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ORIGINAL ARTICLE

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The effect of body temperature on the hunting response of the middle finger skin temperature

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Abstract The relationship between body temperature and the hunting response (intermittent supply of warm blood to cold exposed extremities) was quantified for nine subjects by immersing one hand in 8°C water while their body was either warm, cool or comfortable. Core and skin temperatures were manipulated by exposing the subjects to different ambient temperatures (30, 22, or 15°C), by adjusting their clothing insulation (moderate, light, or none), and by drinking beverages at different temperatures (43, 37 and 0°C). The middle finger temperature (T_{fi}) response was recorded, together with ear canal (T_{ear}), rectal (T_{re}), and mean skin temperature ($\bar{T}_{sk}$). The induced mean T_{ear} changes were −0.34 (0.08) and +0.29 (0.03)°C following consumption of the cold and hot beverage, respectively. $\bar{T}_{sk}$ ranged from 26.7 to 34.5°C during the tests. In the warm environment after a hot drink, the initial finger temperature ($T_{fi,base}$) was 35.3 (0.4)°C, the minimum finger temperature during immersion ($T_{fi,min}$) was 11.3 (0.5)°C, and 2.6 (0.4) hunting waves occurred in the 30-min immersion period. In the neutral condition (thermoneutral room and beverage) $T_{fi,base}$ was 32.1 (1.0)°C, $T_{fi,min}$ was 9.6 (0.3)°C, and 1.6 (0.2) waves occurred. In the cold environment after a cold drink, these values were 19.3 (0.9)°C, 8.7 (0.2)°C, and 0.8 (0.2) waves, respectively. A colder body induced a decrease in the magnitude and frequency of the hunting response. The total heat transferred from the hand to the water, as estimated by the area under the middle finger temperature curve, was also dependent upon the induced increase or decrease in T_{ear} and $\bar{T}_{sk}$. We conclude that the characteristics of the hunting temperature response curve of the finger are in part determined by core temperature and $\bar{T}_{sk}$. Both $T_{fi,min}$ and the maximal finger temperature during immersion were higher when the core temperature was elevated; $\bar{T}_{sk}$ seemed to be an important determinant of the onset time of the cold-induced vasodilation response.

Key words Cold-induced vasodilation · Skin temperature · Core temperature · Cold water immersion · Hunting response

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Introduction

Lewis (1930) was the first author to describe the hunting response that occurs during exposure of the fingers to the cold, the ascending part of which is commonly referred to as a cold induced vasodilation (CIVD). He noted, however, that the CIVD reaction in the fingers often failed to occur when the subjects were exposed to low ambient temperatures prior to immersion. Later, Spealman (1945) investigated the effect of exposing the body to different ambient temperatures on hand blood flow. One hand was immersed in water of between 2 and 35°C, while the rest of the body was exposed to three environmental conditions that made the subjects either uncomfortably warm, comfortable, or uncomfortably cool but not shivering. At any given water temperature, hand blood flow was greater when the body felt warmer. Furthermore, the hunting response was reduced when the body felt cold. Later, several studies supported the observation that ambient temperature had an impact on the hunting response. These studies showed that exposing the body to a high ambient temperature during cold finger stress induced an increased finger or hand blood flow during the hunting response (Bader and Mead 1949; Edwards and Burton 1960; Folkow et al. 1963; Keatinge 1957; Spealman 1945), a higher finger skin temperature (Blaisdell 1951; Kramer and Schulze 1948; Werner 1977; Yoshimura and Iida 1950), an increased heat transfer to the surrounding medium (Elsner et al. 1960; Greenfield et al. 1951) and a faster onset of the hunting response (Adams and Smith 1962; Tanaka 1971; Yoshimura and Iida 1950).

Although the ambient temperature varied and the degree of thermal comfort changed in the experiments cited above, no evidence was provided that the observed differences in the hunting response were the result of a changed core temperature (T_c) or a changed mean skin temperature ($\bar{T}_{sk}$). The purpose of the present study was to try to quantify the relationship between T_c / $\bar{T}_{sk}$ and the characteristics of the hunting response for a finger immersed in cold water.

Methods

Subjects

Nine healthy Caucasian male subjects, whose ages ranged from 19 to 34 years, volunteered for the study. These subjects were accustomed to cold-water exposure of the extremities, either from their profession as divers or from participation in similar studies. The subjects were visually checked for a healthy tympanum by a physician. All subjects were informed of the details, discomforts and risks associated with the experimental protocol and had been granted medical approval before they signed a written consent. The protocol was approved by the Human Ethics Committee of the Defence and Civil Institute of Environmental Medicine.

