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Effects of core temperature, skin temperature, and inter-beat interval on resting metabolic rate measurements in thermoneutral conditions

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ABSTRACT

It is important to identify potential underlying factors that can affect the variability of resting metabolic rate (RMR) measurements. The RMRs of 20 college-aged men were tested twice in stable environmental conditions, with each measurement separated by 40 min. Skin temperature, core temperature, and inter-beat interval were monitored throughout the study as identified factors that could affect RMR measurements. Since environmental conditions in a clinic or laboratory can vary, skin temperature and core temperature can be affected which may affect RMR. Similarly, prior physical activity, stress, sleep, and caffeine intake can affect inter-beat interval and may be a co-variable affecting RMR. Higher RMR measurements were compared to lower RMR measurements. RMR for the higher trial was 2068 ± 66 kcal/day, the lower trial was 1975 ± 65 kcal/day ($t = 4.23$; $p < 0.01$). Core temperature for higher trial was 37.1 ± 0.1 °C, the lower trial was 36.8 ± 0.1 °C ($s = 105.00$; $p < 0.01$). Skin temperature measurements were significantly different for the anterior bicep site ($t = -2.52$; $p = 0.02$), but not for any other site. Inter-beat interval for the higher measurement was 1038 ± 33 ms, the lower measurement was 998 ± 32 ms ($t = 3.82$; $p < 0.01$). However, regression analysis found that none of the variables were significant predictors for the higher RMR, lower RMR, or change in RMR. While the factors affecting RMR measurement variability remain unclear, the results suggest that typical fluctuations in core temperature, skin temperature, and inter-beat interval do not effectively predict changes in RMR in a thermoneutral environment.

1. Introduction

Measurements of metabolic rate are ultimately dependent upon heat production. Direct calorimetry can be used to measure the body's rate of heat production as a result of its metabolic processes (Atwater and Rosa, 1899). Thus, energy expenditure, or metabolic rate was first measured in humans by assessing heat production. When the amount of heat that the body produces changes, due to dietary intake, physical activity, or air temperature, metabolic rate changes and can be directly measured (Hardewig et al., 1991). However, this direct assessment of metabolic rate is impractical due to the large cost and time requirements. Since all exergonic reactions in humans are dependent upon oxygen use, indirect calorimetry, in which oxygen consumption and carbon dioxide production are measured, can be used in place of direct calorimetry, providing comparable results (Seale et al., 1990) with considerably less time and expense requirements. However, several factors, including rest period prior to testing, body position, time of day, fasting period, caffeine intake, nicotine intake, and physical activity are known to affect body temperature, and therefore, resting metabolic rate (RMR) (Compher et al., 2006). As a result, each of these factors must be controlled as much as possible when measuring RMR via indirect calorimetry in order to obtain valid and reliable results.

Even when all factors are controlled and best-practice guidelines are followed, some variability in RMR measurements still exists, particularly in outpatient settings where factors such as physical activity and diet are more difficult to control (Bone and Burke, 2018). The reason for this variability between two different RMR measurements is not entirely clear, but may be due, in part to environmental factors such as air temperature, humidity, and barometric pressure, which in turn can affect physiological factors including skin temperature, core temperature, and heart rate. However, no previous studies have examined multiple environmental factors and the potential impacted with physiological factors during RMR measurements.

Heart rate, for example, which has been used to estimate energy expenditure previously (Spurr et al., 1988), is influenced by environmental conditions. Therefore, changes in heart rate as a result of environmental influences are associated with changes in energy expenditure (i.e. metabolic rate). Interestingly, both increases (Siegrist

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et al., 2006) and decreases in heart rate have been observed following cold air exposure and a drop in skin temperature (LeBlanc et al., 1976) while increases in heart rate has been observed following exposure to heat and humidity (Ravanelli et al., 2015). Heart rate and changes in the inter-beat interval are also affected by altitude exposure (low barometric pressure) during exercise (Åstrand and Åstrand, 1958) and at rest (Horiuchi et al., 2018) and while no studies have specifically examined the effect of humidity or barometric pressure upon RMR measurements (Fullmer et al., 2015), these factors may still be important. Thus, examining heart rate or inter-beat intervals can be utilized to provide insight for physiological responses to the external environment and its potential effects upon RMR measurements.

