levels of dehydration do not significantly alter actual VO_2max (1,11). These results suggest that the decrement in predicted VO_2max reported here is most likely due to a dehydration-induced tachycardia, rather than an actual decrease in oxygen consumption. One possible mechanism for the tachycardia is an increase in norepinephrine release secondary to dehydration, as proposed by Gonzalez-Alonso et al (6). Future studies that include measurement of actual VO_2max and circulating norepinephrine levels would be required to further elucidate the relationship between dehydration and heart rate-based predictions of VO_2max.

CONCLUSIONS

Our findings suggest that hydration status should be considered whenever heart rate data are used in an assessment of aerobic fitness. Decreased fluid consumption, increased sweating, and/or use of diuretics such as alcohol or caffeine prior to a heart rate-based assessment of VO_2max could result in a decreased VO_2max prediction. Surprisingly, even in the hydrated trial of this study, 14 of the 15 subjects were either moderately or significantly dehydrated, suggesting that the HY scores may have been even higher with a more rigorous hydration protocol. Because the increase in heart rate due to dehydration does not reflect an increase in tissue demands for oxygen, we predict that the hydrated trials provide a more accurate estimate of VO_2max. However, further studies will be required to assess the effect of hydration on the correlation between heart rate-based estimates and direct measurements of VO_2max.

ACKNOWLEDGEMENTS

The authors thank Dr. David Hale, Dr. Tom Unangst and Dr. Holly Franz for their thoughtful critiques of this manuscript.

Address for correspondence: Capt Teresa L. Southard, HQ USAFA/DFB, 2355 Faculty Drive, USAFA CO 80840, Phone: (719) 333-6010; Fax: (719) 333-2420; E-mail: teresa.southard@usafa.af.mil

REFERENCES

1. Armstrong, LE, Costill DL, Fink WJ. Influence of diuretic-induced dehydration on competitive running performance. ***Med Sci Sports Exerc*** 1985;17:456-61.
2. Astrand, PO, Rhyming I. A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during submaximal work. ***J Appl Physiol*** 1954;7:218-221.
3. Blair, SN, Ellsworth NM, Haskell WL, Stern MP, Farguhar JW, Wood PD. Comparison of nutrient intake in middle-aged men and women runners and controls. ***Med Sci Sports Exerc*** 1981;12:310-315.
4. Casa, DJ, Armstrong LE, Hillman SK, Montain SJ, Reiff RV, Rich BSE et al. National Athletic Trainers' Association Position Statement: Fluid Replacement for Athletes. ***Journal of Athletic Training*** 2000;35:212-224.
5. Gonzalez-Alonso, J, Mora-Rodriguez R, Below PR, Coyle EF. Dehydration markedly impairs cardiovascular function in hyperthermic endurance athletes during exercise. ***J Appl Physiol*** 1997;82:1229-36.
6. Gonzalez-Alonso, J, Mora-Rodriguez R, Coyle EF. Stroke volume during exercise: interaction of environment and hydration. ***Am J Physiol Heart Circ Physiol*** 2000;278:H321-30.
7. Hartung, GH, Krock LP, Crandall CG, Bisson RU, Myhre LG. Prediction of maximal oxygen uptake from submaximal exercise testing in aerobically fit and nonfit men. ***Aviat Space Environ Med*** 1993;64:735-40.
8. Heaps, CL, Gonzalez-Alonso J, Coyle EF. Hypohydration causes cardiovascular drift without reducing blood volume. ***International Journal of Sports Medicine*** 1994;15:74-9.
9. Kovacs, EM, Senden JM, Brouns F. Urine color, osmolality and specific electrical conductance are not accurate measures of hydration status during postexercise rehydration. ***Journal of Sports Medicine and Physical Fitness*** 1999;39:47-53.
10. Maresh, CM, Bergeron MF, Kenefick RW, Castellani JW, Hoffman JR, Armstrong LE. Effect of overhydration on time-trial swim performance. ***J Strength Cond Res*** 2001;15:514-8.
11. Moquin A, Mazzeo RS, Effect of mild dehydration on the lactate threshold in women. ***Medicine & Science in Sports & Exercise*** 2000;32: 396-402.
12. Nybo, L, Jensen T, Nielsen B, Gonzalez-Alonso J. Effects of marked hyperthermia with and without dehydration on VO(2) kinetics during intense exercise. ***J Appl Physiol*** 2001;90:1057-64.
13. Pollock ML, Garzarella L, DeHoyos D, Brechue W, Beekley M, Werber G et al. The cross-validation of the United States Air Force submaximal cycle ergometer test to estimate aerobic capacity. Brooks Air Force Base, TX: Air Force Materiel Command, Interim Technical Report AL/CR-TR-1994;0046:1-112.

APPENDIX: SCE VO_2max EQUATIONS

Oxygen Consumption Factor (OCF)

OCF = (Workload ? 3054) + (670 ? ((Weight ^ 0.5) ? (Height ^ 0.75) ? 0.00491)

Heart Rate Factor (HRF)

HRF (female) = (210 – 72) / (Average Heart Rate – 72)

HRF (male) = (205 – 61) / (Average Heart Rate – 61)

Age Factor (AF)

AF (female) = 100 / (100 + (1.14 x Age) – 23)

AF (male) = 100 / (100 + (1.37 x Age) – 33.2)

VO_2max (ml/min) = (OCF x HRF x AF)

VO_2max (ml/min/kg) = (OCF x HRF x AF) / weight