Journal of Thermal Biology 82 (2019) 83–89

Contents lists available at ScienceDirect

Journal of Thermal Biology

journal homepage: www.elsevier.com/locate/jtherbio

Thermal and cardiovascular responses and thermal sensation during hot-water bathing and the influence of room temperature

Yuta Masuda[a,b], Shuri Marui[b], Issei Kato[a,b], Mayuka Fujiki[a,b], Mariko Nakada[a,b], Kei Nagashima[b,*]

[a] Graduate School of Human Sciences, Waseda University, Tokorozawa, Japan
[b] Body Temperature and Fluid Laboratory, Faculty of Human Sciences, Waseda University, Tokorozawa, Japan

ARTICLE INFO

Keywords:
Heat stress
Cold stress
Skin blood flow
Skin temperature
Drowing

ABSTRACT

The aim of the present study was to clarify physical risks during hot-water bathing by measuring thermal and cardiovascular responses and thermal sensation. Young men and women (n = 7 and 5, respectively) participated in the present study, which consisted of two trials mimicking bathing behavior at room temperature of 25 °C and 15 °C. Participants bathed in 41 °C water for 20 min to the subclavian level. Before bathing, participants rested fully clothed for 15 min and then rested for 15 min without clothes. After bathing, they rested without clothes for 15 min and afterwards rested fully clothed for another 15 min. Tympanic temperature (T_{ty}), heart rates (HR), mean skin temperature (T_{sk}), mean arterial pressure (MAP), and laser-Doppler flow at the chest and forehead (LDF_{head} and LDF_{chest}) were evaluated. Thermal perception was assessed with a visual analogue scale. Mean T_{sk} in the 15 °C trial decreased during the period without clothing while MAP increased. The value remained unchanged in the 25 °C trial. During bathing, T_{ty}, mean T_{sk}, HR, LDF_{head}, and LDF_{chest} increased in both trials, and MAP decreased to similar levels. Relative change in LDF_{chest} was greater in the 15 °C trial than in the 25 °C trial. Participants felt cold when they were without clothes at 15 °C; however, the thermal perception during bathing was similar between the two trials. Greater changes in cardiovascular and thermal responses were observed during the bathing behavior. In addition, bathing in cold room augmented the changes, which may induce some physical risks during bathing.

1. Introduction

We bathe for various purpose, such as hygiene, medical therapy, and mental health. However, bathing style varies among countries (Boldt et al., 2008; Pall, 2009). In Japan, most people use bathtub, and are immersed in a hot water (usually > 40 °C) to the level of the neck or upper chest. The period of bathing is 20–30 min in average (Takehara et al., 2001). Moreover, the ambient temperature of a bathing room tends to be cooler than that of a living room (Yatsuzuka et al., 2013). On the contrary to the merits of bathing, these conditions during bathing could contribute to physical risks.

Based on the Vital Statistics compiled by the Ministry of Health, Labor, and Welfare, Japan (2018), the number of drowning-related deaths in a bathing room was 5673 in 2017, 1.7 times greater than in 2007. Ninety two percent of the victims were elderly, aged over 65 years-old, and incidents occurred mostly on winter time.

Here, we speculate three possibilities for the cause of the incidents during bathing. Firstly, it can be due to cardiovascular overload. Chiba et al. (2005) reported an increase in blood pressure, total peripheral resistance, and cardiac output during bathing. They also reported that the influence was greater in elderlies. Water immersion to the subclavian level increases stroke volume of the heart according to Starling's law of the heart (Carter et al., 2014). The second possibility is the effect of water temperature. Yamazaki et al. (2000) showed that total peripheral resistance decreased with elevation of water temperature (32 °C, 34.5 °C, and 36 °C) during head-out water immersion. Ono et al. (2017) indicated that, in elderlies, blood pressure elevates during an 8 min hot water bath (39 °C). Increased heat storage would be occurring during hot-water bathing, because thermoneutral water temperature is reported to be around 32 °C when heat balance is equilibrated (Yamazaki et al., 2000). The final possibility is lower room temperature, since reflex vasoconstriction of the skin can prompt cold-induced hypertension (Stephens et al., 2001). However, it remains unclear how these physiological responses work together during bathing. Moreover,

