

Research article

The reliability of adolescent thermoregulatory responses during a heat acclimation protocol

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Abstract

This study investigated the between trial variation of thermoregulatory measures during a heat acclimation protocol. Eight 14-16 y old boys completed three bouts of 20-min cycling at 45 % peak VO_2 in a hot environment (35.1 ± 1.2 °C and 46.4 ± 1.0 % relative humidity) on two occasions separated by a minimum of 24 h. Reliability was assessed through analysis of within-subject variation, the change in the mean, and retest correlation for measurements of aural temperature (T_{au}), mean skin temperature (T_{sk}), heart rate (HR) and oxygen uptake (VO_2). Between trial differences were low for T_{au} , T_{skbout1} , $T_{\text{skbout2and3}}$ and HR with coefficients of variation 0.6 %, 1.5 %, 0.5 % and 4.0 %, respectively. The results demonstrate good reliability that will allow future investigators to precisely determine the extent of heat acclimation protocols in relation to the measurement error.

Key words: Reliability, heat acclimation, aural temperature, mean skin temperature.

Introduction

Heat acclimatisation/acclimation is a process in which a series of adaptations occur to reduce the physiological strain and improve an athlete's endurance performance in a hot environment, thus reducing the likelihood of heat illness (Armstrong and Maresh, 1991). It is well documented that heat acclimation improves thermal tolerance and endurance capacity during low intensity endurance performance. The circulatory and thermal adjustments to heat acclimatisation, in adults, have been studied extensively since the 1950s (Armstrong and Maresh, 1991; Cheung and McLellan, 1998; Eichna et al., 1950; Lind et al., 1963; Sawka et al., 1996; Strydom et al., 1966; Wyndham et al., 1968). More recently research has indicated that intermittent exposure protocols can improve intermittent exercise capacity in team sport athletes (Sunderland et al., 2008)

For an adult population to achieve full heat acclimatisation, it is widely accepted that the optimal time exposure is 10-14 days (Armstrong and Maresh, 1991; Cheung and McLellan, 1998; Sawka et al., 1996). In addition the most notable improvements in exercise-heat tolerance occur in protocols that implement exercise at an intensity in excess of 50 % peak VO_2 (Gisolfi and Robinson, 1969). Improvements in exercise heat tolerance are also considered to be greater following intense interval training acclimation protocols (Gisolfi and Robinson, 1969; Shvartz et al., 1977). To the author's knowledge no such guidelines exist in literature regarding optimal ac-

climatisation protocols for younger athlete populations.

In childhood and adolescence, physical and physiological changes occur during growth and maturation which can impact upon thermoregulation during rest and exercise (Falk, 1998). The early work of Bar-Or (1980) stated that the thermoregulation of children is quantitatively and qualitatively different from adults due to alterations in geometric, metabolic, cardiovascular and evaporative parameters.

When comparing young children to adults; one of the most notable differences is the geometric characteristics that children possess (Bar-Or, 1980, Falk and Dotan, 2008). The greater surface area relative to body mass predisposes them to a greater heat influx from the surrounding environment when ambient temperatures exceed mean skin temperature (Bar-Or, 1980; Falk, 1998). Thus, the higher surface area-to-body mass ratio will increase the absorption of environmental heat to children during exposure to a hot environment (Falk and Dotan, 2008).

Increased thermal strain during intense or prolonged exercise is further attributed to the concept that children have a higher metabolic cost of locomotion at comparable treadmill intensities to adults (Rowland, 2008). The reduced exercise economy results in the production of greater metabolic heat per kilogramme (Bar-Or and Rowland, 2004; Falk, 1998). However, during cycling at comparable intensities, the energy expenditure is similar in pre-pubertal children and adults inferring that muscular efficiency is not altered during different stages of maturation (Rowland, 2008).