Current guidelines recommend air temperature ranges from 20 to 25 °C (Fullmer et al., 2015). Interestingly, it has been suggested that a 20 °C air temperature will result in an increased RMR compared to measurements taken with an air temperature of 25 °C (Kashiwazaki et al., 1990). It is possible that this increase in RMR at 20 °C is due to a drop in core temperature or skin temperature, similar to results seen in participants exposed to 15 °C air (Claessens-van Ooijen et al., 2006). Thus, air temperature can affect RMR measurements and should be controlled as much as possible and monitored to account for potential variation.

If heart rate, core temperature, skin temperature, air temperature, humidity, and barometric pressure are all monitored alongside a RMR measurement following best-practice guidelines, it may be possible to identify underlying factors contributing to variability in RMR measurements. Presumably, in an environment with controlled ambient air conditions, RMR variability should be minimal if best-practice guidelines are followed. Therefore, the purpose of this study was to determine the extent of variability within subjects for two RMR trials under identical conditions and to identify potential physiological factors of within subject variability.

2. Materials and methods

2.1. Participants

Recreationally active college-aged men (n = 20) were recruited to participate in the study. All subjects were non-tobacco users, were not taking any medications, and were considered healthy as indicated by the Physical Activity Readiness Questionnaire (PAR-Q). Detailed participant characteristics are outlined in Table 1 along with environmental data.

2.2. Procedures

Informed consent was obtained from all participants prior to the onset of the study and the study protocol was approved by the University's Institutional Review Board and was in accordance with the Declaration of Helsinki. Participants ingested a CorTemp sensor (HQ Inc., Palmetto, FL) 6–8 h prior to arriving at the lab, per recommended guidelines (Byrne and Lim, 2007). Following an overnight (10–12 h) fast, participants arrived at the lab between the hours of 0500 and 0700 to minimize circadian variability in core temperature (Krauchi and Wirz-Justice, 1994). Capillary blood glucose was measured (Hemocue, Brea, CA) upon arrival to the lab to ensure each participant was fasted (glucose < 100 mg/dl was considered fasted). In order to minimize participant variability and minimize extraneous variables, participants were asked to abstain from alcohol and caffeine consumption as well as strenuous physical activity for 72 h prior to the lab visit. Height and mass were measured using a Detecto medical scale (Cardinal Scale Manufacturing Co., Webb City, MO), subject age was obtained, and BMI was calculated. Air displacement plethysmography (BOD POD, Cosmed USA, Concord, CA) was used to determine body fat percentage. Following the body fat percentage measurement, participants sat quietly for 20 min in a dimly lit room. Participants were not allowed to read or use any electronic devices for the duration of the study, per best practice guidelines (Fullmer et al., 2015).

Table 1
Subject characteristics and environmental data.

	Average	Range
Age (yrs)	22.25 ± 0.46	19–29
Height (cm)	175.90 ± 2.04	149.90–193.00
Weight (kg)	81.28 ± 3.39	55.95–110.23
BMI (kg/m^2)	26.03 ± 1.20	19.4–38.36
Body Fat (%)	22.19 ± 2.27	3.6–42
Barometric Pressure (mmHg)	762.95 ± 0.61	754–766
Dry Bulb (°C)	20.2 ± 0.21	19–22
Wet Bulb (°C)	19.95 ± 0.23	16–20
Relative Humidity (%)	77.85 ± 1.54	60–84

