

THE SYMPATHO-VAGAL REGULATION OF HEART RHYTHM DURING ACCLIMATION TO HEAT: ANALYZING HEART RATE VARIABILITY BY MEANS OF THE MULTIPOLE METHOD

Y Epstein¹, DS Moran^{1,2}, Y Heled¹, A Hadid¹, R Kobo², M Lewkowicz², Y Shapiro², J Levitan²

¹Heller Institute of Medical Research, Sheba Medical Center, Tel Hashomer and ²The Ariel University Center of Samaria, Ariel, Israel

Contact person: yoram.epstein@sheba.health.gov.il

INTRODUCTION

Acclimation to heat is a process of physiological adaptation that results in a higher tolerance to heat. This is manifested both at the physiological level (lower strain) and at the subjective rating. Overall, the lower physiological strain is associated with increased sweat production, lowered skin and body core temperatures, and reduced heart rate (reviewed in 1). Acclimation is a continuum of processes, and although there is no abrupt ending to the improvement in the physiological responses, most changes are achieved during the first week of exposure; with the heart rate showing the most rapid adaptation (2). Most changes in heart rate occur in 4 to 5 days, with changes in skin and core temperatures and in the sweating response following thereafter (2). The effector organs outputs, which are involved in body temperature regulation, are subjected to autonomic control; however, there is limited knowledge about the progressive changes in the sympatho-vagal balance during the process of acclimation to heat.

Heart rate variability (HRV) is defined as spontaneous fluctuations around the mean heart rate. Spectral analysis of HRV offers a reliable, non-invasive, relatively simple method of examining the autonomic balance (3). Power spectrum analysis of HRV opened new venues for studying changes in the sympatho-vagal balance under various physiological and pathological conditions, but the effect of heat exposure received only limited attention.

The series of R-R intervals, of which HRV consists, is a non-stationary and non-linear complex time series, reflecting the complex mechanisms that regulate the heart rhythm. Therefore, analyzing HRV by the traditional models might be incomplete. The multipole method is a recently developed method to describe time series with highly complex time evolution. It includes the integrative measures of HRV and extends beyond it. This method, which extracts information from the time and the frequency domains identifies and quantifies increased randomness (chaotic behavior) in time series and thus is considered to be advanced compared to the traditional methods for HRV analysis, which are imbedded in only one of the two domains (4,5). Thus, in the present study we investigated adaptation of the sympatho-vagal regulation of heart rhythm, during a 12-day heat acclimation process, analyzing HRV by means of the multipole method.

METHODS

Four young healthy male subjects (22 years old) with no history of heat intolerance participated in a 12-day heat acclimation process after signing an informed consent form. The Ethics

Committee of the Sheba Medical Center approved the study, its nature, and the procedures applied.

In order to neutralize the effect of seasonal acclimatization the study was conducted in the winter time (January). Exposed in a climatic chamber to 40°C and 40% relative humidity and dressed in shorts and tennis shoes the subjects walked on a motor driven treadmill at a pace of 5km/h and 2% inclination. Daily exposure lasted 120 min. Body core temperature (T_{re}) was monitored continuously by a thermistor (YSI 401, Yellow Springs Instruments, USA) that was inserted ~10 cm beyond the anal sphincter. From an ECG recording (Lead II) heart beats were accumulated and the respective heart rate (HR) was monitored. Rectal temperature and ECG recordings were logged by the ENVITEC System. Fluid balance was assessed from differences in nude body weight (± 10 g) corrected for fluid intake and urination.

On the first and the last day of acclimation, the changes in the autonomic nervous system outflow were investigated by analyzing the Poincaré plot (a scatter plot of the current R-R interval plotted against the preceding R-R interval). The multipole method, which utilizes a mathematical exact calculation, as recently described by Lewkowicz et al, was applied (4). Two sensitive multipoles, which describe the changes in the autonomic nervous system, were analyzed; the octupole moment T_{yyy} that expresses the skewness on the y-axis and the d_y/d_x ratio, which describes the relative density of the data points on the x and y axes.