* Corresponding author. Body Temperature and Fluid Laboratory, Faculty of Human Sciences, Waseda University, Mikajima 2-579-15, Tokorozawa, Saitama, 359-1192, Japan.
E-mail address: k-nagashima@waseda.jp (K. Nagashima).

https://doi.org/10.1016/j.jtherbio.2019.03.014
Received 15 February 2019; Received in revised form 19 March 2019; Accepted 19 March 2019
Available online 26 March 2019
0306-4565/

we do not know if such responses could lead to drowning in a bath room.

In the present study, experiments mimicking ordinary bathing behavior in Japan were conducted. We assessed thermal and cardiovascular responses and thermal sensation during series of bathing behavior such as taking off clothes, getting in and off of a bathtub filled with hot water, and putting on clothes again. The experiments were done at a room temperature of 25 °C or 15 °C and a bath water temperature of 41 °C. We hypothesized that greater changes in cardiovascular and thermal responses occur during the bathing behavior. Moreover, cold room would augment the response, which could be related to the physical risk during bathing.

2. Methods

2.1. Participants

Twelve young volunteers (7 males and 5 females: male, age of 23.6 ± 1.4 y, height of 1.71 ± 0.04 m, body weight of 68.8 ± 5.8 kg; females, age of 23.4 ± 1.9 y, height of 1.55 ± 0.03 m, body weight of 53.6 ± 3.0 kg (mean ± standard deviations (SD)) were included. All participants were non-smokers and had clinical history of cardiovascular, metabolic, and respiratory diseases"

Experiments for female participants were conducted during their follicular phase. All participants were non-smokers and had clinical history of cardiovascular, metabolic, and respiratory diseases. The experimental protocol was approved by the Ethical Committee of Human Research, Waseda University, and were conducted in accordance with the Declaration of Helsinki. Participants were explained about the purpose and experimental procedures and provided written informed consent before the study.

2.2. Experimental protocols

Participants repeated two different experimental trials on separated days, each separated by at least one week, in a randomized order. Each trial consisted of an 80 min protocol. On the day of experiment, participants entered an environmental chamber (ESPEC, Tokyo, Japan) with a room temperature of 25 °C and relative humidity of 50%. There, participants rested in a sitting position for 30 min, being hydrated with 300 ml water. Participants were asked to change to swim suits after voiding and were weighed.

Tympanic temperature (T_{ty}; infrared thermometry; CE Thermo, Nipro, Osaka, Japan), skin temperature from four sites (the forehead, (T_{head}); the anterior chest (T_{chest}); the forearm (T_{arm}); the lateral sides of the thigh (T_{thigh}) and the lower leg (T_{leg}) were measured with thermistor loggers (Thermochron iButton, Maxim, Dallas, US) each 30 s. Heart rates were continuously monitored (HR; electrocardiography, BSM-2401, Nihon Koden, Tokyo, Japan). Finger arterial pressure was also continuously measured at the left index finger, of which data was corrected by humoral arterial pressure every 10 min (BP; LidcoRapid, LiDCO, Cambridge, UK). Mean arterial pressure and systolic and diastolic arterial pressure (MAP, SAP, and DAP, respectively) were determined from the arterial waveform. In addition, based on the waveform of the arterial pressure, stroke volume of the heart (SV) was estimated with the algorithm as reported before (Jeleazcov et al., 2010). Skin blood flow at non-glabrous skin area of the forearm and the forehead were assessed by laser-Doppler flowmetry (LDF; ALF21, Advance, Tokyo, Japan). Participants rated thermal sensation of the whole-body and periphery (right hand and both feet) on a 15 cm visual analogue scale (VAS), where 'nothing' was indicated 2.5 cm from the left and 'extremely hot' or 'extremely cold' 2.5 cm from the right. The length from the 'nothing' point was determined as the rating value (in cm).