Instrumentation

$\bar{T}_{sk}$ was determined using eight thermistors of 1 cm in diameter (Yellow Springs Instruments, 400 series) taped to the skin with one layer of thin tape on the pad of the left and right middle finger, forehead, back, chest, upper arm, thigh and foot. A thin latex surgical glove was worn over the sensors on the hand that had to be immersed. Rectal temperature (T_{re}) was measured using a Baxter Pharmaseal 400 probe inserted 12 cm beyond the anal sphincter. Ear canal temperature (T_{ear}) was measured using a Baxter Pharmaseal 400 series rectal/oesophageal probe, the plastic cover of which was replaced by silicon tubing. A knot was made near the end of the probe and the knot was fitted tightly into the ear canal. The subjects positioned the end of the probe close to the tympanic membrane, centrally within the ear canal. After touching the tympanic membrane, the probe was withdrawn just enough for the pain sensation to disappear. Hereafter, the external ear was insulated using a cotton ball and head phones.

All temperatures, including the water bath temperature and the ambient temperature were recorded continuously using an automated data acquisition system (Hewlett Packard 85 computer, 3974A scanner/voltmeter), with minute averages calculated and stored for further analysis.

Protocol

There were three main body temperature conditions: warm, neutral and cool. The *warm* body temperature was induced by exposing the subjects to an ambient temperature of 30°C. The subjects were wearing socks, shoes and a sweat shirt and a pair of trousers over shorts and a T-shirt. The *neutral* test (called Nn) was performed in a climatic chamber of 22°C after drinking 750 ml of a beverage (water with added iced tea powder containing mainly sugar) heated to 37°C, and with the subjects wearing shorts, T-shirt, socks and shoes. The *cool* body temperature was induced by an ambient temperature of 15°C, and the subjects wore a swimsuit only.

In the warm and cool conditions the subjects were asked to drink 750 ml of either a cold (0°C) or hot (42–44°C) iced tea beverage. The test in the warm chamber with the cold drink is called Wc, and that with the hot drink is called Wh. In the cool chamber the codes are Cc and Ch, respectively. The beverage was used to vary the T_c, while the ambient temperature was used to vary $\bar{T}_{sk}$.

In the climatic chamber the relative humidity was about 50% for all air temperatures. The horizontal air velocity did not exceed 0.2 m/s.

The order of the sessions was balanced, with the neutral session serving as a control. Each test was performed at the same time of the day for a specific subject with a minimum of 48 h between any two exposures.

After being instrumented with the skin thermistors and the rectal and ear canal probes, the subjects entered the climatic chamber, which was set at a preselected temperature, sat on a chair and waited for stabilization of T_{ear} to its baseline level ($T_{ear,base}$), which took about 20–30 min. The subjects then ingested the beverage within a 5-min period. As the induced change in T_{ear} started to level off (about 15–20 min after consuming the drink), the dominant hand was immersed to the wrist in a temperature-controlled water bath set at 8°C (0.5)°C (Haake, Berlin, Germany) for 30 min. The water bath was positioned at the level of the heart and was vigorously stirred by a jet pump. In order to maintain the elevated or lowered T_{ear}, up to 400 ml of a hot or cold beverage, respectively, was given to the subjects during the immersion. Following the cold water immersion, the hand was withdrawn from the bath and the surgical glove was removed. The hand was then held freely in the ambient air to allow for monitoring of rewarming. The total duration of the test was less than 2 h.

Calculations

$\bar{T}_{sk}$ was calculated according to Hardy and Dubois (1938), with the mean of the left and right finger skin temperature taken as a substitute for hand temperature. $\bar{T}_{sk}$, T_{ear} and T_{re} were averaged over the immersion period and denoted by $\bar{T}_{sk,imm}$, $T_{ear,imm}$ and $T_{re,imm}$, respectively. The following descriptors of the finger hunting response were determined: baseline finger pad temperature just prior to immersion ($T_{fi,base}$), time to the first rise in temperature after immersion (onset time), minimum recorded temperature ($T_{fi,min}$), maximum recorded temperature after the first minimum ($T_{fi,max}$), the largest recorded temperature amplitude (ΔT_{fi}), and the number of waves (N_{waves}, rounded to whole numbers for every subject) during the 30-min immersion period. In some subjects a plateau in finger skin temperature occurred immediately after immersion. In these cases, onset time, N_{waves} and ΔT_{fi} were calculated with reference to the start of the drop following this plateau. The area between the finger skin temperature curve and the 8°C water bath temperature baseline during the 30-min immersion period (AREA) was calculated using a digitization tablet attached to a Hewlett Packard computer. This area has been previously shown to be a good estimator of the heat loss from the fingers during immersion (Hsieh et al. 1965). The descriptors of the hunting response are shown graphically in Fig. 1.