2.3. Skin temperature, heart rate, core temperature, and environment measurements

Following 20 min of sitting quietly, skin temperature sensors (ADInstruments, Sydney Australia) were placed and secured with surgical tape in four locations on each participant based upon previous research (Ramanathan, 1964) as follows on the right side of the body: 1: mid-clavicular line, 2 cm inferior to the clavicle; 2: anterior biceps brachii, midway between the antecubital fossa and the acromion process; 3: anterior thigh (rectus femoris), midway between the patella and the greater trochanter; 4: posterior calf (gastrocnemius), midway between the calcaneus and the popliteal fossa. Skin temperature was monitored continuously during each RMR measurement. Heart rate and inter-beat intervals were measured continuously during each RMR measurement via a non-invasive blood pressure system using arterial pulse recordings from a finger cuff (ADInstruments, Sydney Australia). Core temperature was measured at the beginning and end of each RMR measurement using the CorTemp Data Recorder (HQ Inc., Palmetto, FL). Wet bulb and dry bulb temperature as well as relative humidity were measured with a sling psychrometer prior to the onset of each RMR measurement. Barometric pressure was measured with a digital sensor prior to the onset of each RMR measurement (Cole Parmer, Davis Perception II, Vernon Hills, IL).

2.4. RMR measurements

Following 20 min of sitting quietly, an initial resting Metabolic Rate (RMR) measurement was taken. RMR was determined via indirect calorimetry canopy system (CPET system, COSMED, USA, Concord, CA). Each participant was placed in a supine position, with the hips and knees flexed to 90°, with the lower legs resting on an adjustable-height step. Participants were not allowed to sleep but were instructed to lie quietly. This position was maintained throughout the measurement (20 min in duration). Per best practice guidelines, the first 5 min of the RMR measurement were discarded and a minimum of 4 min of the measurement in which the coefficient of variation (%CV) for both VO_2 and VCO_2 were less than 10% was required. VO_2 and VCO_2 data were recorded every few seconds during RMR measurements and thus, hundreds of data points were collected for each measurement. During a typical RMR measurement, the VO_2 and VCO_2 values fluctuated, as the participant became more still and calm, the values for VO_2 and VCO_2 the values became steadier. The %CV of less than 10% for VO_2 and VCO_2 indicated the participant was in a rested state, that the respiratory data was reliable, and that the data could be used to calculate RMR. Following the initial RMR measurement, participants were returned to a sitting position for an additional 40 min, during which time RMR data was not collected. Following the 40-min rest period, a second RMR measurement was then completed following the same protocol described for the initial RMR measurement. The total time prior to the

second RMR measurement included 20 min rest plus 20 min testing for the first measurement plus 40 min resting totalling 80 min of rest prior to the second measurement. The second measurement took an additional 20 min, after which, the participants were free to leave the lab. The total time spent in the lab for each participant, therefore, was one hundred minutes. Participants were tested on the same day rather than different days in order to minimize differences between trials. Testing on different days would elicit different sleep, stress, and dietary input as well as slightly different air temperature, humidity, and barometric pressure.

2.5. Statistical analysis

For all measurements, the higher value trials were compared to the lower value trials to determine differences. This was done rather than simply comparing the first trial to the second trial since the effect of time was not the primary research question. All data were checked for normality using a Shapiro Wilk test. Differences between the initial measurement and second measurement for RMR, inter-beat interval, core temperature, skin temperature, and environment were determined using a paired samples *t*-test for normally distributed data. A Wilcoxon signed-rank test was used for non-normally distributed data. Multiple linear regression was used to determine the relationship between inter-beat interval, core temperature, skin temperature, and environment on RMR measurements. All data are presented as mean ± SD. $P \leq 0.05$ was considered statistically significant.

3. Results

Barometric pressure, relative humidity, and dry bulb temperature, core temperature data and mid-clavicular skin temperature data for the higher and lower measurements were not normally distributed ($W < 0.05$). Data for these variables were not normal following a log transformation and therefore, nonparametric statistics were used to analyse these data. All other variables were normally distributed ($W > 0.05$). Environmental factors did not vary significantly between the higher and lower measurements and the environmental data are summarized in Table 1.

In 7 of the 20 participants, the first RMR measurement was higher than the second RMR measurement, order effect was not significant. RMR for the higher trial was 2068 ± 66 kcal/day and RMR for the lower trial was 1975 ± 65 kcal/day. The mean difference between the two trials was 92 kcal/day and was significant ($t = 4.23$; $p < 0.01$). Fig. 1 shows the mean RMR measurement for each individual and the corresponding degree of change in RMR from the higher and lower measurement.

