

## NOTE

## The validity of tympanic and exhaled breath temperatures for core temperature measurement

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### Abstract

We examined the efficacy of tympanic ( $T_{ty}$ ) and exhaled breath ( $T_X$ ) temperatures as indices of rectal temperature ( $T_{re}$ ) by applying heat (condition A) and cold (condition B) in a dynamic A-B-A-B sequence. Fifteen healthy adults (8 men; 7 women;  $24.9 \pm 4.6$  years) volunteered. Following a 15 min baseline period, participants entered a water tank maintained at  $42^\circ\text{C}$  water temperature and passively rested until their  $T_{re}$  increased by  $0.5^\circ\text{C}$  above baseline. Thereafter, they entered a different water tank maintained at  $12^\circ\text{C}$  water temperature until their  $T_{re}$  decreased by  $0.5^\circ\text{C}$  below baseline. This procedure was repeated twice (i.e. A-B-A-B).  $T_{ty}$  demonstrated moderate response delays to the repetitive changes in thermal balance, whereas  $T_X$  and  $T_{re}$  responded relatively fast. Both  $T_{ty}$  and  $T_X$  correlated significantly with  $T_{re}$  ( $P < 0.05$ ). Linear regression models were used to predict  $T_{re}$  based on  $T_{ty}$  and  $T_X$ . The predicted values from both models correlated significantly with  $T_{re}$  ( $P < 0.05$ ) and followed the changes in  $T_{re}$  during the A-B-A-B thermal protocol. While some mean differences with  $T_{re}$  were observed ( $P < 0.05$ ), the 95% limits of agreement were acceptable for both models. It is concluded that the calculated models based on tympanic and exhaled breath temperature are valid indicators of core temperature.

Keywords: ear canal temperature, expiratory temperature, rectal temperature

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## Introduction

Monitoring the body's core temperature is crucial as deviations from its optimal range are suggestive of a pathological condition (Romanovsky 2007). The main value of thermometry in clinical decision making stems from monitoring changes in core temperature across time (i.e. medical history), not from comparing the patient's temperature with what is regarded as 'normal' temperature. This is because 'normal temperature' has a relatively large range across different individuals (Mackowiak *et al* 1992) and measurement sites (Farnell *et al* 2005).

A number of investigations have been designed to find a valid, practical, non-invasive and economically viable method for monitoring core temperature change (Farnell *et al* 2005, Khorshid *et al* 2005, Fisk and Arcona 2001). Rectal temperature ( $T_{re}$ ) is regarded as the most valid core temperature index but it is impractical, invasive and expensive for everyday clinical use. Tympanic temperature ( $T_{ty}$ ) is regarded by some as an effective core temperature index (Fisk and Arcona 2001), yet several recent investigations raise concerns regarding its validity (Farnell *et al* 2005, Fulbrook 1997, Khorshid *et al* 2005). Given that airway temperature is a very good indicator of mucosal and bronchial blood flow (Gilbert and McFadden 1992, Paredi *et al* 2003, 2005), exhaled breath temperature ( $T_X$ ) may be a valuable index for clinical core temperature monitoring that is valid, practical, non-invasive and economically viable. The strong link between  $T_X$  and pulmonary circulation led previous authors to propose non-invasive  $T_X$ -based indices for determining pulmonary blood flow (Serikov *et al* 1992). However, despite evidence that step increases in core temperature correlated with  $T_X$  (Hanson Rde 1974), to date there have been no attempts to examine the efficacy of  $T_X$  as an index of core temperature. Our objective in this experiment was to examine the efficacy of  $T_{ty}$  and  $T_X$  as indices of  $T_{re}$  during repetitive hot (condition A) and cold (condition B) water immersion in an A-B-A-B sequence.

## Methods

### *Participants and procedures*

The experimental protocol was approved by the ethical review board at Dalhousie University. Fifteen healthy non-smoking adults (men: 8; women: 7; age  $24.9 \pm 4.6$  years; body mass index  $25.0 \pm 4.3$ ; body fat:  $16.3 \pm 9.2\%$ ) volunteered. Participants were screened for pregnancy and medications for high blood pressure. Women were tested during the early follicular phase (days 1–6) of their menstrual cycle. Written informed consent was obtained from all participants after full explanation of the procedures involved.

