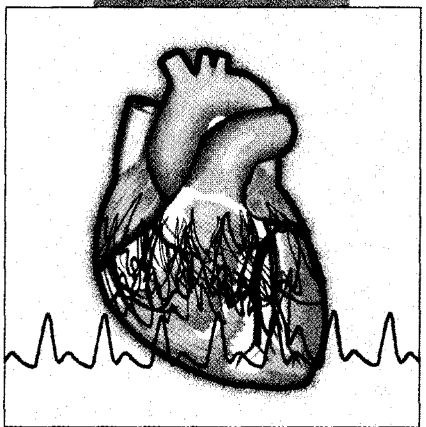

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Examining Changes in HRV in Response to Varying Ambient Temperature

The Effects of Ambient Temperature on Cardiovascular Responses in College-Aged Men and Women

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Heart-rate variability (HRV) analysis has been used as a method to examine the underlying mechanisms involved in autonomic control of the heart. Traditionally, spectral analysis of the rhythmic fluctuations in the beat-to-beat time series have led to the identification of three fairly distinct peaks: high (0.15-0.5 Hz), low (0.07-0.14 Hz), and very low (0.02-0.06 Hz) frequency bands [1]-[3]. The very-low-frequency (VLFP) band in the HRV spectra has been associated with thermoregulation [1]. Low-frequency spectral power (LFP) reflects sympathetic and vagal influences on cardiac control via baroreceptor-mediated regulation of blood pressure [2], [3]. High-frequency power (HFP) is a function of respiratory modulation of vagal activity [3]. In the past 20 years, many studies have used HRV analysis to examine the autonomic contributions as an aid in understanding cardiovascular differences observed across various experimental situations in both men and women. Only recently has the very slow-changing VLFB been experimentally examined.

Several studies have indicated that increases and decreases in power in both the high- and low-frequency bands can be examined to illuminate the underlying mechanisms that produce a given cardiovascular response to changes in skin or core temperature [4]-[7]. Specifically, the very-low-frequency component increased with core cooling [4]-[6] while the parasympathetic outflow was reduced [4]-[7]. Whereas the previous research findings are consistent, in this article we address several methodological issues present in the previous literature such as the use of only between-subject designs and insufficiently long data collection intervals to establish good resolution of the slower changing components. The present study is designed to examine changes in HRV in response to ambient temperature change in college-aged men and women. We hypothesize that the VLFP component would be increased in the cold environment whereas the HFP component would be reduced in the hot environment with no differences between baseline and the cold condition.

Method

Participants

The sample comprised 20 (ten males and ten females) college students from a large midwestern university who received course credit in their Introductory Psychology class in exchange for participation in our study. Informed consent was obtained from all participants, and the Human Subjects Committee of the University of Missouri-Columbia approved the protocol. Participants refrained from eating, drinking, smoking, and taking any psychoactive medications for two hours prior to taking part in the study. All participants indicated they were in good health, did not smoke, were not taking any psychoactive medications, and had no history of neurological or cardiovascular disease.

Apparatus

Psychophysiological data were collected using the Ambulatory Monitoring System (AMS; Free University, Netherlands) set to record continuous interbeat interval (IBI) data from a three-lead array at 1,000 Hz (see Figure 4 for an example of the data). Heart rate and blood pressure were recorded using the IDA-70 Automated Blood Pressure/Pulse Monitor system. The temperatures of the experimental rooms were controlled by

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Table 1. Mean (S.E.) value for baseline, hot, and cold conditions.			
Variable	**Baseline**	**Hot**	**Cold**
HR	69.15 (2.47) *b*	73.66 (2.601) *a,c*	69.86 (2.57) *b*
VLFP	1819.37 (252.95) *c*	2199.613 (396.758) *c*	2945.421 (332.855) *a,b*
NLFP	.535 (.027) *b*	.619 (.034) *a,c*	.565 (.028) *b*
NHFP	.512 (.029) *b*	.416 (.037) *a,c*	.479 (.031) *b*
SBP	114.61 (2.23) *b*	109.60 (2.38) *a,c*	114.68 (2.63) *b*
DBP	69.35 (1.77) *c*	68.83 (1.62) *c*	74.70 (2.11) *a,b*
All differences are at least $p < 0.05$; *a* = different than baseline; *b* = different than hot; *c* = different than cold.			

independently working heat pumps, with the cold room kept at 55 °F and the hot room at 95 °F. Participants watched a nature video titled "Rainforest" from the *National Geographic* library of documentaries (approximate running time 60 min). The video was presented simultaneously to both rooms using a standard Panasonic VHS videocassette recorder.