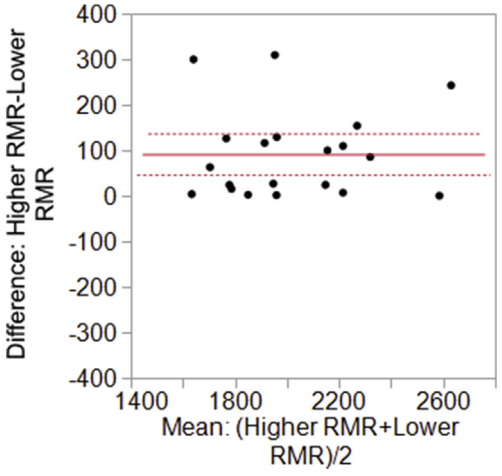

Fig. 1. The difference between the higher and lower RMR measurements are plotted against the mean RMR values for the higher and lower RMR measurements. Dots represent individual participants.

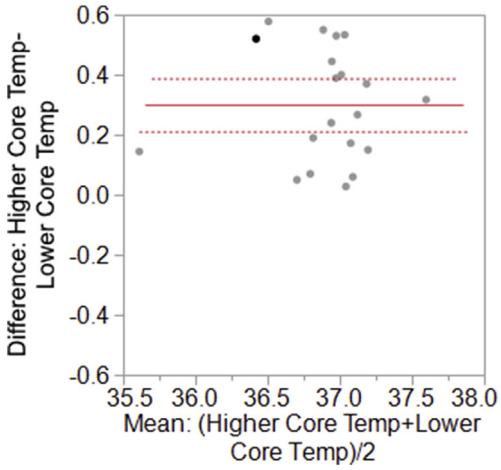

Fig. 2. The difference between the higher and lower core temperature measurements are plotted against the mean core temperature values for the higher and lower RMR measurements. Dots represent individual participants.

In 60% of the participants, the first core temperature measurement was higher than the second core temperature measurement, order effect was not significant. Core temperature for higher trial was 37.1 ± 0.1°C and core temperature for the lower trial was 36.8 ± 0.1 °C. The mean differences between the two trials was 0.03 °C and was significant ($s = 105.00$; $p < 0.01$). Fig. 2 shows the mean core temperature measurement for each individual and the corresponding degree of change in core temperature from the initial and second measurement. 40% of the participants exhibited a higher RMR and higher core temperature measurement within the same trial.

Skin temperature measurements were not significantly different between measurements for the for the mid-clavicular site ($s = -35.00$; $p = 0.20$), the anterior thigh site ($t = 1.03$; $p = 0.32$, or the posterior calf site ($t = -0.07$; $p = 0.94$). Skin temperature measurements were significantly different for the anterior bicep site ($t = -2.52$; $p = 0.02$). Comparisons of each skin temperature site are summarized in Fig. 3.

The inter-beat interval for the higher measurement was 1038 ± 33 ms and the inter-beat interval for heart rate for the lower measurement was 998 ± 32 ms. The mean difference between the two trials was 40 ms, which was significant ($t = 3.82$; $p < 0.01$). Heart rate for the higher measurement was 61 ± 2 beats per minute (bpm) and 59 ± 2 bpm for the lower measurement. The mean difference between the two trials was 2 bpm, which was significant ($t = 6.13$; $p < 0.01$).

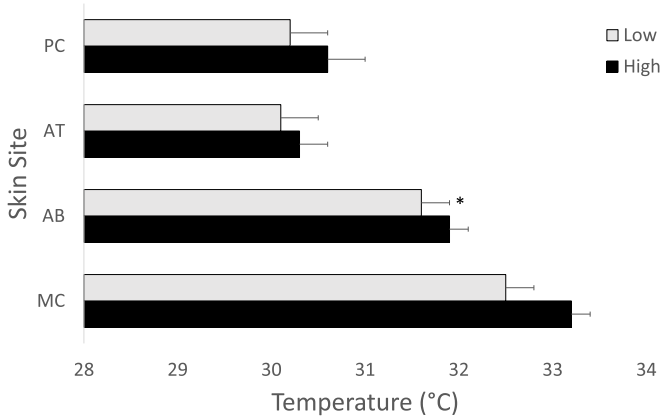

Fig. 3. Average values for skin temperature for each trial and each site are shown. Bars represent SEM. MC mid-clavicular; AB anterior bicep; AT anterior thigh; PC posterior calf. * Denotes significant difference from ABH.