Statistical analysis

A two-way analysis of variance was performed with treatment (beverage, ambient temperature) and subjects as independent variables. If main effects were found for a particular independent variable, all combinations were then analysed by post-hoc analysis (SYSTAT, module MGLH-CONTRAST). Significance was accepted at the level of $P < 0.05$. A multiple linear regression was performed using the least-square criterion, with the order of the independent variables entering the equation determined by the correlation coefficient. All mean values are given with the standard error of the mean (SEM).

Results

Core temperature

The mean values of $T_{ear,base}$ were 0.02–0.65°C [mean: 0.33 (0.03)°C] lower than $T_{re,base}$. Table 1 shows that the

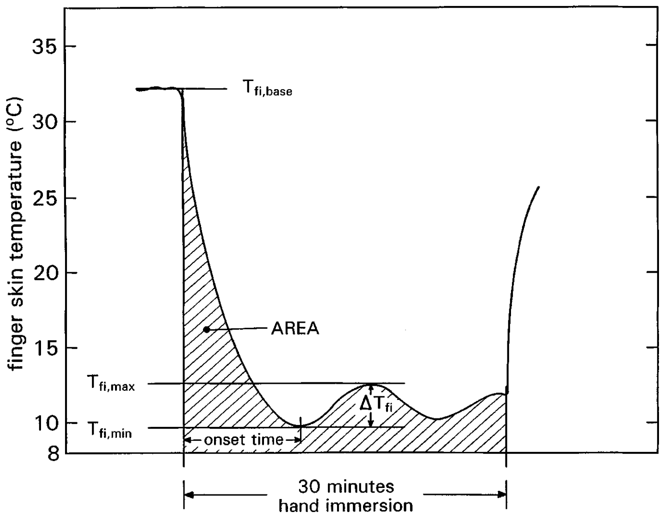

Fig. 1 Schematic representation of the finger hunting response. ($T_{fi,base}$ baseline finger pad temperature just prior to immersion, *onset time* time to the first rise in temperature after immersion, $T_{fi,min}$ minimum recorded finger temperature, $T_{fi,max}$ maximum recorded finger temperature after the first minimum, ΔT_{fi} the largest recorded finger temperature amplitude, *AREA* the area between the finger skin temperature curve and the 8°C water bath temperature baseline during the 30-min immersion period. This parameter is an estimator of heat transfer)

ingestion of either a hot or cold beverage caused significant changes in both T_{ear} and T_{re}. With thermoneutral ingestion there was no change in these T_c measures. The hot beverage caused an increase in T_{ear} and T_{re}. The cold beverage decreased T_{ear} and T_{re}.

In the warmest condition (Wh), the raised T_{ear} could not be fully maintained, probably because of the induced sweating response. However, additional drinking of up to 400 ml of a hot beverage limited the drop of T_{ear} to about 0.1°C during the 30-min immersion period. A lowered T_c could be maintained with only minimal drinking during the immersion period, even though all subjects were shivering during the coldest condition (Cc).

Figure 2 shows the body temperatures at baseline level, just prior to the hand immersion, and just prior to withdrawal of the hand from the water bath.

Mean skin temperature of the body

$\bar{T}_{sk}$ was not different between conditions Wh and Wc, and between Ch and Cc, which indicates that the temperature of the beverage did not influence the $\bar{T}_{sk}$. During the hand immersion, $\bar{T}_{sk}$ decreased insignificantly (Fig. 2). The mean values of $\bar{T}_{sk}$ were 26.8 (0.3)°C in the cool chamber, 32.0 (0.3)°C in the neutral chamber, and 34.4 (0.2)°C in the warm chamber. Mean values of $\bar{T}_{sk}$ obtained at the start and termination of the hand immersion are shown in Fig. 2.

