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PRIORITY REPORT

Age-related reductions in heart rate variability do not worsen during exposure to humid compared to dry heat: A secondary analysis

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ABSTRACT

We conducted a secondary analysis to investigate whether age-related attenuations in heart rate variability (HRV) worsen during exposure to moderate, dry (36.5°C, 20% RH) or humid (36.5°C, 60% RH) heat conditions that resulted in greater body heat storage among older compared to young participants, and during humid compared to dry heat, regardless of age. Six HRV indices [heart rate (HR), coefficient of variation (CoV), detrended fluctuation analysis: α1, low frequency power, high frequency power, and low/high frequency ratio] were assessed in 10 young (21 ± 3 y) and 9 older (65 ± 5 y) adults for 15-min prior to (baseline), and at the end of a 120-min exposure to dry and humid heat while seated at rest. Our results demonstrated a condition (dry and humid) x time (baseline and end) interaction effect on HR ($p = 0.047$) such that HR gradually increased during humid heat exposure yet remained similar during dry heat exposure across groups. We also found an age-related attenuation in CoV at baseline for both the dry (young: 0.097 ± 0.023%; older: 0.054 ± 0.016%) and humid (young: 0.093 ± 0.034%; older: 0.056 ± 0.014%) heat conditions ($p < 0.02$). Those age-related attenuations in CoV, however, were not magnified throughout the exposure nor different between conditions ($p > 0.05$). While older adults stored more heat during a brief 120-min exposure to dry heat compared to their young counterparts, this was not paralleled by further age-related impairments in HRV even when body heat storage and cardiovascular strain were exacerbated by exposure to humid heat.

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Introduction

Aging has long been associated with local impairments in heat loss responses of skin blood flow and sweating [1,2,3]; however, it remained uncertain whether those impairments translate to reductions in whole-body heat loss that exacerbate body heat storage in older adults during heat exposure. Using a direct air calorimeter to measure whole-body heat loss (evaporative + dry), combined with estimates of metabolic rate via indirect calorimetry, Stapleton et al. [4] quantified body heat storage (metabolic rate – heat loss) in 12 young (mean ± SD: 21 ± 3 y) and 12 older (65 ± 5 y) adults during a 120-min exposure to both dry (36.5°C, 20% RH) and humid (36.5°C, 60% RH) heat; conditions representative of temperate continental climates during summer months. The cumulative change in body heat storage was greater among older compared to young participants during both dry (young: 131 ± 27 kJ; older: 212 ± 25 kJ) and humid (young: 317 ± 45 kJ; older: 426 ± 37 kJ) heat exposures [4]. Both groups, however, stored significantly more heat during humid compared to dry heat exposure, primarily due to attenuated whole-body evaporative heat loss. These findings indicate that, when compared to younger persons, older individuals store more heat during a brief exposure to both dry and humid heat, while the latter appears to exacerbate body heat storage regardless of age. Further, greater heat storage experienced during heat stress may increase cardiovascular strain due to the demands placed on the heart to support blood pressure regulation and heat transfer to the periphery.

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Based on these findings, it is reasonable to suggest that due to greater heat storage, older individuals living in temperate continental climates may have a higher risk of experiencing potentially dangerous cardiovascular disturbances possibly leading to adverse cardiac events during a brief heat exposure, particularly when humidity is high. Heart rate variability (HRV) is a noninvasive indicator of cardiac parasympathetic (vagal) and sympathetic autonomic modulation [5] that diminishes with age [6]. Moreover, extreme heat exposure (44°C, 30% RH) has been shown to amplify those age-related attenuations in HRV [7]. Yet, the effects of less extreme heat (<40°C) with varying ambient humidity (20–60% RH) on HRV remains unclear. This is a critical knowledge gap given that such conditions are far more common, especially in temperate continental climates during summer months. Additionally, attenuated cardiac autonomic function, reflected by HRV may provide a predictive index for risk of adverse cardiac events, even in individuals without previous cardiovascular disease [8]. To evaluate the effects of moderate dry or humid heat exposure, we conducted a secondary analysis of HRV derived from electrocardiogram (ECG) recordings obtained by Stapleton et al. [4] during a brief 120-min exposure to both dry and humid heat with matched air temperature in young and older adults. We hypothesized that age-related attenuations in HRV would occur during less extreme, dry heat exposure, with the magnitude of that attenuation increasing in more humid heat with matched ambient temperature.

