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Oral Temperature as an Index of Core Temperature During Heat Transients*

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Summary. Rectal (T_{re}), oral (T_{or}) and oesophageal (T_{es}) temperatures were measured in five exercising subjects exposed for two hours to five conditions (1) a steady condition (WR) involving a constant work load (50 W) at a constant air temperature ($T_a = 36.5°$ C); (2) air temperature variations (ΔT_a) between 28° C and 45° C and (3) between 23° C and 50° C at constant work load (50 W); (4) and (5) to work load variations (ΔW) between 25 W and 75 W at a constant T_a (= 36.5° C). Oral temperature recordings were taken sublingually and were either continuous or discontinuous. When discontinuous, the time needed for T_{or} to stabilize after the mouth opening was taken into account. The respective reliability of T_{or} and T_{re} as estimates of T_{es} were compared in each condition. Results showed that the resting ($T_{or} - T_{es}$) difference (+ 0.12° C) was barely modified after two hours of exposure, whereas T_{re} overestimated T_{es} by 0.2° C to 0.4° C depending on the condition. The T_{or} variations were highly correlated with T_{es} variations under steady condition and under air temperature variations. In these conditions, T_{or} represented the best estimate of T_{es}. Under work-load variations, T_{or} was less closely related to T_{es} than was T_{re}. It is suggested that the relative inertia of T_{or} to step changes in exercise intensity could be ascribed to work induced variations in mouth blood flow.

Key words: Exercise – Heat – Oral – Rectal and oesophageal temperatures

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Introduction

In temperature regulation studies, the oesophageal temperature (T_{es}) is used as the best indirect measure of the arterial blood temperature. T_{es} has been shown to follow the right arterial blood temperature variations with relatively little lag (Carlsten and Grimby 1958; Cooper and Kenyon 1957) and therefore to quickly reflect rapid changes in the body heat content (Aikäs et al. 1962). Assuming that the temperature of the deep sites of the body closely follows the arterial blood temperature, T_{es} can be considered as the best index of core temperature.

However, when the body temperature in everyday life has to be measured, preference is commonly given to other sites of measurement because of the difficulties of inserting an oesophageal probe. Numerous experiments have thus used either tympanic, ear, rectal or oral temperatures as an indication of core temperature variations.

For ear measurements, it is difficult and often painful to maintain the temperature sensor on the tympanic membrane which can result in auditory canal rather than tympanic membrane temperature being measured. Even in a satisfactory experimental condition, the tympanic temperature is influenced by head skin temperature (Nadel and Horvath 1970; Greenleaf and Castle 1972) and thus reflects the variations of ambient temperature (Marcus 1973; McCaffrey et al. 1975).

Rectal temperature (T_{re}) is usually considered as representative of core temperature in steady ambient conditions (Mead and Bonmarito 1949) but its validity can be questioned during thermal transients (Aikäs et al. 1962). Moreover, during leg exercise, rectal temperature is influenced by local factors (Aulick et al. 1981) and rises higher than the central blood temperature estimated from the oesophageal temperature (Nielsen and Nielsen 1962; Nielsen 1968). Therefore it cannot be considered as representative of the actual core temperature level in such conditions.

Oral temperature (T_{or}) measurements are easy to take and they are well correlated with oesophageal temperature in resting subjects (Cranston et al. 1954). Nevertheless, it has been known for a long time that oral measurements are affected by ambient air temperature (T_a) (Bardswell and Chapman 1911). The core-oral temperature difference rapidly expands when ambient temperature decreases below 18° C whereas, at ambient temperatures higher than 25° C, it tends toward zero or even it becomes slightly negative (Sloan and Keatinge 1975). Accordingly in hot steady conditions ($38° C \leq T_a \leq 48° C$), we found a small difference (−0.26° C) between T_{es} and T_{or} (Candas and Sagot 1980). However all the works mentioned above on oral measurements have been done on subjects in resting conditions.