Hunting response

The mean (SEM) values of the descriptors of the hunting response for every experimental condition are given in Table 2. The highest finger skin temperatures and area and the shortest onset time were found for the Wh conditions, followed by those of Wc, Nn, Ch and Cc, respectively. In condition Wh, all subjects showed an initial plateau of the finger skin temperature around 20°C. The largest number of waves were found for the Wh condition followed by Nn, Wc, Ch and Cc, respectively. Contrast analysis revealed that all variables but $T_{fi,base}$ differed between Wh and Nn, and that all variables but ΔT_{fi} differed between Nn and Cc. Interindividual variability remained evident, even under these thermally standardized conditions, as is shown by the SEM values given in Table 2.

The hunting response for conditions Wh, Nn and Cc is visualized in Fig. 3, based on the parameters shown in Table 2.

The relationship between AREA and both T_c and $\bar{T}_{sk}$ was quantified by multiple regression analysis. The best predictors for changes in AREA were $\Delta T_{ear,imm}$ ($T_{ear,imm}$

Table 1 Effect of beverage temperature on core temperature. All core temperatures are expressed as the mean (SEM). (*Nn* Neutral test condition, *Wh* warm chamber plus hot drink condition, *Ch* cool chamber plus hot drink condition, *Wc* warm chamber plus cold drink condition, *Cc* cool chamber plus cool drink condition, T_{ear} temperature of the ear canal, T_{re} rectal temperature)

	Beverage temperature					
	Neutral (37°C) (condition Nn)		Hot (43°C) (conditions Wh & Ch)		Cold (0°C) (conditions Wc & Cc)	
	T_{ear}	T_{re}	T_{ear}	T_{re}	T_{ear}	T_{re}
Before drinking (°C)	36.79 (0.09)	37.20 (0.08)	36.86 (0.06)	37.16 (0.06)	36.86 (0.06)	37.20 (0.06)
After drinking (°C)	36.83 (0.09)	37.19 (0.08)	37.15 (0.06)	37.25 (0.06)	36.52 (0.10)	36.99 (0.07)
Temperature change (°C)	0.03 (0.01)	−0.01 (0.01)	0.29 (0.03)*	0.09 (0.03)*	−0.34 (0.08)*	−0.21 (0.02)*

* Significantly different before and after drinking [paired *t*-test ($P < 0.01$)]

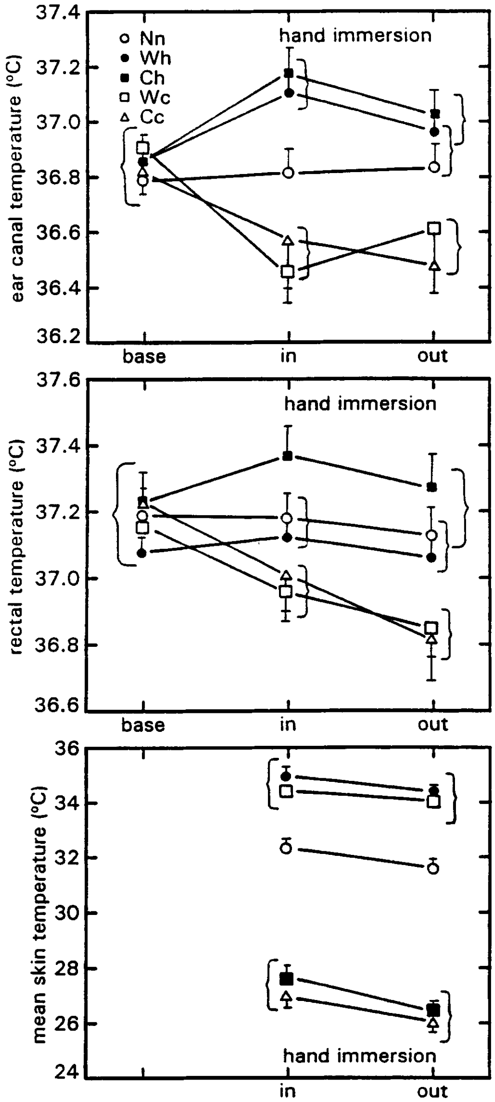

Fig. 2 Core and mean (SEM) skin temperatures ($\bar{T}_{sk}$) observed before and during the hand immersion tests for the five different experimental conditions described in Table 1 (n = 9). The baseline $\bar{T}_{sk}$ was not measured since it was not controlled by the protocol. The values that were not statistically different are grouped by parentheses. (*Nn* Neutral test condition, *Wh* warm chamber plus hot drink condition, *Ch* cool chamber plus hot drink condition, *Wc* warm chamber plus cold drink condition, *Cc* cool chamber plus cool drink condition)