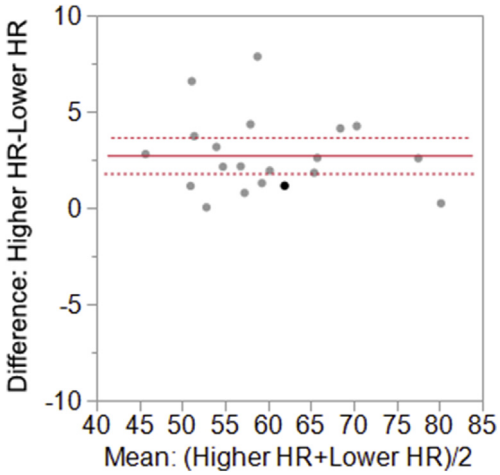

Fig. 4. The difference between the second and first inter-beat interval measurements are plotted against the mean core temperature values for the first and second inter-beat interval measurements. Dots represent individual participants.

Fig. 4 shows the mean heart rate measurement for each individual and the corresponding degree of change in heart rate from the higher and lower measurement. 50% of the participants exhibited a higher RMR and higher heart rate measurement within the same trial.

The change in RMR versus core temperature ($F = 1.352$; $p = 0.26$), MC skin temperature ($F = 0.173$; $p = 0.90$), AT skin temperature ($F = 0.51$; $p = 0.49$), and PC skin temperature ($F = 0.01$; $p = 0.91$) were not significant. The change in RMR versus AB skin temperature was significant ($F = 5.97$; $p = 0.03$) and the change in RMR versus change in inter-beat interval was not significant ($F = 1.78$; $p = 0.20$).

Multiple regression analysis did not reveal any significant relationship between core temperature, skin temperature, inter-beat interval, or environmental factors and RMR measurements. None of the variables were significant predictors for the higher RMR measurement, lower RMR measurement, or change in RMR measurement. Spearman's rho correlations are shown for barometric pressure, relative humidity, dry bulb temperature, core temperature, and mid-clavicular temperature. Pearson correlations are shown for all other variables. Correlation values and the statistical probabilities for each variable are summarized in Table 2.

4. Discussion

Despite following best practice guidelines for obtaining RMR measurements, when 2 separate measurements were taken under the same environmental conditions on the same day, different results were found. Thus, while differences may have been significant, they were within normal variability ranges and are in agreement with previous research. One previous research study found that outpatient RMR measurements varied by approximately 80 kcal per day (Haugen et al., 2003), another found an average difference of 100 kcal per day (Bone and Burke, 2018), while the current study found an average of 90 kcal per day. Some of the variability may be accounted for by residual effects from the minimal physical activity required to get to the clinic or lab. In a research study examining RMR measurements following an inpatient stay (8 h resting) versus outpatient (30 min resting), the authors found differences of approximately 100 kcal per day, an 8% increase in RMR following 30 min of rest (Berke et al., 1992) compared to an overnight stay. However, another study found no difference in RMR following 30 min of rest compared to an overnight stay (Turley et al., 1993) at 22 °C. Thus, the exact reasons for the 80–100 kcal differences in RMR in the current study and in previous studies cannot be fully accounted for by minimal physical activity alone. Neither of the aforementioned studies reported skin temperature or core temperature and therefore it is not known whether changes in core temperature or skin temperature may have contributed to the increase in RMR in the study by Berke et al. Some of the variability in RMR may have also been due to instrumentation (Wells and Fuller, 1998) as well as other biological factors that are not reported such as diurnal variation, thermic effect of food, or pharmaceutical agents, and some may be human error, such as inadequate calibration or methodological errors.

Table 2
Correlations.