Participants attended a trial performed at 1000 h. Prior to testing, participants dressed down to a bathing suit (men wore a regular one-piece swimming suit, while women wore either a one- (whole body) or a two-piece swimming suit). During the first phase of data collection, baseline measurements were conducted with participants relaxed and seated in a thermoneutral environment (ambient temperature and humidity of  $25^\circ\text{C}$  and 40%, respectively) for 20 min. In the second phase, participants entered a water tank maintained at  $42^\circ\text{C}$  water temperature and passively rested until their  $T_{re}$  was increased by  $0.5^\circ\text{C}$  above baseline. Thereafter, in the third phase, they exited the warm bath and entered a different water tank maintained at  $12^\circ\text{C}$  water temperature until their  $T_{re}$  was decreased by  $0.5^\circ\text{C}$  below baseline. This procedure was repeated twice (i.e. A-B-A-B design) with a total of five phases: one baseline, two warming phases and two cooling phases. No certain timeframe was set, as the objective of the protocol was to reach a certain increase or decrease in  $T_{re}$  during each phase.

A flexible thermistor (MA-100, Thermometrics, Edison, NJ, USA) was inserted in the participants' ear canal to assess  $T_{ty}$ . The probe was pushed gently until such a time as it touched the tympanic membrane. At this point, the participant sensed a slight discomfort and the probe was then retracted slightly. Assessment of breath-by-breath  $T_X$  was achieved while participants inspired room air through a mask (7400 Series Vmask, Hans Rudolph Inc., Kansas City, USA) connected to a low-resistance one-way valve (5710 Series, Hans Rudolph Inc., Kansas City, USA) incorporating a unidirectional silicone spiral-type diaphragm that allowed only expired air to flow through the valve, while inspired air came from the environment. Measurements of  $T_X$  were taken using a ceramic chip thermistor (MA-100, Thermometrics, Edison, NJ, USA) placed inside the valve, approximately 2 cm from the participants' lips. To ensure that  $T_X$  was not a function of respiratory rate, the aforementioned low-resistance one-way valve was connected to an automated gas analyzer (TrueOne<sup>®</sup> 2400, Parvo Medics, Sandy, UT, USA) to record breath-by-breath respiratory rate (breaths  $\text{min}^{-1}$ ). To assess  $T_{re}$ , participants self-inserted a flexible rectal temperature probe (Mon-A-Therm Core, Mallinkrodt Medical, St Louis, USA) to a depth of 15 cm beyond the anal sphincter.

### Statistical analyses

In order to derive  $T_{ty}$  and  $T_X$  models predicting  $T_{re}$ , the sample was randomly divided into the model (men: 6; women: 5) and validation (men: 2; women: 2) groups. Pearson's correlation coefficients and repeated-measures ANOVA incorporating Bonferroni post hoc  $t$  tests were used to assess the agreement between  $T_{re}$  and either  $T_{ty}$  or  $T_X$ . Thereafter, two simultaneous linear regression models were calculated incorporating  $T_{re}$  as dependent variable and either  $T_{ty}$  or  $T_X$  as independent variables. The ability of the calculated models to predict  $T_{re}$  was assessed in the validation group using correlation coefficients, repeated-measures ANOVA incorporating Bonferroni post hoc  $t$  tests as well as 95% limits of agreement analysis according to known procedures (Bland and Altman 1986, Flouris *et al* 2004, 2005). Finally, given the possibility that  $T_X$  may be influenced by respiratory rate, simultaneous linear regression analysis was used to model the effect of respiratory rate (independent variable) on  $T_X$  (dependent variable) using data from the entire sample. All statistical analyses were performed with SPSS (version 17, SPSS Inc., Chicago, Illinois) statistical software package. The level of statistical significance was set at  $P < 0.05$  except for post hoc tests in which a Bonferroni adjustment was applied.