In working conditions, Wyndham et al. (1959) have observed much higher rectal temperatures than oral temperatures, especially during recovery periods. Other authors (Strydom et al. 1965) subsequently concluded that, during exercise, the rectal-oral difference increases linearly as a function of the work load level and they emphasized the fallacy of relying on oral temperature to estimate the core temperature during heat stress and physical work. These authors however pointed out that the ($T_{re} - T_{or}$) difference could correspond to the temperature difference between the rectum and the oesophagus during leg exercise as previously observed by Nielsen and Nielsen (1962). Therefore, no firm conclusion can be drawn without measuring the oesophageal temperature.

In fact, the only study involving a critical comparison of oral and oesophageal temperatures during work (Edwards et al. 1978) indicated that in neutral conditions (T_a = 24° C) oral temperature gives an accurate prediction of oesophageal temperature.

The present study was undertaken therefore to examine the relationships between rectal, oral and the oesophageal temperature in warm ambient conditions. The three body temperatures were compared during exposures both to steady conditions and to variations in environmental or metabolic loads.

Methods

This study was conducted on five healthy male volunteers (mean physical characteristics: ht, 176 ± 7 cm; wt, 70 ± 7 kg; age, 23 ± 2.4 yr; maximal O_2 consumption, $3.4 \pm 0.4 \, l \cdot min^{-1}$). Each subject participated in five randomly ordered experiments, in a climatic chamber; one week elapsed between tests on the same subject to avoid acclimation effects. Before the experiment, the subject had a light meal in the laboratory and dressed in briefs and gym shoes. Once fitted with the temperature probes, he entered the climatic chamber and sat on the cyclo-ergometer, at rest, for 30 min in conditions of thermal neutrality: both air temperature (T_a) and wall temperature (T_w) were 28° C. After this rest period, each experiment consisted of a 120 min work period followed by 30 min of rest in the same conditions as above (Fig. 1). Water vapor pressure was kept constant at 2.0 kPa and air velocity at $0.20 \, m \cdot s^{-1}$ throughout the whole experiment.

As illustrated in Fig. 1, subjects were exposed to five different experimental conditions:

* 1, a steady condition (WR) involving a constant work load (50 W at 60 rpm) at a constant T_a = 36.5° C;
* 2–3, two air temperature variations (ΔT_a) between 28 and 45° C ($\Delta T_a 1$) and between 23 and 50° C ($\Delta T_a 2$) at constant work load (50 W);
* 4–5, two work load variations ($\Delta W1$ and $\Delta W2$) respectively between 75–25 W and 25–75 W at constant air temperature (Ta = 36.5° C). These work load levels represented, on average, 19 and 35% respectively of the subjects maximal oxygen consumption.

Both environmental temperature and work load were varied in positive and negative step changes occurring at 20 min intervals.

Three internal body temperatures were measured: a) in the rectum (T_{re}) 11 cm beyond the anal sphincter with a platinum probe; b) in the oesophagus (T_{es}) at the heart level by using the electrocardiographic method of Brengelmann et al. (1979); and c) in the mouth (T_{or}) under the tongue 4 cm beyond the lips, with thermistor probes. All temperature data were punched on a tape at 1 min intervals but T_{or} and T_{es} were also graphically recorded.

For the oral temperature measurements, the subject was instructed to keep the mouth permanently closed with the probe maintained under the tongue in either the left or right posterior sublingual pocket at the base of the tongue as recommanded by Erickson (1976). While T_{es} and T_{re} were measured continuously, oral temperature measurement was interrupted on certain occasions. Firstly, when the two oxygen consumption measurements were carried out in the experiment. Secondly, at the subject's request in order to reduce the feelings of discomfort, he was allowed to pull out the probe for short periods.