− $T_{ear,base}$) and $\Delta\bar{T}_{sk,imm}$ ($\bar{T}_{sk,imm}$ − 32.2), where 32.2 represents the $\bar{T}_{sk}$ (in °C) during the immersion period for the neutral condition. The regression equation is as follows:

$$\mathrm{AREA}(^{\circ}\mathrm{C\ min}) = 79.0\ \Delta T_{ear,imm} + 15.1\ \Delta\bar{T}_{sk,imm} + 146.5 \quad (1)$$

with a multiple correlation coefficient of 0.71. This means that the heat transfer of the middle finger during cold immersion is influenced more by changes in T_c (i.e. $\Delta T_{ear,imm}$) than by changes in $\bar{T}_{sk}$.

Discussion

It has been shown previously that the timing and magnitude of the hunting response is dependent upon ambient temperature, but the actual T_c and skin temperatures have not been measured or reported adequately. The results of the present study show that the hunting pattern is in part determined by body temperatures. When the body core and skin were warmest (condition Wh), the heat transfer (as assessed by the area under the finger skin temperature curve), $T_{fi,min}$, $T_{fi,max}$ and ΔT_{fi} were highest with a corresponding short onset time and high hunting frequency. When the body core and skin were coolest (condition Cc), the heat transfer and finger skin temperatures were the lowest of all experimental conditions. Moreover, it took almost 19 min before CIVD occurred and the hunting frequency was low. The heat transfer was almost five times higher in condition Wh as compared to condition Cc.

Blaisdell (1951) exposed subjects for 2–3 h to an ambient temperature of 12–15°C and found no decrease in T_{re}, due to the increased metabolism caused by shivering. It is likely that the 1-h exposure of minimally dressed subjects to an ambient temperature of 7°C (Adams and Smith 1962), or to temperatures of 5–6°C (Keatinge 1957) was also insufficient to cause a significant decrease in T_c. However, changes in hunting parameters have been observed in all these investigations. This indicates that $\bar{T}_{sk}$ is probably an important determinator of the hunting response.

The relative contributions of $\bar{T}_{sk}$ and T_c to the hunting response parameters were investigated by comparing condition Wc to Nn (decrease in $\bar{T}_{sk}$ and increase in T_c) and Ch to Nn (increase in $\bar{T}_{sk}$ and decrease in T_c). In condition Wc the hunting response was not significantly different from the thermoneutral condition (Nn), as can be seen in Table 2. The reduced T_c thus counterbalanced the effect of the increased $\bar{T}_{sk}$ on the hunting response. Figure 2 indicates that T_{ear} is 0.33°C less and $\bar{T}_{sk}$ is 2.2°C higher in condition Wc as compared to Nn. Thus, the ratio of $\Delta\bar{T}_{sk}$ over ΔT_c is 6.7. This supports formula (1), where the increase in $\bar{T}_{sk}$ has to be 5.2 times higher than the increase in T_c in order to have the same effect on AREA.

In condition Ch the T_{ear} was 0.27°C higher and $\bar{T}_{sk}$ was 5.0°C lower as compared to condition Nn. The ratio of $\Delta\bar{T}_{sk}$ over ΔT_c is more than 18, and this is about three times higher than the ratio found in the comparison of condition Wc to Nn, to obtain a good counterbalance of $\bar{T}_{sk}$ and T_c on the hunting response parameters. Thus, $\bar{T}_{sk}$ has a strong impact on the onset time of CIVD. As a result, the onset time and the number of waves were different in condition Ch as compared to Nn. The onset time is much longer when the climatic chamber temperature and $\bar{T}_{sk}$ are low (Table 2).