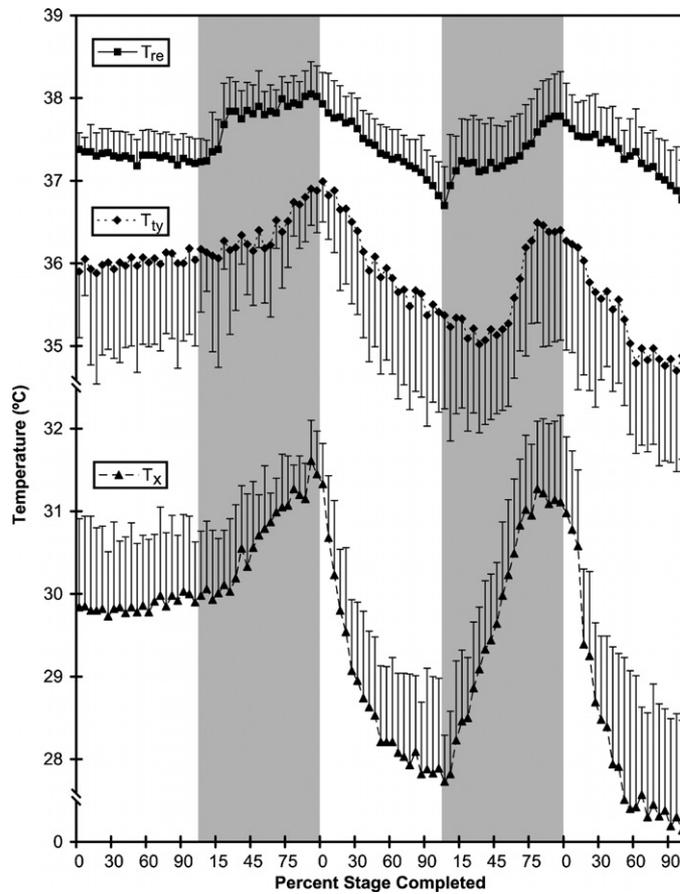
### Results

Mean $\pm$ SD values for  $T_{ty}$ ,  $T_X$  and  $T_{re}$  across time in the entire sample are presented as a function of percent stage completion in figure 1. It was evident that  $T_{ty}$  demonstrated moderate response delays to the repetitive changes in thermal balance, whereas  $T_X$  and—to a lesser extent— $T_{re}$  responded relatively fast. Table 1 shows mean $\pm$ SD for  $T_{ty}$  and  $T_X$  with corresponding correlation coefficients against  $T_{re}$  for the model group in each phase of the experiment. Both  $T_{ty}$  and  $T_X$  correlated significantly with  $T_{re}$  ( $P < 0.05$ ), while the mean value comparisons illustrate the ability of  $T_X$  to respond fast to changes in thermal balance.

Using data from the model group, the linear regression models for  $T_{ty}$  ( $R^2 = 0.19$ ,  $F = 33.76$ ,  $P < 0.001$ ) and  $T_X$  ( $R^2 = 0.34$ ,  $F = 74.23$ ,  $P < 0.001$ ) for predicting  $T_{re}$  were

$$T_{re} = (T_{ty} * 0.20) + 30.05 \quad (P_{ty})$$

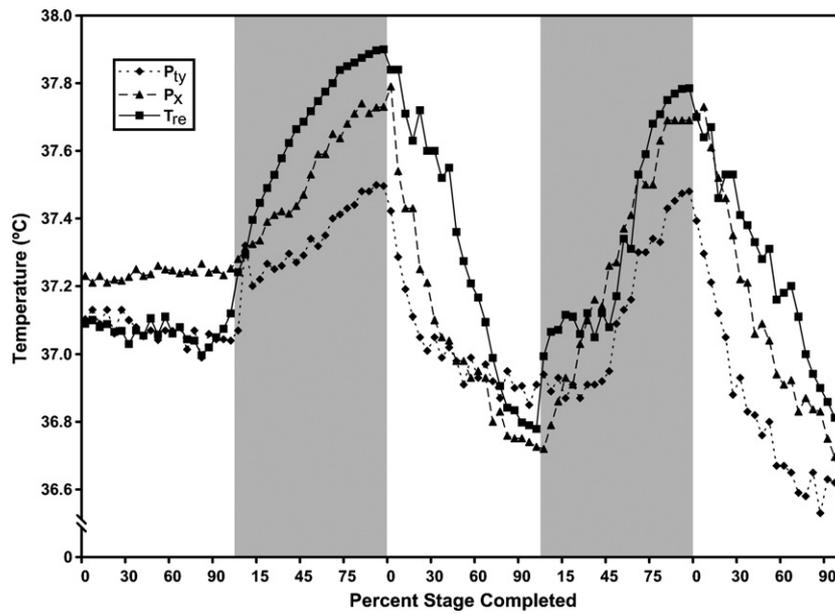
$$T_{re} = (T_X * 0.25) + 29.99 \quad (P_X).$$