The relationships between the three body temperatures were tested using linear regression analysis. Rectal and oral temperature data were compared to oesophageal data, taken as the independent variable, as showing the smallest source of variation. The data submitted to analysis were the temperature values recorded during the 120 min working period, at the 8th min and at the 20th min of each square pulse variation; in the steady condition (WR), the data were collected at the

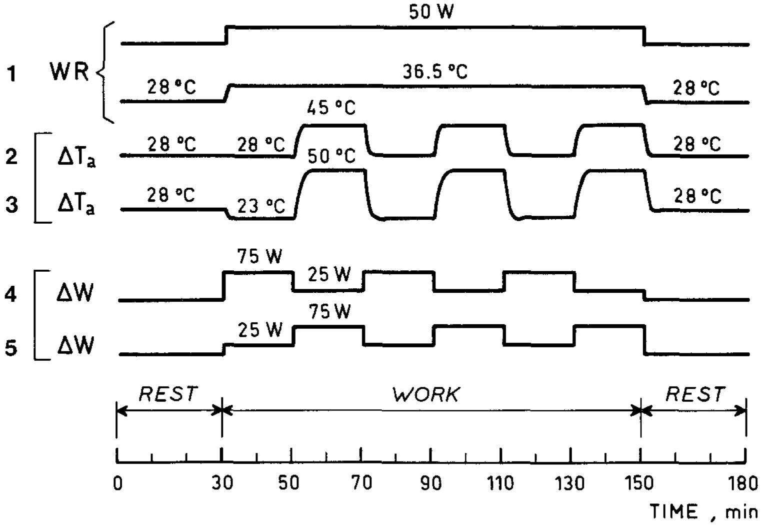

Fig. 1. Experimental conditions

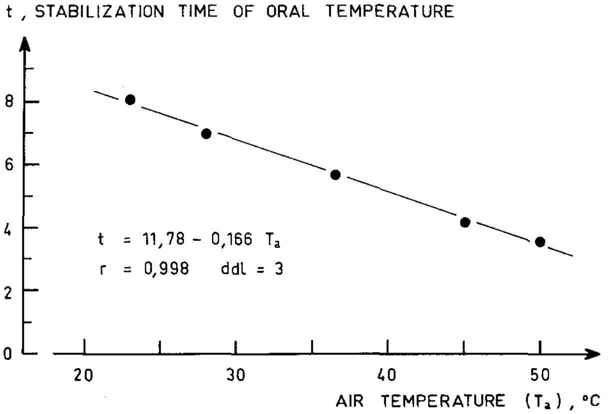

Fig. 2. Stabilization time of oral temperature (one subj.), after 8 min of mouth breathing, as a function of room air temperature. Best fit line significant at $p < 0.02$

same time intervals. However, since this study involved discontinuous as well as near continuous measurements of T_{or}, depending on the subject tolerance, the stabilization of T_{or} was checked every time that the measure was resumed after a mouth opening period. In such circumstances, the recorded T_{or} data were excluded from the analysis if the rate of oral temperature increase ($\Delta T_{or}/dt$) was higher than $0.02° C \cdot min^{-1}$ and higher than the oesophageal rate of increase ($\Delta T_{es}/dt$) as determined from the graphical recording.

In a separate experiment, the stabilization time of oral temperature after mouth cooling was assessed on one subject for five ambient air temperatures ranging from 23° C to 50° C. After observing a steady state of oral temperature with the mouth closed, the temperature probe was taken off, and the subject wearing a nose clip, had to breath by the mouth for 8 min. Then the clip was removed and the subject put the oral probe back again under the tongue. The stabilization time was defined as the time before T_{or} reached its previous steady state level. When plotted against the ambient air temperature (Fig. 2) it decreases with the level of air temperature, ranging from about 8 min at 23° C to less than 4 min at 50° C.