Variable	Correlation with Change in RMR	P value
Barometric Pressure	0.33	0.15
Dry Bulb	0.12	0.61
Wet Bulb	−0.04	0.85
Relative Humidity	0.07	0.75
Change in core temperature	0.01	0.98
Change in inter-beat interval	−0.24	0.29
Change in mid-clavicle temp	0.01	0.96
Change in anterior bicep temp	−0.12	0.60
Change in anterior thigh temp	−0.17	0.48
Change in posterior calf temp	0.12	0.62

In the current study, significant differences between trials were found for heart rate and core temperature despite following best-practice guidelines for RMR measurements as well as stable air temperature and humidity. Since heart rate has been used to estimate energy expenditure previously (Spurr et al., 1988) and heart rate is known to change following exposure to cold (Cannon and Keatinge, 1960) and humidity (Ravanelli et al., 2015), it was expected that significant changes in heart rate would affect RMR measurements. However, it should be noted that the absolute change in heart rate between trails was approximately two beats per minute, which has little to no effect upon physiological outcomes. It is important to remember that both statistical significance and physiological relevance are necessary considerations for interpreting results. The current results for heart rate were significantly different between trials, but physiologically there was no difference. Similarly, inter-beat interval differences between trails was significant, yet the absolute difference was only 40 ms which generally indicates that stress levels, from the environment or otherwise, were not different between trials (Zhong and Wargocki, 2019).

Larger decreases in skin temperature, by several degrees, following cold water immersion have been associated with changes in RMR (Cannon and Keatinge, 1960), but half of 1 °C change at the anterior bicep site combined with non-significant changes in skin temperature at the mid-clavicular, anterior thigh, and posterior calf sites suggest that prolonged resting up to 80 min will not decrease skin temperature to a large enough degree to affect RMR measurements. Similarly, absolute change in core temperature was 0.03 °C, which also has little to no effect upon physiological outcomes. Thus, it was unsurprising that the differences in RMR measurements did not correlate significantly with heart rate or core temperature changes.

Since RMR values were higher for 7 participants during the first RMR measurement, but RMR values were higher for 13 participants during the second RMR measurement the effect for time was not significant ($F = 0.0231$; $p = 0.88$). Taken together with the aforementioned findings, it appears that minor fluctuations in core temperature and heart rate are unlikely to affect RMR. The current findings also suggest that typical environmental fluctuations in the lab environment are unlikely to affect RMR measurements While it is well documented that air temperature can affect RMR values (Azaz et al., 1992; Claessens-van Ooijen et al., 2006; Kashiwazaki et al., 1990; Vanooijen et al., 2004). Kashiwazaki et al. were previously the only group to examine air temperatures of a typical laboratory or clinic environment, both 20 °C and 25 °C. The authors found that 20 °C air increased RMR values by 6–9 percent during the winter months, but did not have an effect during the summer months. In the current study, participants

completed the RMR measurements during the spring months. However the air temperature in south Louisiana, the location of the current study, in the spring is similar to that of Tokyo, the location of the aforementioned study, in the summer. Thus, the results of the current study are in agreement in that air temperatures inside a lab or a clinic ranging from 20 to 25 °C do not significantly impact RMR measurements if the outside air temperature is relatively warm. The current findings suggest that relative humidity can vary to a large degree and exceed 80% without affecting RMR measurements when air temperature is maintained between 20 and 25 °C.

It is also noteworthy that body composition of the participants did not appear to be affected by fluctuations in air temperature or humidity. Previous research has shown that RMR measurements tend to be affected more in thinner men compared to overweight men (Cannon and Keatinge, 1960; Claessens-van Ooijen et al., 2006) following cold exposure while the current study suggests that minor fluctuations in air temperature or humidity within a thermoneutral environment will not affect RMR measurements, regardless of body composition.

5. Conclusions

The exact reasons for the variability between two RMR measurements taken on the same day under the same conditions are unclear. However, the results of the current study indicate that if best-practice guidelines are followed and the environment is thermoneutral, typical heart rate, core temperature, and skin temperature fluctuations are unlikely to change in a physiologically meaningful way and therefore are unlikely to impact RMR measurements.

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Conflicts of interest

The authors have no conflicts of interest to declare.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jtherbio.2019.102399.

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