RESULTS

Summarized in fig.1 are the respective changes in T_{re} , HR and sweat rate on the 1st and 12th day of acclimation after 120 min of exercise-heat stress. These observed changes correspond to the expected response attained by acclimation to heat.

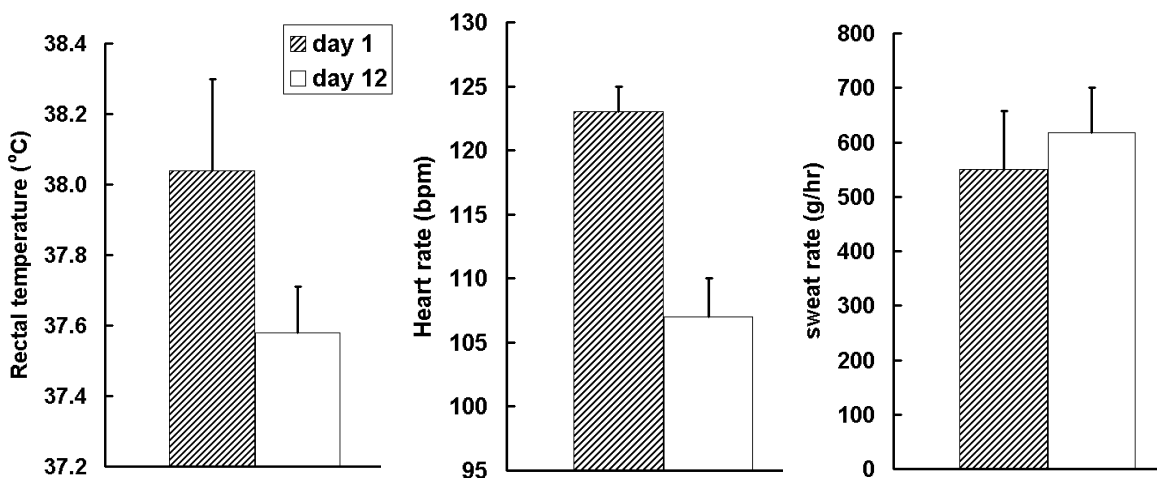


Fig. 1: Rectal temperature, heart rate (at the end of 120 min. exposure to heat), and sweat rate measured on the 1st and 12th day of the process of acclimation

The changes in the Poincaré plots over the course of acclimation were similar for the 4 subjects (in the following figures a representative Poincaré plot of one subject is shown).

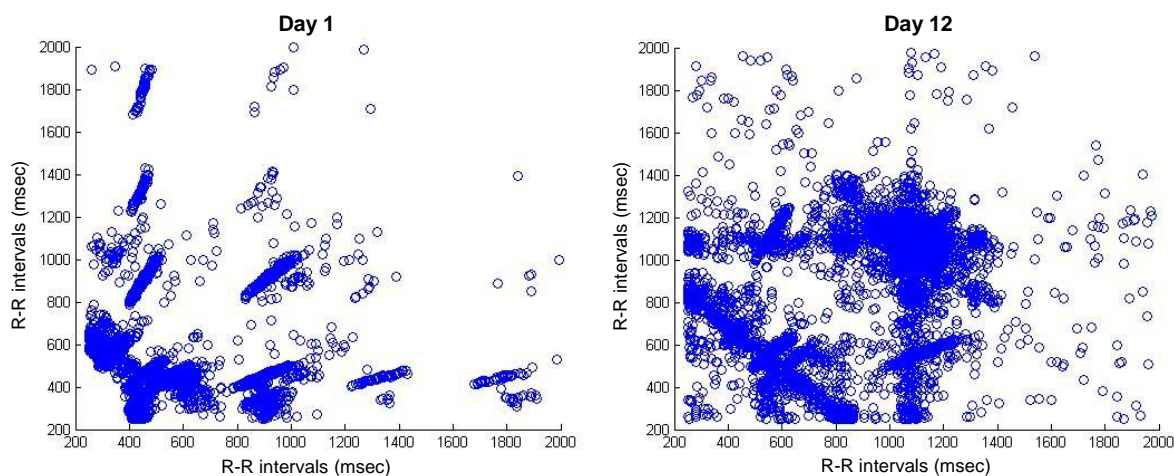


Fig. 2: Poincaré plots of R-R intervals for day 1 and day 12 of acclimation to heat

The dispersed Poincaré plot for the 1st day depicts the stress on the cardiovascular system, which is still evident also after the 12th day of acclimation. The subsequent multipole analysis of these plots uncovered, however, a more effective response of the autonomic nervous system following twelve days of acclimation to heat, which is evident in both parasympathetic and sympathetic systems.