Methods

This study was part of a larger investigation evaluating body heat storage in young and older adults during exposure to both dry and humid heat, the experimental procedures of which have been published previously [4] and are summarized below for convenience. The study was approved by the University of Ottawa Health Sciences and Science Research Ethics Board and is in accordance with the guidelines set forth by the Declaration of Helsinki. Verbal and written informed consent were obtained from all volunteers before their participation in the study.

Ten healthy young [age: 21 ± 3 y; body mass index (BMI): 24.9 ± 4.1 kg/m^2] and nine healthy, older [age: 65 ± 5 y; BMI: 25.4 ± 4.1 kg/m^2] adults participated. Each participant completed one screening session where physical characteristics were recorded, and two experimental sessions, each separated by ≥72 h. Participants were instructed to refrain from over-the-counter medications (including nonsteroidal anti-inflammatory drugs and supplements) for >48 h, as well as alcohol, caffeine and heavy exercise at least 24 h before each session. Furthermore, participants were instructed to arrive at the laboratory 2 h postprandial and having consumed ~200-500 ml of water ~2 h before arrival.

After confirming euhydration (urine specific gravity: <1.020), participants underwent a 30-min instrumentation period, where baseline data were recorded, followed by 120-min seated rest in either dry (36.5°C, 20% RH) or humid (36.5°C, 60% RH) heat. Throughout, R-R interval data were collected from a Philips DigiTrak XT Holter Monitor and analyzed using Philips Zymed Software (Philips Zymed Version 3.0, Andover, MA, USA). Only normal-to-normal (NN) beats were used for further analysis. HRV analyses were performed employing the Continuous Individualized Multiorgan Variability Analysis – CIMVA^{TM} software (http://ohridal.org/cimva/CIMVA_UserGuide.pdf). Six HRV indices were derived throughout each exposure: heart rate (HR), coefficient of variation (CoV), detrended fluctuation analysis: α1 (DFA α1), low frequency power (LF), high frequency power (HF), and LF/HF ratio (LF/HF), with a 15-min average at baseline (non-heat stress) and at the end of each exposure being used for statistical analysis (three-way, mixed model ANOVA [condition x group x time]).

Results

We observed a condition (dry and humid) x time (baseline and end) interaction effect on HR ($p = 0.047$) such that HR gradually increased (compared to baseline) during humid heat exposure yet remained similar during dry heat exposure across groups. We also found an age-related attenuation in CoV at baseline prior to both the dry (young: 0.097 ± 0.023%; older: 0.054 ± 0.016%) and humid (young: 0.093 ± 0.034%; older: 0.056 ± 0.014%) heat conditions ($p < 0.02$). Those age-related attenuations in CoV, however, were not magnified throughout the exposure nor

different between humid and dry conditions ($p > 0.05$) (Figure 1). No significant differences observed in DFA α1, LF, HF, and LF/HF (Figure 1, Figure 2).

Discussion

In this secondary analysis, we demonstrate that during humid heat exposure, representative of temperate continental climates during summer months, mean HR in both groups was elevated when compared to baseline yet remained similar to baseline at the end of the dry heat exposure. This suggests that the rise in body heat storage that occurred during humid compared to dry heat observed by Stapleton et al. [4] was likely paralleled by increased cardiovascular strain. Further, our data (i.e. CoV) also demonstrated an age-related attenuation in HRV at baseline and at the end of dry and humid heat exposure. It is believed that CoV is a marker of short-term vagal cardiac autonomic modulation [9]. This age-related reduction is consistent with previous reports of a linear decrease in global cardiac autonomic regulation with age [6], and stronger resting cardiac parasympathetic tone in aerobically trained and healthy young subjects [10]. Contrary to our working hypothesis, however, age-related attenuations in HRV were not exacerbated following a brief exposure to either dry or humid heat, despite body heat storage during humid exposure (and therefore the level of hyperthermia) being more than twice that observed during dry heat exposure [4].