Procedures

Participants were brought into the lab and seated in a comfortable lounge chair. Subsequent to obtaining informed consent, surface electrodes were attached to the abdomen and thorax of the participants. Baseline data were collected (room temperature between 70-73 °F) while the participants rested comfortably in the lounge chair. All participants wore a short-sleeved shirt and long pants. The AMS and Automated Blood Pressure devices were fitted to the participants and two test readings were taken. After the test values, baseline data were collected continuously for 30 min using the AMS device while heart rate and blood pressure were recorded every 2 min using the automated blood pressure device. After the baseline, subjects were taken to the temperature-controlled rooms and were randomly assigned either the "hot" or "cold" room to begin the experiment. Once subjects were seated, the blood pressure cuff was placed on their nondominant arm and they were asked to remain as still as possible. The nature video was started and the subjects stayed in the first room for 30 min. At the end of 30 min, participants were taken to the other room and had the cuff replaced on their arm. The video was restarted and both participants watched the second half of the documentary. Subjective affective responses were obtained from the participants after the baseline and after each 30 min period. The questionnaire consisted of 14 items that the participants rated on a 5-point Likert-like scale from none to extreme. The items were as follows: serenity, interest, relaxation, excitement, happiness, agitation, anger, sad, tired, like, pleasantness, activation, stress, and pain. These data will be presented elsewhere.

Data Reduction & Analysis

Heart-rate and blood-pressure data from the IDA-700 were averaged across 30 min for the baseline and 30 min for each of the temperature conditions. Continuous ECG data were converted to interbeat interval time series and subjected to fast Fourier transform (FFT) spectral analysis. FFTs were performed on each successive 5 min piece of data and combined to determine spectral power estimates for each condition. Activity in three separate bands that have been linked to physiological responses was examined. The very-low-frequency (VLFP; 0.02-0.06 Hz) band has been linked to thermoregulation and hormonal changes. Power was extracted within the LF (0.07-0.14 Hz) and HF (0.15-0.50 Hz) ranges and served as indices of baroreceptor-mediated blood pressure variations and respiratory-mediated vagal influences, respectively. In addition, "normalized" values were computed for LF and HF (NLFP and NHFP, respectively) by dividing the power in the specified band by the total power minus the power in the VLFP band [2] (e.g., HF/(total power-VLFP)).

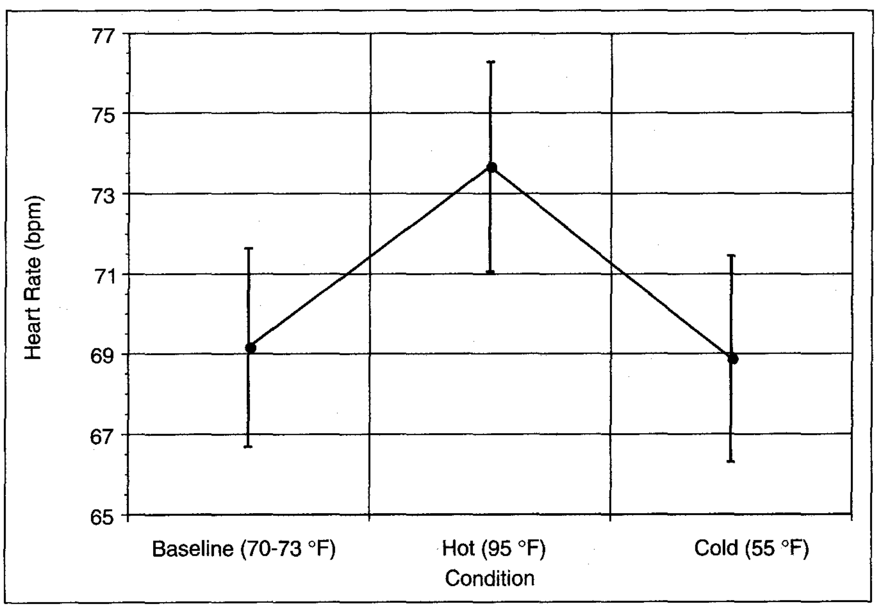
Data were analyzed using multivariate analysis of variance (MANOVA). Follow-up *t*-tests were performed to determine the locus of specific effects when a significant omnibus result was found. Statistical significance was set at the $p < 0.05$ level.