The two parameters (T_{yyy} and the d_y/d_x) that were used to assess adaptability of the autonomic nervous system revealed a noticeable difference between day 1 and day 12 of the acclimation process, which reflect a tendency of the autonomic nervous system to adapt to the stress. Negative values of T_{yyy} on the 1st day of acclimation turned to be positive on the 12th day (average: -525 vs. 745, respectively). The negative value indicates a relatively slow decrease and fast increase in heart rate, which is a sign of a poorly adapted autonomic nervous system. The high positive value of the T_{yyy} parameter, following 12 days of acclimation, implies a slower increasing and faster decreasing pulse rate, which reflects the tendency of the autonomic nervous system to adapt to the stress. The higher value of the d_y/d_x index on the 12th day of acclimation vs. the 1st day (average: 2.9 vs 4.3 on the 1st and 12th day of acclimation, respectively) reflects general increase in HRV that indicates adaptation to heat stress.

CONCLUSIONS

Acclimation to heat is a process of physiological adaptation that results in a reduced physiological strain during exercise-heat stress. In a previous study, we have shown that by analyzing the time and frequency domains of HRV, changes in the sympatho-vagal balance could be described following a 10-day acclimation to heat (6). Acclimation to heat was associated with a higher HRV, which depicts a more efficient autonomic control, allowing more responsiveness and sensitivity to changing environmental demands. Noteworthy, the ten day acclimation process was also associated with an increase in the sympathetic activity (or a parasympathetic withdrawal), which was indicated by an increase in the low frequency band values and low to high bands ratio. By utilizing the multipole analytic method that identifies and quantifies increased chaos in non-stationary and non-linear complex time series, we showed that the stress on the cardiovascular system diminishes following the course of acclimation, but not to its complete relief. This is in line with the previous assertions drawn from observations in

animals and humans that acclimation to heat is a much longer process than can be judged from the early phenotypic picture (7,8).

REFERENCES

1. Wenger BC. Human heat acclimatization. In: Human performance physiology and environmental medicine at terrestrial extremes. Pandolf KB, Sawka MN, Gonzalez RR (eds). Benchmark Press Inc, Indianapolis, IN. 1988; 153-197.
2. Pandolf KB, Bruse RL, Goldman RF. Role of physical fitness in heat acclimatization, decay and reinduction. *Ergonomics* 1977; 20:399-408.
3. Akselrode S, Gordon D, Ubel FA, Shannon DC, Berger AC, Cohen RJ. Power spectrum analysis of heart rate fluctuation: a quantitative probe of beat-to-beat cardiovascular control. *Science* 1981; 213:220-222.
4. Lewkowicz M, Levitan J, Puzanov N, Shnerb N, Saermark K. Description of complex time series by multipoles. *Physica A* 2002; 311:260-274.
5. Olesen RM, Bloch Thomsen PE, Saermark K, Glikson M, Feldman S, Lewkowicz M, Levitan J. Statistical analysis of the DIAMOND MI study by the multipole method. *Physiol Meas* 2005; 26:591-598.
6. Frank A, Belokopytov M, Moran d, Shapiro Y, Epstein Y. Changes in heart rate variability following acclimation to heat. *J Basic Clin Physiol Pharmacol* 2001; 12:19-32.
7. Werner J. Temperature regulation during exercise: an overview. In: Perspective in exercise science and sports medicine. Gisolfi CV, Lamb DR, Nadel ER (eds). Brown & Benchmark, Dubuque, IA. 1993; 6:49-84.
8. Horowitz M. Heat acclimation and cross-tolerance against novel stressors: genomic-physiological linkage. *Prog Brain Res* 2007; 162:373-392.