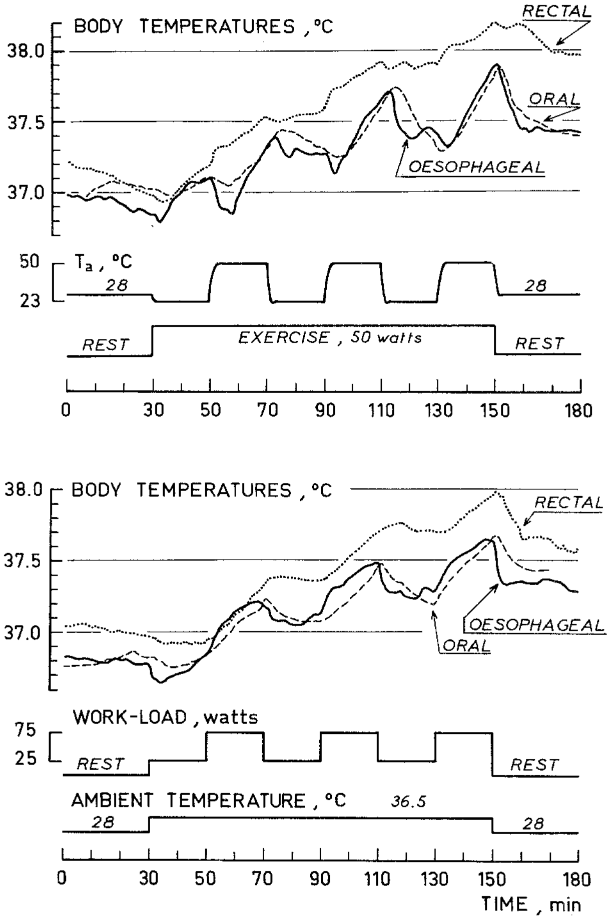

Fig. 3. Rectal, oral and oesophageal response patterns (one subj.) to *top:* air temperature variations and *bottom:* work load variations

Results

Figure 3 shows one subject's typical responses of rectal, oral, and oesophageal temperatures *top:* to variations in air temperature at a constant work load and *bottom:* to variations in work load at a steady air temperature level. Missing oral temperature data during the oxygen consumption measurements have been interpolated. In both conditions, the oral-oesophageal difference was clearly smaller than the rectal-oesophageal one. Moreover, the rectal temperature increased more than the oesophageal one throughout the 2 h of exposure. This trend was observed in all experimental conditions and by each subject. When considering the average levels of T_{re} and T_{es} on the five subjects (Table 1), the rectal-oesophageal difference at the end of work amounted to 0.4° C and was thus increased by 0.2° C during the work period, with regard to the difference observed at rest. Figure 3 shows also that this $T_{re} - T_{es}$ difference further

Table 1. Average levels (± 1 SD) on five subjects of rectal, oral and oesophageal temperatures at different times of the exposure

	Rest	End of work period	Recovery	End recovery
	Time (min)			
	26–30 (n = 18)	138–150 (n = 18)	155 (n = 14)	170 (n = 14)
T_{re} (°C)	36.85 (± 0.19)	37.64 (± 0.33)	37.63 (± 0.37)	37.49 (± 0.29)
T_{or} (°C)	36.75 (± 0.21)	37.31 (± 0.28)	37.28 (± 0.30)	37.16 (± 0.21)
T_{es} (°C)	36.63 (± 0.17)	37.23 (± 0.32)	37.17 (± 0.27)	37.14 (± 0.25)

increased during the first minutes of the recovery period. In comparison, the oral-oesophageal difference observed during the initial rest was barely modified as a function of the time of exposure (Fig. 3 and Table 1).

However, when separately considering each 20 min period of environmental or metabolic change, it can be seen that T_{es} and T_{or} did not exhibit an identical pattern of variation. Under ΔT_a condition (top), although T_{es} and T_{or} both showed a transient drop in temperature at the start of heating periods, T_{es} response was more marked, reflecting the greater sensitivity of T_{es} to the peripheral vasodilation (induced by the T_a increase). Under exposure to ΔW condition (bottom), T_{es} increased and decreased rapidly with each step increase and decrease in work intensity, whereas T_{or} response lagged behind.

All the temperature data selected for analysis (see Methods) in the different conditions have been pooled and are plotted in Figs. 4 and 5 showing respectively the rectal-oesophageal and oral-oesophageal temperature relationships.

In Table 2, the regression equations are presented for each set of experimental conditions: WR, ΔTa and ΔW. All regression coefficients indicate that at least 75% of the variation is taken into account by these relationships. It clearly appears that the smallest residual mean squares are observed for the $T_{or} - T_{es}$ relationship.