Results

The means and standard errors for each dependent variable along with follow-up tests for the pair-wise comparisons are presented in Table 1.

Heart Rate

There was a significant condition effect for HR (Wilks' Lambda = 0.611, $F(2,17) = 5.408, p = 0.015$). HR showed a significant increase in the hot condition whereas the baseline and the cold conditions were not significantly different (see Figure 1). The increase in the HR in the hot condition replicates previous research [4]-[7].

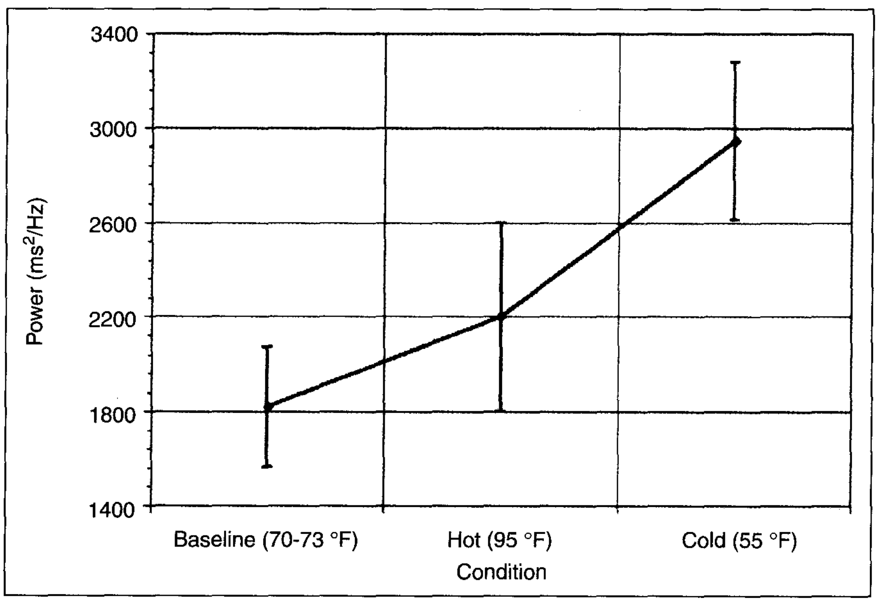


1. Mean heart rate (S.E.) across baseline, hot, and cold conditions.

Important differences between the conditions in which VLFP has been shown to be predictive of cardiovascular disease and the present experiment need to be noted.

Very-Low-Frequency Power

There was a significant condition effect for VLFP (Wilks' Lambda = 0.376, F (2,14) = 11.609, p = 0.001). VLFP increased in the cold condition as compared to both baseline and the hot conditions. The baseline and hot conditions were not significantly different (see Figure 2). These data are consistent with previous reports indicating that the VLFP component is sensitive to temperature manipulations [5].



2. Mean VLFP (S.E.) across baseline, hot, and cold conditions.

As can be seen in Figure 3, there was also a gender by condition interaction which indicated that the males compared to the females in the study showed a greater increase in VLFP to the cold (Wilks' Lambda = 0.524, F (2,14) = 6.365, p = 0.011). These data indicate that the VLF component may be differentially responsive to the effects of thermal stimulation for males and females.

Low-Frequency Power

There was a significant condition effect for NLFP (Wilks' Lambda value = 0.555, F (2,14) = 5.608, p = 0.016). NLFP increased in the hot condition with respect to the baseline and cold conditions, whereas the baseline and cold conditions were not significantly different. This increase in the hot condition taken together with the increase in HR also observed in the hot condition indicates a relative shift from vagal to more sympathetically mediated cardiovascular control [4]-[6].

High-Frequency Power

There was a significant condition effect for NHFP (Wilks' Lambda = 0.511, F (2,13) = 6.214, p = 0.013). NHFP decreased in the hot condition compared to baseline and cold conditions, which did not differ significantly from each other. These data indicate that vagal withdrawal plays an important role in the HR increase observed in the hot condition.