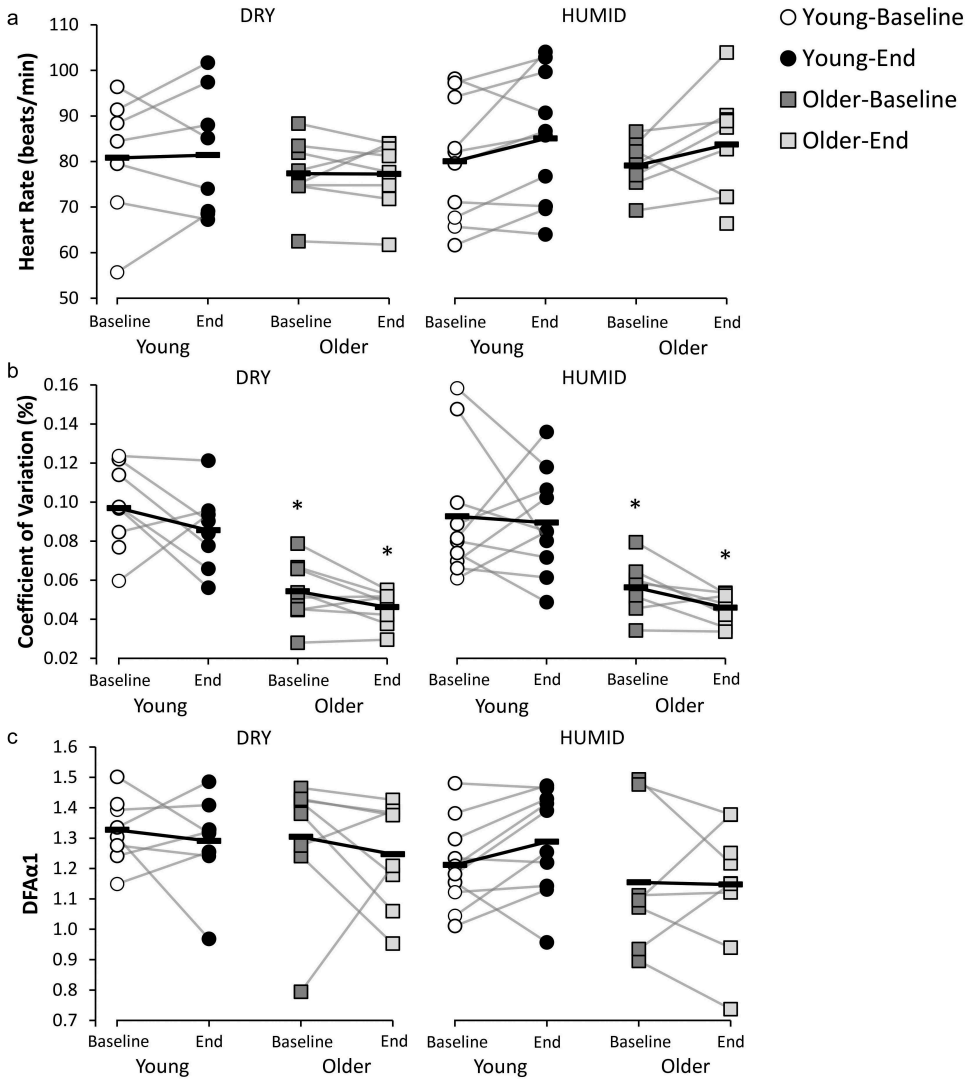

Figure 1. (a) Heart rate; (b) Coefficient of variation; and (c) Detrended fluctuation analysis in young and older adults prior to (Baseline, non-heat stress) and at the end (End, 105–120 min) of the 120-min DRY and HUMID heat exposures. *Significantly different from young at the same time point and during the same condition ($p < 0.05$).