Figure 6 is more informative for interpretation of results: this figure shows the range of variation in T_{re} and T_{or} when T_{es} varies from 36.30° C to 37.80° C, the range of T_{es} variation in our conditions. At low levels of core temperature (start of exercise data), both T_{re} and T_{or} are similar and somewhat higher than T_{es}.

At high levels of internal temperature (end of exercise data), T_{or} reaches values near the oesophageal ones. In comparison, T_{re} levels always overestimate by 0.2° C to 0.4° C the T_{es} levels in each of our conditions. The overall relationships between these variables confirm these observations: T_{or} varies between 36.44° C to 37.79° C when T_{es} varies between 36.30° C and 37.80° C, while T_{re} varies from 36.42° C to 38.17° C in the same conditions.

Data presented in Table 2 and Fig. 6 strongly suggest that oral temperature provides a better estimation of core temperature than rectal temperature, both

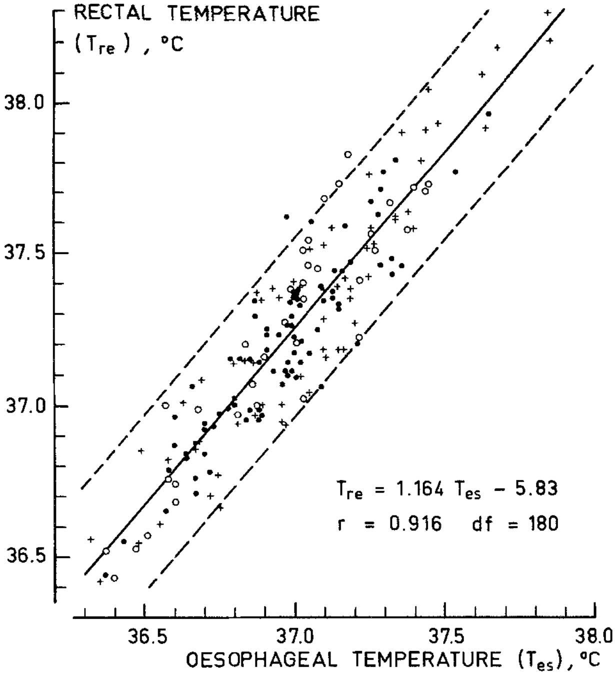

Fig. 4. Relationship between rectal and oesophageal temperature during exercise. The graph shows the calculated regression line (———) with two standard deviations of this line (– – –). ○ Steady conditions, + Air temperature variations, ● Work load variations data

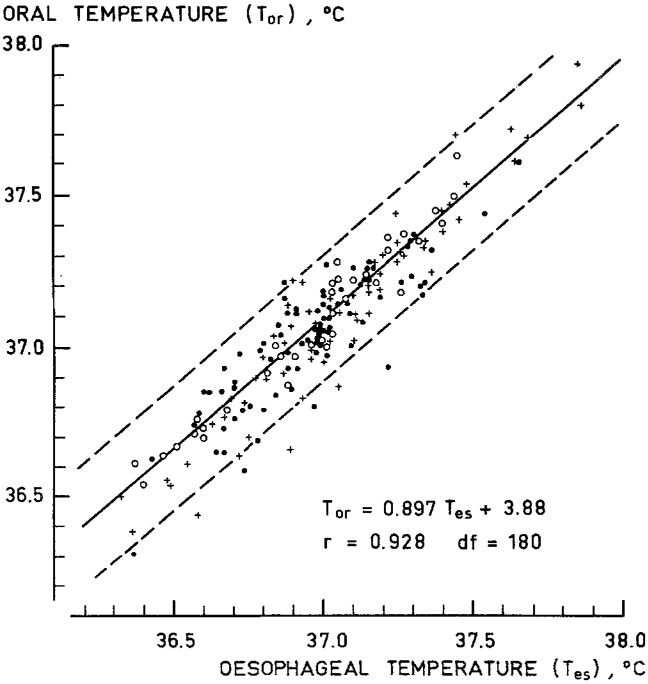

Fig. 5. Relationship between oral and oesophageal temperature during exercise. For symbols, see legend of Fig. 4