**Figure 1.** Mean $\pm$ SD tympanic temperature ( $T_{ty}$ ), exhaled breath temperature ( $T_x$ ) and rectal temperature ( $T_{re}$ ) as a function of percent stage completion in the entire group. The far-left clear area represents the baseline phase, shaded areas represent the warming phases and the remaining two clear areas represent the cooling phases of the experiment.

The mean $\pm$ SD  $T_{re}$  as well as the predicted  $T_{re}$  based on tympanic ( $P_{ty}$ ) and exhaled breath temperatures ( $P_x$ ) in the validation group are illustrated in figure 2 as a function of percent stage completion. Both  $P_{ty}$  and  $P_x$  appeared to follow the changes in  $T_{re}$  during the A-B-A-B thermal protocol. The mean $\pm$ SD for  $P_{ty}$  and  $P_x$  with corresponding correlation coefficients and 95% limits of agreement against  $T_{re}$  for the validation group in each phase of the experiment are presented in table 2. The predicted values correlated significantly with  $T_{re}$  ( $P < 0.05$ ), yet mean comparisons demonstrated statistically significant differences ( $P < 0.05$ ). However, the calculated 95% limits of agreement suggest that  $P_{ty}$  and—particularly— $P_x$  were acceptable alternatives for  $T_{re}$ . For instance, a hypothetical  $T_{re}$  value of 37 °C can be predicted as high as 37.83 °C or as low as 36.73 °C based on  $P_{ty}$ . Using  $P_x$ , a hypothetical  $T_{re}$  value of 37 °C can be predicted as high as 37.55 °C or as low as 36.75 °C.

The mean $\pm$ SD respiratory rate as a function of percent stage completion in the entire group is illustrated in figure 3 showing no apparent influence from the A-B-A-B thermal protocol across time. This was confirmed via linear regression analysis which showed no association between  $T_x$  and respiratory rate ( $R^2 = 0.00$ ,  $F = 0.24$ ,  $P > 0.05$ ).



**Figure 2.** Mean±SD rectal temperature ( $T_{re}$ ) as well as predicted  $T_{re}$  based on tympanic ( $P_{ty}$ ) and exhaled breath temperatures ( $P_X$ ) as a function of percent stage completion in the validation group. Graph properties are similar to figure 1.

**Table 1.** Mean±SD for  $T_{ty}$  and  $T_X$  with corresponding correlation coefficients against  $T_{re}$  for the model group in each phase of the experiment.

Phase	$T_{ty}$	$T_X$	$T_{re}$
1	$36.2 \pm 0.6_{0.43\ddagger}$	$29.6 \pm 0.7_{0.58\ddagger}$	$37.3 \pm 0.3$
2	$36.5 \pm 0.6_{0.47\ddagger}$	$30.6 \pm 0.8^*_{0.69\ddagger}$	$37.9 \pm 0.5^*$
3	$36.2 \pm 1.0_{0.69\ddagger}$	$28.6 \pm 1.2^*_{0.22\ddagger}$	$37.8 \pm 0.4$
4	$36.0 \pm 1.1_{0.63\ddagger}$	$30.1 \pm 1.3^*_{0.35\ddagger}$	$37.6 \pm 0.6^*$
5	$35.4 \pm 1.1^*_{-0.27\ddagger}$	$28.8 \pm 1.4^*_{0.51\ddagger}$	$37.7 \pm 0.5$

Differences between  $T_{re}$  and  $T_{ty}$  or  $T_X$  were significant at  $P < 0.001$  for all phases.