Systolic Blood Pressure

There was a significant condition effect for systolic blood pressure (Wilks' Lambda = 0.447, F (2,17) = 10.517, p = 0.001). Follow-up tests indicated that the hot condition produced reduced pressure compared to the baseline and the cold conditions with no difference between cold and baseline.

Diastolic Blood Pressure

There was a significant condition effect for diastolic blood pressure (Wilks' Lambda = 0.621, F (2,17) = 5.182, p = 0.017). Follow-up tests indicated that diastolic pressure increased in the cold condition compared to baseline and the hot condition. There was no significant difference between the hot and baseline conditions.

Discussion

The present study was performed to examine the effects of ambient temperature on cardiovascular responses in men and women. Heart rates were higher in the hot room compared to either baseline or the cold room, which were not different. Systolic blood pressure dropped in the hot condition relative to the baseline. The baseline and cold conditions did not differ reliably. Importantly, diastolic blood pressure increased in the cold room relative to the baseline whereas the baseline and the hot room did not differ. When we considered the underlying dynamics, we found that, as hypothesized, VLF increased in the cold relative to both the baseline and the hot room with no significant difference between the hot and baseline conditions. Interestingly, there was an interaction for VLF (see Figure 3) where the men showed increased VLF activity in the cold while the women showed very little change across conditions. If increases in power in the VLF range are associated with thermoregulation, it is possible that the lack of an increase in response to cold in the women may be a factor in the commonly observed greater sensitivity of women to cold ambient temperatures. Also, as expected, reduced NHFP coupled with increased NLFP indicated the increase in heart rate found in the hot condition was primarily due to parasympathetic withdrawal.

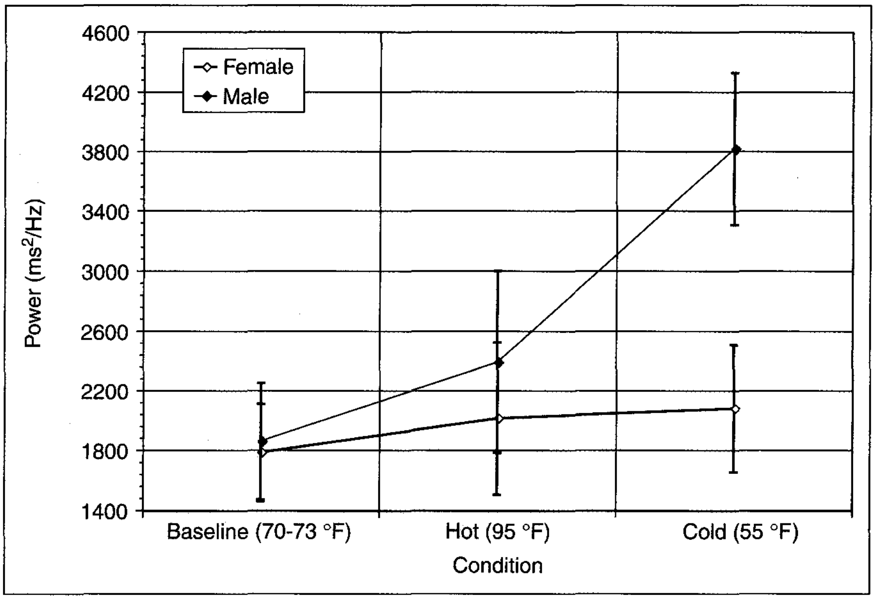
The physiological origins of the various components of HRV are a topic of some interest. Much of this interest has focused on the nature of the LFP component. However, given that the VLFP component has shown value in predicting cardiovascular disease, research directed at this component is needed [8]. Important differences between the conditions in which VLFP has been shown to be predictive of cardiovascular disease and the present experiment need to be noted. In the clinical literature 24-h recordings are used to generate the VLFP values. In such conditions movement may be a significant source of variability and has been suggested to reflect physical mobility and thus better health outcomes. In the present experiment movement was kept to a minimum and thus could not account for the effects reported here. The present data are consistent with numerous previous studies of thermal stimulation. However, the present experiment rectified some methodological issues that may have compromised the previous studies. Importantly, a potential gender difference was evident in our data that has not been previously reported. Clearly, more experimental work is needed to clarify the nature of the VLFP component in HRV analysis.