Table 2. Relationships between T_{re}, T_{or} and T_{es} as the independent variable (in °C) for each set of experimental conditions. T_{re} or T_{or} = $aT_{es} + b$

Exp	*n*	Dependent variable	a	b	r	SD
WR	36	T_{re}	1.207	−7.38	0.923	0.16
		T_{or}	0.898	+3.86	0.974	0.06
Δ T_a	62	T_{re}	1.179	−6.39	0.919	0.17
		T_{or}	0.973	+1.05	0.948	0.11
Δ W	84	T_{re}	1.116	−4.05	0.903	0.13
		T_{or}	0.796	+7.60	0.866	0.11

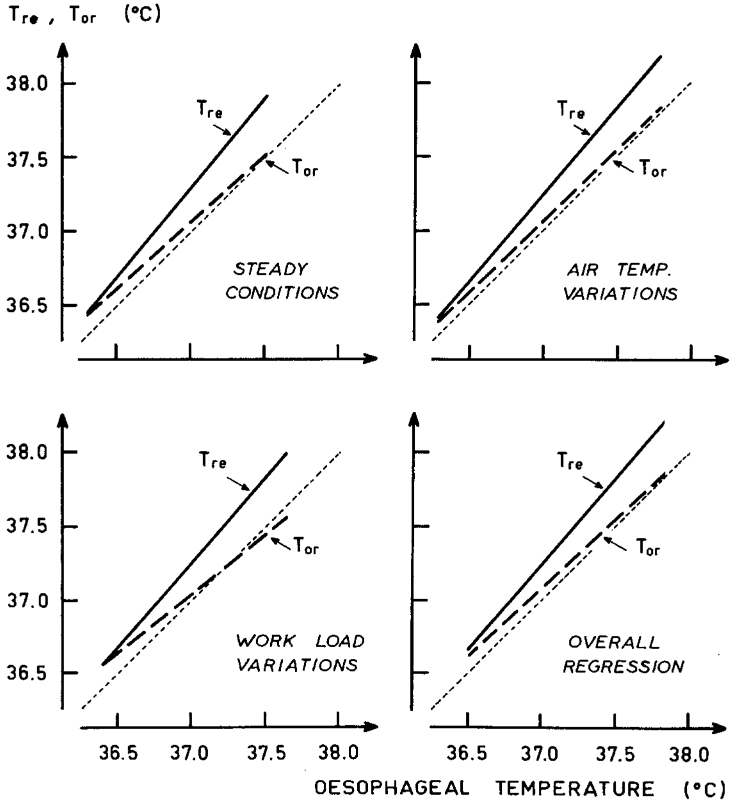

Fig. 6. Relationships between rectal/oral temperature and oesophageal temperature, during the different experimental conditions

during exposure to steady conditions and during exposure to air temperature variations. However, during work-load variations, the oral oesophageal relationship is weaker than in the other conditions and oral temperature slightly underestimates high levels of T_{es}. In such conditions, T_{re} as index of core temperature, seems to be as good or even better than oral temperature.

Discussion

The reliability of oral temperature as an index of core temperature cannot be assessed without taking into account the methodology used for its determination. The stabilization time for oral temperature measurement is indeed not only dependent on the physical characteristics of the temperature sensor but also on the ambient conditions at the time of measurement. When the air temperature is lower than oral temperature, breathing through the mouth induces a cooling by both convection and evaporation at the surface of the oral mucosa. For air temperatures higher than oral temperature, a thermal equilibrium will become established between the convective heat gain and the evaporative heat loss.

Several authors (Bardswell and Chapman 1911; Cranston et al. 1954; Sloan and Keatinge 1975) stated that oral temperature may take 10–20 min to stabilize after the mouth has been closed at room temperature between 18° C and 24° C. In a clinical investigation at the same ambient temperatures, Nichols and Kucha (1972) stated that the optimum duration of measurement was 8 or 9 min, depending on the sex. However, that optimum duration was lower (7 min) when ambient temperature was between 24° C and 30° C. Their observation is in close agreement with our own data (Fig. 2) gathered after 8 min of mouth breathing in different ambient temperatures. In view of these observations, the validity of routine measurements with a clinical thermometer placed under the tongue for two or three minutes only seems to be highly questionable. The conclusions of this study could hardly be extrapolated to such conditions of measurement.