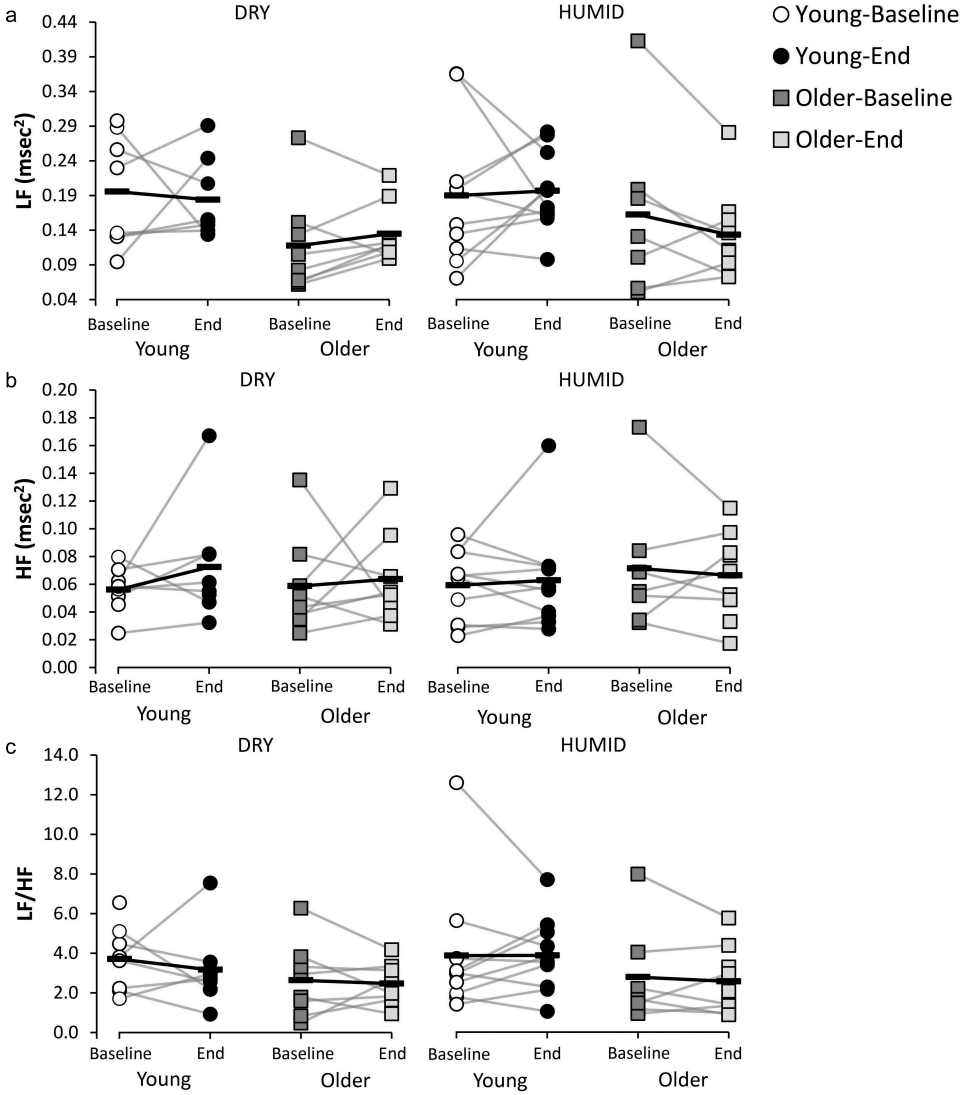

Figure 2. (a) Low frequency power (LF); (b) High frequency power (HF); and (c) LF/HF ratio in young and older adults prior to (Baseline, non-heat stress) and at the end (End, 105–120 min) of the 120-min DRY and HUMID heat exposures.

Although multiple factors may explain this outcome, it is possible that the magnitude of heat stress and/or duration of exposure (120 min) were insufficient to further attenuate HRV in older adults. Indeed, our previous work [7] showed that longer exposure (180 min) to more extreme heat stress (i.e. 44°C) resulted in further age-related attenuations in HRV. This is consistent with previous evidence [11] which suggests that environmental temperature has a greater impact on HRV (i.e. LF/HF) when compared to humidity, and that humidity may only impact HRV when it is high (~80%). These findings are particularly important given the threat to human health posed by rising global temperatures. Indeed, new research predicts that periods of extreme heat in temperate continental zones will be more frequent and five times more deadly [12]. It is an ominous signal of what increasing temperatures portend for the most vulnerable. Further research, however, is required to establish evidence-based exposure limits to safeguard the health of vulnerable people during prolonged exposures that can occur during extreme heat events.

Author contributions

All experiments took place at the Human and Environmental Physiology Research Unit of the University of Ottawa. A.E.C. and G.P.K. conceived and designed the study. C.L.H., S.R.N., M.J.M., H.E.W B., and A.J.E.S. contributed to the acquisition, analysis, assembly, and interpretation of data. A.E.C. and A.D. F. completed the statistical analysis. A.E.C., S.R.N., M.J.M., and G.P.K. drafted the manuscript. All authors provided critical revisions of the manuscript, approved its final version, and are

accountable for all aspects of the work. G. P. Kenny is supported by a University of Ottawa Research Chair. S. R. Notley is supported by a Postdoctoral Fellowship from the Human and Environmental Physiology Research Unit.

Disclosure statement

A.J.E.S. is a patent holder, Director and shareholder of Therapeutic Monitoring Systems (TMS) Inc., focused on commercialization of variability-derived clinical decision support tools developed in OHRI's Dynamical Analysis Laboratory. C.L.H. is a patent holder related to variability monitoring and physiological waveform analysis.

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Abbreviations

CoV	Coefficient of variation
DFA α1	Detrended fluctuation analysis: α1
HF	High frequency power (0.15–0.4 Hz)
HR	Heart rate
HRV	Heart rate variability
LF	Low frequency power (0.04–0.15 Hz)
LF/HF	Low/high frequency power ratio
RH	Relative humidity

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