To evaluate the effectiveness of heat acclimation, a protocol needs to be reliable to minimise the two components of measurement error; systematic bias and random error due to biological variation that often encompass equipment noise (Atkinson and Nevill, 1998; Hopkins, 2000a). The within-subject variation represents the random variation of a variable when one individual is tested several times (Hopkins, 2000a); consequently quantification of reliability studies allow the precise detection of physiological adjustments for the benefit of future heat acclimation studies.

In addition to the lack of heat acclimation protocol guidelines for adolescent populations, no study exists that has examined the reliability of thermoregulatory measures previously adopted within paediatric heat acclimation studies. To allow future heat acclimation guidelines to be produced, the extent of heat acclimation needs to be established once biological and mechanical variation has been accounted for. Therefore, the aim of this study was to determine the reliability of thermoregulatory measures

during a previously adopted paediatric acclimation protocol (Bar-Or and Inbar, 1977; Inbar et al., 1981; 1985) subsequent to its use in future heat acclimation trials.

Methods

Subject characteristics

Eight well-trained male footballers volunteered to participate in the study. The mean (SD) age, stature, and body mass were 14.6 ± 0.50 y, 1.70 ± 0.06 m, and 55.9 ± 7.6 kg, respectively. All the subjects were based at a Professional Football Club's Youth Centre of Excellence and had been at the centre for a minimum of 1.5 y. The subjects trained on average 1-2 h, 3-4 days per week. The experiment was described verbally and in writing to the subjects and their parents. Written informed consent was obtained from the parents and written assent from the subjects. The study was approved by the Institutional Ethics Committee.

Protocol

The experimental protocol was similar to that described in three previous studies from the laboratory at the Wingate Institute for Physical Education and Sport, performed in the late 1970s and early 1980s (Bar-Or and Inbar, 1977, Inbar et al., 1981). The aforementioned studies determined the effectiveness of heat acclimation trials for children aged 8-10 y cycling at 40-45 % peak $\dot{V}O_2$ in environmental temperatures in excess of 40°C. The protocol design includes cycling bouts of exercise at intensities indicative of previous heat acclimation work.

Preliminary visit

On the first visit to the laboratory a Par-Q form was completed. Stature was obtained to the nearest 0.1 cm using a Holtain stadiometer (Crymch, Dyfed, UK). Body mass was determined to the nearest 100 g using a beam balance (Avery Berkel, Birmingham, UK) with the participants wearing football shorts and shirt but no shoes. Skinfold thickness and adiposity were estimated from the sum of four skinfolds measured over the triceps, biceps, subscapular and suprailiac regions using age-appropriate equations (Durnin and Ramahan, 1967). Each skinfold measurement was taken twice and the mean score recorded.

Participants then completed a continuous incremental cycle protocol to determine peak $\dot{V}O_2$. The peak $\dot{V}O_2$ test was performed upon an electromagnetically braked cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands). The $\dot{V}O_2$ was measured using a metabolic cart (Cortex Metalyser II, Leipzig, Germany) that was calibrated prior to all tests according to the manufacturers' instructions. The work rate commenced at 20 W and increased continuously by 20 W every minute until volitional exhaustion was reached and the cyclists could no longer maintain a cadence of 60 rpm despite strong verbal encouragement. Heart rate was monitored in 60 s intervals via a telemetry system (Polar, Kempele, Finland). Peak $\dot{V}O_2$ was determined as the highest $\dot{V}O_2$ averaged over 60 s. A regression equation was computed from the data obtained to calculate the required intensity for the experimental exercise bouts.

Experimental heat trials

Within 1 week the subjects returned to complete the first of two identical trials upon the electromagnetically braked cycle ergometer in a climate-controlled chamber. Each trial was separated by a minimum of 24 h and a maximum of 1 week. Within subject variation was minimised by testing each participant at the same time of day. Participants avoided strenuous exercise and caffeine 24 h prior to each trial.