Owing to a systematic checking of the T_{or} stabilization, the results of this study showed both very small differences between the respective levels of oral and oesophageal temperatures and a high correlation between the variations of these two temperatures, in all conditions of measure, whether continuous or discontinuous.

In resting conditions at near thermal neutrality (T_a = 28° C), the ($T_{es} - T_{or}$) difference that we observed (−0.12° C, Table 1) can be compared to the positive difference reported in cooler conditions (Cranston et al. 1954; Edwards et al. 1978) and to the larger negative difference (−0.26° C) observed in hot conditions (Candas and Sagot 1980). This variation of ($T_{es} - T_{or}$) difference with ambient conditions is quite similar to that reported by Sloan and Keatinge (1975) for air temperatures between 18° C and 44° C.

At work and under step changes in air temperature (Table 2), the strong relationship between T_{es} and T_{or} variations substantiates previous observations made in resting subjects whose limb or other part of the body was immersed in a hot bath (Cranston et al. 1954; McCaffrey et al. 1975; Edwards et al. 1978). It supports, for exercising subjects, Cranston's conclusion that the variations in cutaneous vasomotor tone are highly correlated with changes in oral temperature. The rich blood supply provided to the tongue via the lingual branch of the external carotid artery could explain the sensitivity of the sublingual temperature measurements to rapid variations in central blood temperature. Data gained from animal studies have shown that the blood flow per gramme of tissue in resting conditions is higher in the tongue than in most other muscular organs of the body (Hellekant 1972).

Under step changes in work load however, results showed that oral temperature leads to an underestimation of high levels of T_{es} (Fig. 6). This trend could be interpreted, when related to previous observations made at 24° C ambient temperature by Edwards et al. (1978). They observed that the increase in oral temperature during two 10 min exercise periods at 75 W or 100 W lagged behind the T_{es} increase by 0.18° C. In their condition, several local factors could have contributed to slow down the oral response: the temperature of the saliva (Sloan and Keatinge 1975), the skin temperature of the head (McCaffrey et al. 1975) and the increased ventilation through the nose (Cranston et al. 1954). But conversely, in our conditions at 36.5° C air temperature, these factors cannot have depressed the oral temperature. The relative inertia of oral temperature response to an increase in work intensity could suggest a simultaneous decrease in mouth blood flow. The sympathic vasomotor activity is known to increase in proportion to the severity of exercise and consequently to reduce blood flow to non-exercising regions of the body (Bevegard and Shepherd 1967). To what extent does that phenomenon affect the mouth? Unfortunately, we have been unable to trace any publication dealing with oral blood flow response to exercise variations.

As regard to the ($T_{re} - T_{or}$) difference, a 0.33° C difference was observed between the two temperatures after 2 h of exercise (Table 1). It is markedly less than the 0.65° C ($T_{re} - T_{or}$) difference observed by Strydom et al. (1965) after three hours work at the same work load. This larger difference in temperature is likely to be due to the short duration (3 min) of oral measurements in that latter study. More, our results clearly showed that the increases in ($T_{re} - T_{or}$) and in ($T_{re} - T_{es}$) difference during work were of the same order. Therefore in our conditions, the ($T_{re} - T_{or}$) difference did not correspond to a difference between oral and core temperature but is a further illustration of the well documented rectal temperature rise during leg exercise (Nielsen and Nielsen 1962; Nielsen 1968; Aulick et al. 1981).

In summary, the sublingual temperature represents an accurate estimate of oesophageal temperature in both steady and fluctuating warm ambient conditions, for subjects exercising at a work intensity up to 35% of their V_{O2} max. When oral temperature recording is not continuous, the stabilization time of oral temperature after the mouth is closed has to be taken into account to ensure the reliability of the measurement.

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