\* Difference from the previous phase significant at  $P < 0.05$ .

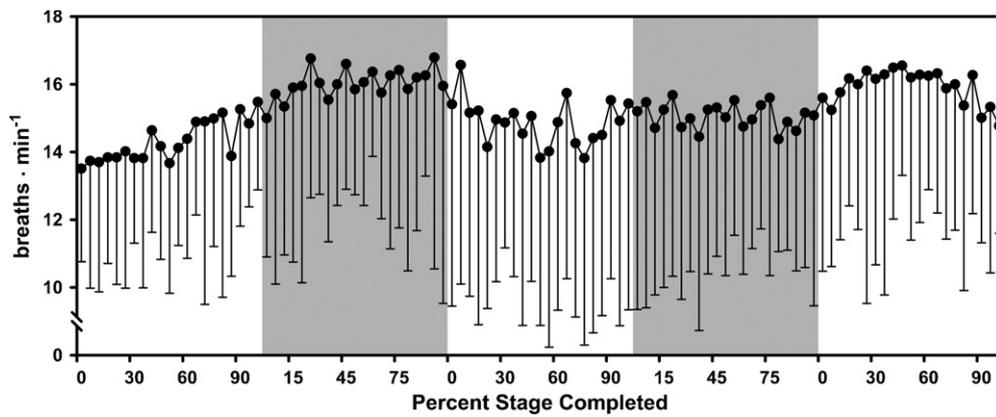
† Correlation with  $T_{re}$  significant at  $P < 0.001$ .

$T_{ty}$ ,  $T_X$ , and  $T_{re}$  = tympanic, exhaled and rectal temperatures, respectively; phase 1: baseline; phases 2 and 4: warming; phases 3 and 5: cooling.

## Discussion

We found that  $P_{ty}$  and—particularly— $P_X$  are valid indicators of  $T_{re}$  during repetitive hot (condition A) and cold (condition B) water immersion in an A-B-A-B sequence. Based on the calculated 95% limits of agreement, the worst possible predictions of  $P_{ty}$  and  $P_X$  were over-predictions of 0.83 °C and 0.55 °C, respectively. Moreover,  $P_X$  was not influenced by breathing patterns, since no association was observed between  $T_X$  and respiratory rate.

The adopted A-B-A-B design is one of the most widely used designs to examine the causal effects of an intervention as well as the causal relationships between target responses and causal variables (Hersen 2007, Flouris and Cheung 2009). While core temperature is



**Figure 3.** Mean $\pm$ SD respiratory rate as a function of percent stage completion in the entire group. Graph properties are similar to figure 1.

**Table 2.** Mean $\pm$ SD for  $P_{ty}$  and  $P_X$  with corresponding correlation coefficients and 95% limits of agreement against  $T_{re}$  for the validation group in each phase of the experiment. The actual range of agreement limits is also shown for a hypothetical  $T_{re}$  value of 37 °C.