The session in the chamber lasted for 84 min, or until termination criteria were reached, and consisted of three, 20 min cycle bouts separated by 8 min of rest. Termination criteria consisted of a 2°C increase in T_{au} , nausea, dizziness, chills, exhaustion or headaches. The mean dry bulb temperature and relative humidity were 35.1 ± 1.2 °C and 46.4 ± 1.0 % respectively throughout the testing session. The air velocity was less than 0.2 m·s⁻¹. The work rate was predetermined to elicit 45 % peak $\dot{V}O_2$.

Physiological variables

On arrival to the lab the subjects provided a urine sample, which was analysed, using a hand held digital refractometer calibrated from 0 to 1500 mOsmols·kgH₂O⁻¹ (Pocket Osmocheck, Vitech Instruments, Sussex, U.K.). If values in excess of 600 mOsmols·kgH₂O⁻¹ were recorded, subjects consumed 8 mL·kg⁻¹·min⁻¹ of water one hour prior to the start of the test. Following the urine analysis, nude body mass was ascertained, accurate to 100 g. Subjects were shown how to use the weighing scales to record their mass prior to entering a locked changing room area to undertake the procedure in private.

The subjects then rested in a normal environment (22.89 ± 1.11 °C) for 30-min. T_{au} (Alaris Medical Systems, San Diego, U.S.), arm, chest, thigh and calf temperature, (T_{sk} , Squirrel 851 Data Logger, Eltek, Cambridge, U.K.), measures were recorded before entering the chamber and at 4 min intervals. T_{sk} was measured from the 4 skin surface thermistors and (T_{sk}) calculated using the weighted equation of Ramanathan (1964); $T_{sk} = 0.3(T_{chest} + T_{arm}) + 0.2(T_{thigh} + T_{calf})$. HR was recorded before entering the chamber and at 1 min intervals. The rate of metabolism ($\dot{V}O_2$) was measured halfway through the second exercise bout via the Cortex metabolic cart for a duration of 8-10 min. Ratings of perceived exertion (Borg, 1982) and thermal comfort were recorded at 5 min intervals, solely to allow the subjects to communicate their perceptions. The subjects were encouraged to drink water throughout the trials and consumed 1.36 ± 0.17 vs 1.23 ± 0.39 L for trials 1 vs 2, respectively.

Treatment of data

All data obtained are reported as mean (SD). Measures of reliability are presented as the change in mean value between the 2 exercise trials, the standard error of measurement (change score) and the estimation of the typical error; calculated from the standard deviation of the change scores $\div \sqrt{2}$ (Hopkins, 2000a). The typical error was expressed as a percentage of its respective mean to form the co-efficient of variation (CV). The percentage CV was obtained from the spreadsheet developed by Hopkins (2000b) which also provided the confidence intervals for the calculated CV. T_{au} , T_{sk} , HR and $\dot{V}O_2$