In this study, both $\bar{T}_{sk}$ and T_c have been shown to exert a potent influence on the hunting response. The data from the skin and core serve as inputs for the va-

Table 2 Mean (SEM) values of various descriptors of the hunting response. For each descriptor three statistically different groups were found. These groups are indicated by *normal typeface*, *dark background* and *bold typeface* respectively. Within each group the differences are not statistically different. (*AREA* Area between the finger skin temperature curve and the 8°C water bath temperature baseline during the 30-min immersion period, $T_{fi,base}$ baseline finger pad temperature, $T_{fi,min}$ minimum recorded finger temperature, $T_{fi,max}$ maximum recorded finger temperature after the first minimum, ΔT_{fi} largest recorded finger temperature amplitude, N_{waves} number of waves)

Descriptors	Condition				
	Wh	Wc	Nn	Ch	Cc
AREA (°C min)	240 (31)	135 (14)	118 (14)	113 (21)	**49 (7)**
$T_{fi,base}$ (°C)	35.3 (0.4)	33.5 (0.3)	32.1 (1.0)	27.9 (2.3)	**19.3 (0.9)**
Onset time (min)	3.0 (0.9)	10.7 (2.6)	10.6 (2.0)	**17.0 (2.7)**	**18.9 (3.0)**
$T_{fi,min}$ (°C)	11.3 (0.5)	9.8 (0.3)	9.6 (0.3)	9.4 (0.4)	**8.7 (0.2)**
$T_{fi,max}$ (°C)	17.0 (1.8)	13.0 (0.8)	12.6 (0.8)	**10.7 (0.6)**	**9.5 (0.4)**
ΔT_{fi} (°C)	5.9 (1.6)	3.3 (0.6)	**3.0 (0.6)**	**1.2 (0.3)**	**0.8 (0.2)**
N_{waves}	2.6 (0.4)	**1.2 (0.2)**	1.6 (0.2)	**1.0 (0.2)**	**0.8 (0.2)**

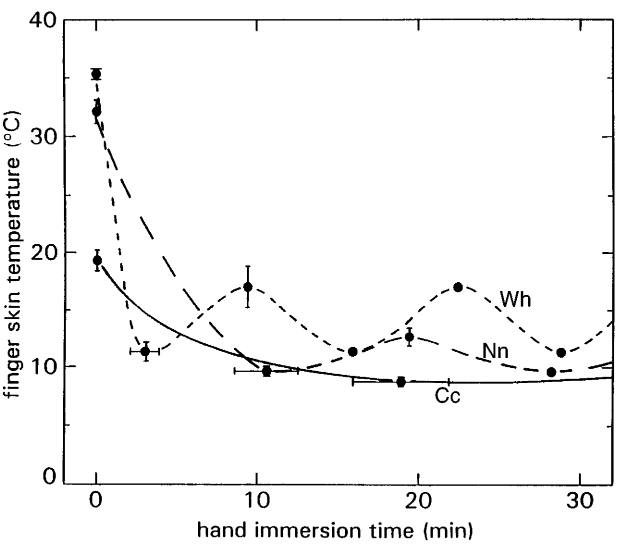

Fig. 3 Typical hunting response of a middle finger immersed in 8°C water for the warmest (Wh), coldest (Cc) and neutral (Nn) condition, as reconstructed from an average response from the nine subjects.

somotor centre in the central nervous system. This centre determines the vasomotor status in the fingers by modifying the sympathetic output to the peripheral nerves. When the core and skin are cool the sympathetic output increases and peripheral vasoconstriction occurs. The hunting response seems to be superimposed upon the general vascular status of the peripheral blood vessels.

It is important to consider the fact that the changes in finger skin temperatures occur later than changes in finger blood flow (Nilsson et al. 1986). However, the finger skin temperature gives an overall impression of the thermal changes in the finger tip.

The changes in T_c due to the drinking of the beverages are seen in both the ear canal and in the rectum. It is possible that the ingestion of the fluid caused reflex thermoregulatory effects (Goldman et al. 1973). However, the ingestion of the hot beverage caused no decrease in $\bar{T}_{sk}$, so that the thermoregulatory effects of drinking the beverages are likely to be minimal. The induced changes in T_c and $\bar{T}_{sk}$ observed in this study are small, and more research is needed to investigate the hunting response in conditions of hyperthermia and, in particular, hypothermia. This is important since the protective properties of the hunting response for the prevention of local cold-induced injuries (e.g. Iida 1949) are most relevant in hypothermic conditions.

We suggest that the ingestion of warm fluids prior to work in the cold may raise the T_c sufficiently to cause a slowing of the finger skin cooling, thus prolonging the ability to carry out manual work requiring dexterity in the cold.

In conclusion, this study shows that a slightly elevated T_c and $\bar{T}_{sk}$ enhances the hunting response. The $T_{fi,min}$ and $T_{fi,max}$ during immersion in cold water are higher when the body T_c is elevated; $\bar{T}_{sk}$ seems to have the strongest impact on the onset time of CIVD.

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