	Phase	Mean $\pm$ SD	$r$	LoA	LoA range for $T_{re} = 37$ °C	
$P_{ty}$	1	37.07 $\pm$ 0.04	0.45 $\ddagger$	0 $\pm$ 0.07	36.93	37.07
	2	37.34 $\pm$ 0.11* $\dagger$	0.89 $\ddagger$	0.33 $\pm$ 0.23	37.10	37.56
	3	37.01 $\pm$ 0.14* $\dagger$	0.82 $\ddagger$	0.28 $\pm$ 0.55	36.73	37.83
	4	37.12 $\pm$ 0.23*	0.98 $\ddagger$	0.22 $\pm$ 0.18	37.04	37.40
	5	36.82 $\pm$ 0.25* $\dagger$	0.90 $\ddagger$	0.42 $\pm$ 0.25	37.17	37.67
$P_X$	1	37.24 $\pm$ 0.02*	-0.31	-0.17 $\pm$ 0.08	36.75	36.91
	2	37.53 $\pm$ 0.16* $\dagger$	0.96 $\ddagger$	0.14 $\pm$ 0.14	37.00	37.28
	3	37.04 $\pm$ 0.30* $\dagger$	0.91 $\ddagger$	0.24 $\pm$ 0.31	36.93	37.55
	4	37.28 $\pm$ 0.32* $\dagger$	0.92 $\ddagger$	0.06 $\pm$ 0.25	36.81	37.31
	5	37.10 $\pm$ 0.34*	0.95 $\ddagger$	0.14 $\pm$ 0.22	36.92	37.36
$T_{re}$	1	37.07 $\pm$ 0.03				
	2	37.67 $\pm$ 0.21 $\dagger$				
	3	37.29 $\pm$ 0.37 $\dagger$				
	4	37.34 $\pm$ 0.30				
	5	37.25 $\pm$ 0.29				

\*Mean difference with  $T_{re}$  significant at  $P < 0.05$ .

$\dagger$  Mean difference from the previous phase significant at  $P < 0.05$ .

$\ddagger$  Correlation with  $T_{re}$  significant at  $P < 0.05$ .

$P_{ty}$  and  $P_X$  = tympanic and exhaled predicted temperatures, respectively;  $T_{re}$  = rectal temperature; phase 1: baseline; phases 2 and 4: warming; phases 3 and 5: cooling;  $r$  = Pearson's correlation coefficient; LoA = 95% limits of agreement.

typically not rapidly fluctuating in sick individuals as much as in the present experiment, the underlying premise in our experiment was that applying heat (condition A) and cold (condition B) in an A-B-A-B sequence would allow us to draw inferences for the efficacy of  $P_{ty}$  and  $P_X$  as indices of  $T_{re}$ . Indeed, while the limits of agreement found herein for the

$P_X$  and, particularly, the  $P_{ty}$  were not very narrow, it seems reasonable to suggest that the two predictive models will perform better in a real life scenario where temperature fluctuations are less abrupt.

From a theoretical perspective,  $T_{ty}$  is regarded by some as an effective core temperature index (Fisk and Arcona 2001), yet several recent investigations raise concerns regarding its validity (Farnell *et al* 2005, Fulbrook 1997, Khorshid *et al* 2005). On the other hand, the efficacy of  $T_X$  as an index of core temperature has not been previously investigated. To date, research has shown that step increases in core temperature correlate with  $T_X$  (Hanson Rde 1974) and that it can be used as an indicator of mucosal and pulmonary blood flow (Gilbert and McFadden 1992, Paredi *et al* 2003, 2005, Serikov *et al* 1992). From a practical standpoint, both indices provide easy, non-invasive and economically viable measurements of core temperature. Based on these notions, if the efficacy of  $T_X$  is confirmed in future studies, it can be suggested that this index may be a more appropriate index of core temperature.

It is important to highlight that the absolute  $T_{ty}$  and  $T_X$  values differ significantly from  $T_{re}$ , as shown in figure 1. In order to derive  $T_{re}$  values, the  $P_{ty}$  and  $P_X$  models calculated herein should be applied. The potential benefit for  $P_{ty}$  and  $P_X$  being accurate diagnostic indices for  $T_{re}$  may be very significant where seriously ill patients are being regularly and frequently monitored. Time lost before a cooling intervention is instituted may be vital in conditions such as meningitis. Therefore, it may be possible to integrate real-time monitoring of exhaled breath temperature into existing ventilator masks. This human cost is not the sole benefit as the financial cost to the health system of inaccurate, and, therefore, questionable, equipment is potentially vast. Applications of the present results also include biomedical engineering systems such as liquid conditioning garments that can adopt  $T_X$  as an indicator of change in thermal balance for an automated control system (Flouris and Cheung 2006). It is concluded that the calculated models based on tympanic and exhaled breath temperature are valid indicators of core temperature for diagnosing abrupt changes in  $T_{re}$  within 0.5 °C from normal resting levels.

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