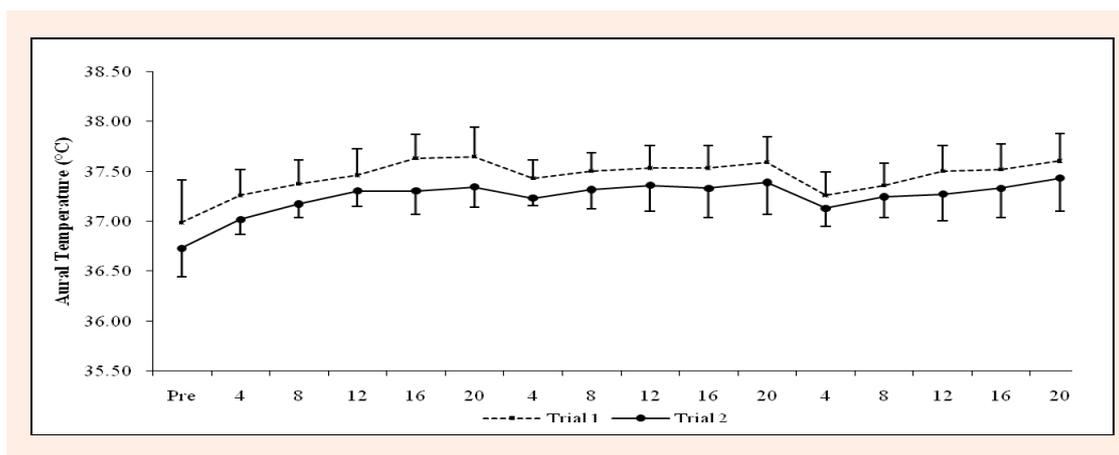


Figure 1. Mean (SD) aural temperature ($^{\circ}\text{C}$) values during the 3 exercise bouts for the 2 trials.

were selected for the calculation of the typical error. Additional paired sample t-test analysis was performed to check for systematic bias. Repeated measures analysis of variance (ANOVA) were conducted on HR, T_{au} and T_{sk} data to determine significant differences between the 3 individual exercise bouts for each exercise trial. When significance was detected a post hoc Tukey_{HSD} was employed. Significance was accepted at an alpha level of $p < 0.05$.

Results

The results from the preliminary test are presented in Table 1. The subjects cycled at a mean (SD) power output of 106 ± 28 W during the 3 exercise bouts to elicit 45 % peak VO_2 .

All but one subject completed both exercise trials. Figure 1 demonstrates the chronological changes in T_{au} during exercise in the climatic chamber for the 2 trials. The mean T_{au} measure increased in trial 1 and trial 2 by 0.61 ± 0.25 and $0.70 \pm 0.07^{\circ}\text{C}$, respectively following the 84-min of exposure in the climatic chamber. The repeated measures ANOVA indicated that there was no significant difference between the absolute T_{au} temperature values throughout each bout of 20 min exercise ($p > 0.05$).

Figure 2 outlines the sequential change in HR during the two exercise trials. The repeated measures ANOVA indicated that there were no significant differences in the HR values across the 3 exercise bouts for

each of the exercise trials ($p > 0.05$). The mean HR values for trial 1 and 2 were 153 ± 11 and 150 ± 13 $\text{b}\cdot\text{min}^{-1}$, respectively.

Table 1. Peak oxygen uptake and anthropometric values of the subjects ($n = 8$ males). Values are mean (SD).

Variable	
Body fat (%)	18 (3)
Peak VO_2 ($\text{L}\cdot\text{min}^{-1}$)	3.06 (.60)
Peak VO_2 ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	54.8 (6.8)
Peak power output _{max} (W)	247.5 (30.1)
Peak power output _{max} ($\text{W}\cdot\text{kg}^{-1}$)	4.4 (4.0)

Figure 3 demonstrates the change in T_{sk} during the 2 exercise trials. The results of the repeated measures ANOVA indicated that there was a significant difference between bout 1 vs bouts 2 and 3 for the 2 exercise trials. The mean T_{sk} values for bout 1 across the 2 exercise trials were 35.76 ± 0.42 and $35.32 \pm 0.35^{\circ}\text{C}$. The mean T_{sk} for bouts 2 and 3 during the 2 trials were 36.89 ± 0.36 and $36.81 \pm 0.33^{\circ}\text{C}$.

Table 2 presents the change in mean values and CV values upon log-transformed data. The CV for T_{au} was 0.6 % between trials 1 and 2. The CV for mean T_{sk} varied between bout 1 and the combined mean for bouts 2 and 3; 1.5 and 0.5 %, respectively. The intraclass correlations were highest for VO_2 (0.91-0.96). Table 3 presents the change in mean values and typical error values as raw values. The typical error for T_{au} was 0.1°C between trials 1 and 2. The typical error for mean T_{sk} varied between