John J. Sollers III received his B.S. in psychology from Towson University and master's and Ph.D. degrees from the University of Missouri-Columbia. After post-doctoral positions at the University of Oklahoma and at the National Institute on Aging, he accepted a staff scientist position in the Emotion and Quantitative Psychophysiology Unit of the Laboratory of Personality and Cognition at NIA. He is a newly appointed member of the board of the Rocky Mountain Biomedical Engineering Symposium.

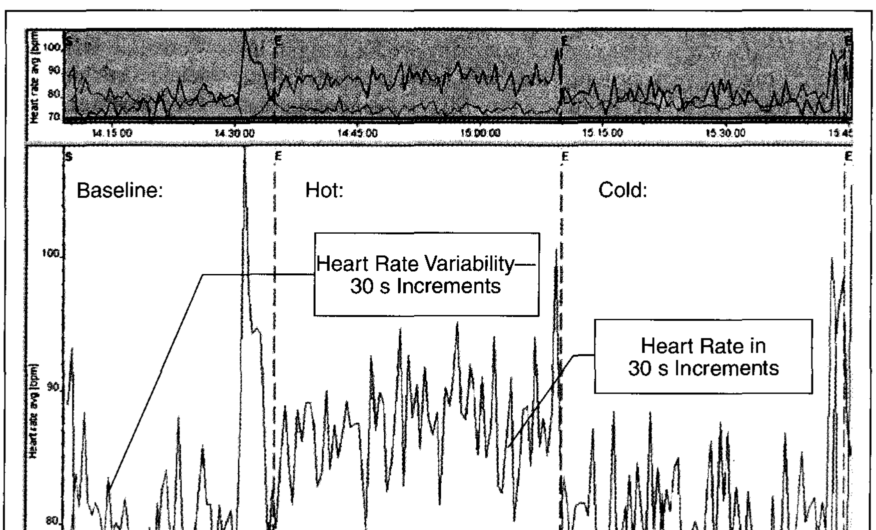
Tiffany A. Sanford graduated summa cum laude from the University of Missouri-Columbia in 1998 with a B.A. degree in psychology. She received her M.A. degree in counseling psychology in 2000 from the University of Missouri-Columbia. She is currently a doctoral candidate in counseling psychology at the University of Missouri-Columbia in the Department of Educational and Counseling Psychology. She will begin her internship in psychology this fall at the VA Medical Center in Milwaukee, Wisconsin.

Rachel Nabors-Oberg graduated summa cum laude in 1992 from St. Louis University with an honors B.A. degree in psychology. In 1997, she began her doctoral studies at the University of Missouri-Columbia in clinical psychology with a minor focus in statistics and methodology. She was awarded her M.A. degree in this program in 1999. She is currently finishing her requirements for the Ph.D. with support from an Individual Predoctoral National Research Service Award from the National Institutes of Alcohol Abuse and Alcoholism (1 F31 AA13673-01).

Craig A. Anderson received his B.A. in psychology and sociology from Butler University in 1976. His M.A. in psychology from Stanford University was awarded in 1978; Lee Ross was his M.A. advisor. He received his Ph.D. in psychology from Stanford University in 1980, with J. Merrill Carlsmith serving as his dissertation advisor. Anderson was assistant (1980-1985) and associate (1985-1988) professor at Rice University, and a visiting professor at Ohio State (1984-1985). He joined the University of Missouri-Columbia in 1988 and became full professor there in 1992. He has served on Faculty Councils at Rice (1987-1988) and at Missouri (1995-1996). He also served as director of graduate studies for the Department of Psychology at Mis-



3. Mean VLFP (S.E.) across baseline, hot, and cold conditions by gender.



4. Heart rate and HRV data for one female subject.

souri from 1988-1996 and as director of graduate admissions from 1988-1991. He joined the Iowa State University faculty in 1999, as professor and chair of the Department of Psychology. Dr. Anderson's research interests are in social and personality psychology, with a strong dose of cognitive psychology. Most of his current research focuses on aggression and potentially harmful effects of exposure to violent video games.

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