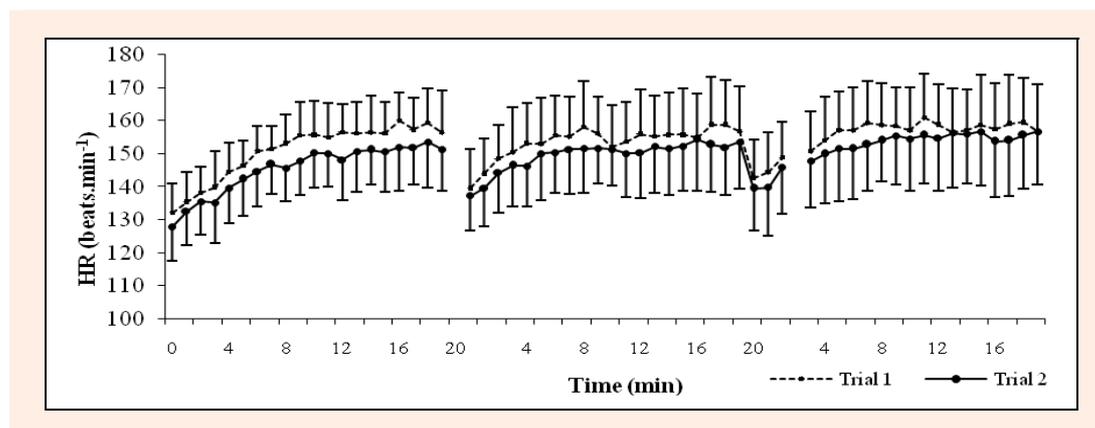


Figure 2. Mean (SD) heart rate ($\text{b}\cdot\text{min}^{-1}$) values during the 3 exercise bouts for the 2 trials.

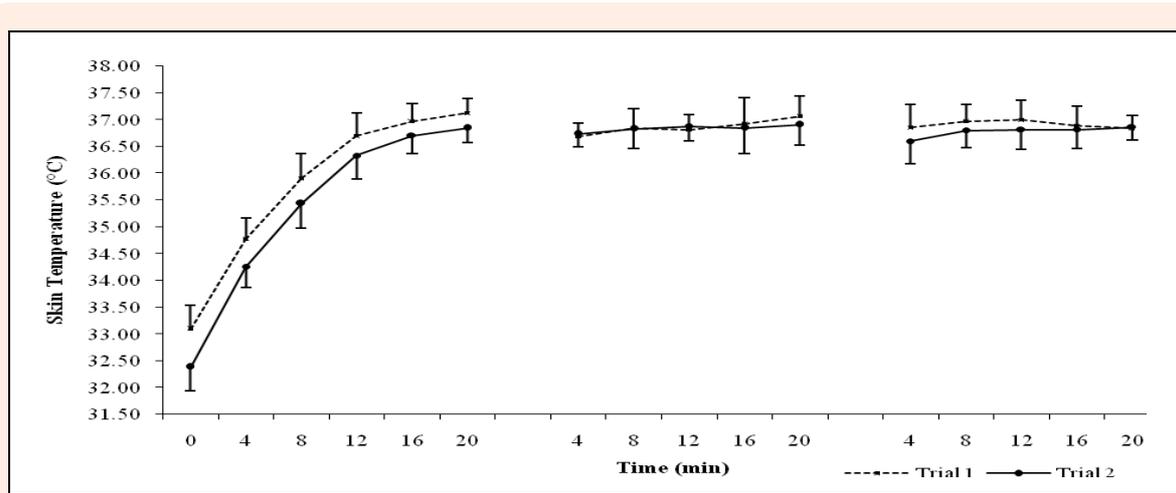


Figure 3. Mean (SD) skin temperature ($^{\circ}$ C) values during the 3 exercise bouts for the 2 trials.

bout 1 and the combined mean for bouts 2 and 3; 0.28 and 0.09 $^{\circ}$ C, respectively. The intraclass correlations for the raw data were high for T_{sk} bouts 2 and 3 combined, HR and VO_2 (0.92-0.99) but lower for T_{au} and T_{sk} bout 1 ranging from 0.48-0.58.

Discussion

The aim of the study was to examine the reliability of thermoregulatory measures recorded during previous heat acclimation studies in adolescents. The experimental design incorporated three, 20-min cycle bouts interspersed with an 8 min rest period resulting in an overall exposure time of 84 min. The protocol was in accordance with a previously adopted heat acclimation protocol in which pre-pubertal subjects completed a total of 5 treatment sessions to achieve acclimation (Bar-Or and Inbar, 1977, Inbar et al. 1981, Inbar et al. 1985). Although the protocol has been adopted for several paediatric studies, there appears to be no research available that has examined the reliability of the measures that were recorded to conclude acclimation effectiveness.

Given that most adolescent athletes will fail to encounter extremely hot climatic conditions, as utilised in the work of Bar-Or and Inbar ($>40^{\circ}$ C) the present study focused upon the reliability of the aforementioned protocol in a warm ambient environment. The main findings were that the lowest variability was found for T_{au} , $T_{skbouts1}$, and $T_{skbouts2and3}$ with mean CV values of 0.5 - 1.5 % (Table 2). The physiological measures included for analysis were selected on the basis that the degree of heat acclimation is often based upon alterations in core temperature, heart rate, improved exercise economy, mean skin temperature, and lower core temperature at the onset of sweating in a

hot-dry environment (Armstrong and Maresh, 1991).

The heat acclimation research performed with adults is extensive with studies indicating that full acclimation is achieved during protocols up to 14 d in duration (Eichna et al. 1950; Strydom et al. 1966; Wyndham et al. 1968). To date there is limited research about the mechanisms and the time course of heat acclimation in the paediatric population compared to adults.

Falk (1998) states that alterations in physiological measures post acclimatisation in paediatric subjects follow the same trends as adults but the extent of change is lower. The reduced extent of acclimation in a younger cohort makes the establishment of measurement reproducibility crucial to quantify the success of adopted protocols. For researchers to be confident in fully determining the degree of acclimation within a paediatric cohort the degree of error within temperature measures must first be established. Hence, reproducible techniques are critical in order for future studies to be able to detect change.

The typical error for mean T_{au} across the 3 bouts of exercise was 0.1 $^{\circ}$ C between the 2 trials. Inbar et al. (1981, 1985) examined the degree of acclimation following exercise in a 43 $^{\circ}$ C dry bulb and 24 $^{\circ}$ C wet bulb (21 % humidity) environment for 8-10 y old boys. Reductions in rectal temperature (T_{re}) were reported to be $0.23 \pm 0.13^{\circ}$ C following 1 baseline trial and 5 further exercise trials using a protocol similar to that employed in the current study. Although the present study used aural measures to calculate absolute CV values, comparisons to core temperature measurements can be drawn. Lim et al. (2008) acknowledge that tympanic measures are thought to have the highest association to core temperature in contrast to other non-invasive techniques such as sublingual and axilla measures.

Table 2. Measures of reliability for aural, mean skin temperature, VO_2 and HR data for log transformed data.

Measures	ICC (confidence limits)	Change in mean (%) (confidence limits)	Typical error as CV (%) (confidence limits)
T_{au} ($^{\circ}$ C)	.62 (-.94, -.25)	-.5 (-.9, -.2)	.6 (.4, 1.2)
T_{sk} bout 1 ($^{\circ}$ C)	-.94 (-.99, -.66)	-1.2 (-2.2, -.2)	1.5 (1.0, 3.5)
T_{sk} bouts 2 and 3 ($^{\circ}$ C)	.71 (-.10, .95)	-.2 (-.5, .1)	.5 (.3, 1.1)
HR ($b \cdot min^{-1}$)	.74 (-.03, .96)	-2.8 (-5.2, -.2)	4.0 (2.6, 9.1)
VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	.91 (.51, .98)	-.1 (-3.9, 3.9)	6.0 (4.0, 14.2)

Table 3. Measures of reliability for aural, mean skin temperature, VO₂ and HR data for raw data.

Measures	ICC (confidence limits)	Change in mean (%) (confidence limits)	Typical error as CV (%) (confidence limits)
T _{au} (°C)	0.58 (-0.31, 0.93)	-0.2 (-0.34, -0.06)	0.1 (0.07, -0.23)
T _{sk} bout 1 (°C)	0.48 (-0.43, 0.91)	-0.44 (-0.80, -0.07)	0.28 (0.18, 0.61)
T _{sk} bouts 2 and 3 (°C)	0.92 (0.56, 0.99)	-0.08 (-0.20, 0.04)	0.09 (0.06, 0.20)
HR (b·min ⁻¹)	0.95 (0.67, 0.99)	-4 (-8, 1)	3 (2, 6)
VO ₂ (mL·kg ⁻¹ ·min ⁻¹)	0.58 (-0.31, 0.93)	-0.2 (-0.34, -0.06)	0.1 (0.07, -0.23)

The use of aural measurement as a non-invasive core temperature measurement site is well established. Chamberlain and Terndrup (1994) consider the tympanic membrane to be an advantageous method of assessing core temperature. It is readily accessible and the temperature of the tympanum is thought to closely reflect that of the hypothalamus, due to its proximity and sharing of vasculature (Wilson et al. 1971, Davis, 1993). In addition, tympanic temperature is thought to track changes in core temperature quicker than T_{re}. The inability of the infrared tympanic thermometer to monitor temperature continuously makes it less favourable in comparison to rectal thermometry. However to overcome the associated disadvantages and invasiveness of rectal contact probes, infrared technology was initiated in the 1980s and used in the presented study (Davis, 1993).

The CV value obtained of 0.6 % for T_{au} is in good agreement with the findings of Hayden et al. (2004) who reported a CV of 0.3 % for T_{re} in adult subjects during 60-min of fixed intensity cycling in a 36°C, 60 %_{RH} environment across 3 trials. Hayden et al. (2004) indicated that their study was the first to quantify the degree of between-trial variation for core temperature; therefore the result of the present study was encouraging. Prior to the work of Hayden et al. (2004), Barnett and Maughan (1993) reported no significant differences in T_{re} of adults across 3 trials of 60-min submaximal cycling in a 34.6°C, 67 %_{RH} environment. In the absence of other CV values this indicates that the non-invasive aural measurement also exhibits a low between-trial variation in line with rectal thermometry.

The repeated measures analysis of mean T_{sk} resulted in findings of significant differences between bout 1 and bout 2, and bout 1 and 3 for both exercise trials. The increase in mean T_{sk} during bout 1 most likely reflects the transition from the cool environment to the hot-dry environment. During this transition phase; the increase in mean T_{sk} is most likely reflective of heat absorption from the environment to equilibrate existing peripheral thermal gradients existing between the skin and environment. In addition the increase in mean T_{sk} may be attributable to the metabolic heat dissipated from the core via convective mechanisms. The absence of significance between bouts 2 and 3 between the two trials is most likely reflective of thermal equilibrium being attained between the environment and periphery.

Inbar et al. (1981; 1985) noted that a reduction occurred in T_{sk}, measured from the arithmetic mean of 2 sites, of $-0.64 \pm 0.15^\circ\text{C}$ post heat acclimation in prepubertal boys. The present study established a typical error value of 0.28°C for bout 1 and 0.09°C for combined mean T_{sk} from bouts 2 and 3 across the 2 trials. The CV values for T_{sk} varied from 1.5 – 0.5 % for bout 1 and bouts 2 and

3, respectively. These values are in agreement with Hayden et al. (2004) who documented a CV of 0.7 % and typical error score of 0.3°C across the 3 trials for a 3-site weighted equation. Given the higher surface area to body mass ratio of young athletes, the ability to recognise the alterations in mean surface temperature and the extent of those is important to assess for future acclimation processes. It is also encouraging to note similar reliable values despite differences in the mean 2 and 3 site surface temperature equations being used.

The mean change in average HR was 4 b·min⁻¹, which resulted in a typical error of 3 b·min⁻¹ and a CV of 4 %. Inbar et al. (1981, 1985) established that HR decreased by 11.4 ± 2.8 b·min⁻¹ following heat acclimation. The CV is in agreement with the findings of Hayden et al. (2004) who determined that between-trial variation of HR was 3.9 %. The work of Hayden et al. (2004) was the first to quantify the variability of HR during submaximal exercise in the heat and was in agreement with the previous work of Wilmore et al. (1998) who had reported similar CV values during 2 different submaximal cycling protocols (4 and 6.1 %) in a cooler environment for males and females (34.9 ± 14.3 y). It is interesting to note that despite alterations in ambient temperature conditions the reported CV values are similar.

The mean HR values for trial 1 and 2 were 153 ± 11 and 150 ± 13 b·min⁻¹, respectively. The slightly lower mean HR value recorded in trial 2 is in agreement with the reproducibility study of Hayden et al. (2004) in adults. It was reported that the initial exercise trial may have induced anxiety due to a lack of familiarity of exercise in hot conditions accompanied by continuous measurement of physiological variables in a laboratory setting. If the anxiety levels were sufficient to augment sympathetic nervous activity the higher HR values obtained in the first trial could be explained.

Given that the 2 trials being undertaken were in close proximity it is unlikely that any heat acclimation had occurred to account for the reduced heart rate. Wyndham et al. (1968) analysed the changes in central circulation and body fluid spaces during 17-d of heat acclimation in men. The results indicated that the improvement in venous return to the heart via an increase in plasma and interstitial fluid volume did not occur until day 3 or 5. At this time point the increased stroke volume would account for cardiac output being maintained at a lower HR. The limited exposure to the hot conditions and the time between trials would be unlikely to cause any acclimation in the present study.

The authors acknowledge the presence of systematic bias between trials for measures of T_{au}, HR and T_{sk}_{bout1} following paired sample t-test analysis ($p < 0.05$). This was not unexpected for the participating cohort given

their lack of familiarity of cycling in a hot environment. The most prevalent example of systematic bias is a learning effect or habituation, with participants performing better on a second trial simply because they have benefited from the experience of the first trial. This is often the case in the absence of a familiarisation trial. Given the intensive time demands and resource implications for heat acclimation protocols, familiarisation work is not generally feasible; however this does not invalidate the reliability study.

Atkinson and Nevill (1998) highlight the critical importance of minimal measurement error (reliability) during work in sports research. The documentation of measurement error, comprising systematic bias and random error within this study allows future investigators to quantify the degree of change of several thermoregulatory measures following the removal of measurement error. In addition, Hopkins (2000a) proposes that sample size (n) can be established once typical error is known to allow a better indication of the change in the mean from the calculation $n = 8 \cdot CV^2/d^2$. For the present study d^2 would represent the least worthwhile difference expected to be seen post heat acclimation. For example, a sample size of 8 would be necessary to analyse the precise change in HR post acclimation due to d^2 being 4.

Conclusion

In conclusion, this study demonstrated acceptable reliability of a number of physiological measures used to determine the extent of heat acclimation. T_{au} and mean T_{sk} demonstrated the lowest between trial variations across 2 repeated trials. The results will enable future investigators to establish the effectiveness of heat acclimation with precision and the appropriate sample size to detect change for the ambient conditions reported.

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Key points

- To allow paediatric heat acclimation guidelines to be produced, the extent of heat acclimation needs to be established once biological and mechanical variation has been accounted for.
- The results of the present study indicate that between trial differences were low for aural temperature, mean skin temperature and heart rate with coefficient of variation values ranging from 0.6 - 4.0 %.
- Future investigators will be able to utilise the coefficient of variation values to establish the effectiveness of heat acclimation with precision alongside the selection of appropriate sample size.

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