After attaching measurement devices, the ambient temperature of the chamber was set at 15 °C (15 °C trial) or remained at 25 °C (25 °C trial) with the same relative humidity. Participants put on sweat shirts and pants over swim suits. They sat on a chair for another 15 min (time point: 0–15 min, clothed period). If participants felt cold, they could have a blanket during this period. The measurement data for the last 5 min of this period was defined as the baseline value of each parameter. During the next 15 min (time point: 15–30 min, naked period), participants were asked to take off sweat shirts and pants, wearing only swim suits.

At the time period between 30 and 50 min (bathing period), participants moved to a bathtub filled with 41 °C water and they immersed to the clavicle level. While wiping body with towel after bathing, participants sat on a chair wearing swim suits at the time period between 50 and 65 min (naked period). After putting on sweat shirts and pants, participants sat at the time point between 65 and 80 min (clothed period) and used a blanket if they felt cold. Thermal sensation of the whole-body and periphery was measured at the following time points: 0, 15, 20, 30, 35, 50, 55, 70, and 80 min.

2.3. Calculation and statistics

The sample size was determined by G * Power 3.1.9.2 (Faul et al., 2007): effect size, 0.4; and α error probability, 0.05. For the assessment of thermal perception, the number of groups and the power was set at 10 and 0.8, respectively; and the total sample size of 12 was estimated. For other parameters, the number of groups and the power was set as 80 and 0.95, respectively; and the total sample size was calculated as 6. Therefore, in the present study, the number of participants was set at 12.

Weighted mean skin temperature (mean T_{skin}) was obtained as $0.3 \cdot T_{chest} + 0.3 \cdot T_{arm} + 0.2 \cdot T_{thigh} + 0.2 \cdot T_{leg}$ (Ramanathan, 1964). Cardiac output (CO) was calculated as HR x SV. Total peripheral resistance was estimated as mean arterial pressure (MAP)/CO, expressed as mmHg • min/L. LDF was expressed as the value relative to the baseline (%LDF, resting value was defined as 100%; Nilsson et al., 1980). Cutaneous vascular conductance (CVC) was estimated as LDF/MAP and also shown in % value as LDF (%CVC; Holowatz et al., 2011).

Two-way analysis of variance (ambient temperature x time) was conducted to compare values between the two trials. When a significant difference was observed, a post-hoc test was conducted by the Bonferroni method. The null hypothesis was rejected at $p < 0.05$. Data were presented as means ± standard error of mean (SE).

3. Results

3.1. Tympanic and skin temperature

During the experiment, T_{ty} in the 25 °C trial was higher than that in the 15 °C trial. The baseline temperature was 36.5 ± 0.1 °C and 36.1 ± 0.1 °C in the 25 °C and the 15 °C trial, respectively.

Fig. 1 illustrates change in T_{ty} from the baseline (ΔT_{ty}, a), mean T_{sk} (b), and T_{head} (c) in both trials. T_{ty} from the baseline (ΔT_{ty}) was not different between the two trials. T_{ty} became greater than the baseline at 43–64 and 45–55 min (bathing period and naked period after bathing), reaching ΔT_{ty} of 1.7 ± 0.1 °C and 1.4 ± 0.1 °C at the end of bathing time in the 25 °C and the 15 °C trial, respectively. Mean T_{sk} in the 15 °C trial were lower than values measured in the 25 °C trial at 16–30 min (naked period before bathing; by 2.8 °C at 30 min). During bathing period, mean T_{sk} increased, but no differences were observed between two trials (39.0 °C and 39.4 °C at the end in 15 °C trial and 25 °C trial, respectively). Mean T_{sk} in the 25 °C trial were higher than values measured in the 15 °C trial at 15–30 and 53–65 min (naked periods before and after bathing). T_{head} was higher in the 25 °C trial than in the 15 °C trial at time periods of 0–47 and 54–80 min. An exception was observed in the bathing period at 48–53 min. T_{head} in both trials increased from the baseline during bathing period, at 42–50 min (37.2 ± 0.3 °C and 35.8 ± 0.3 °C at 50 min in 25 °C and 15 °C trials,

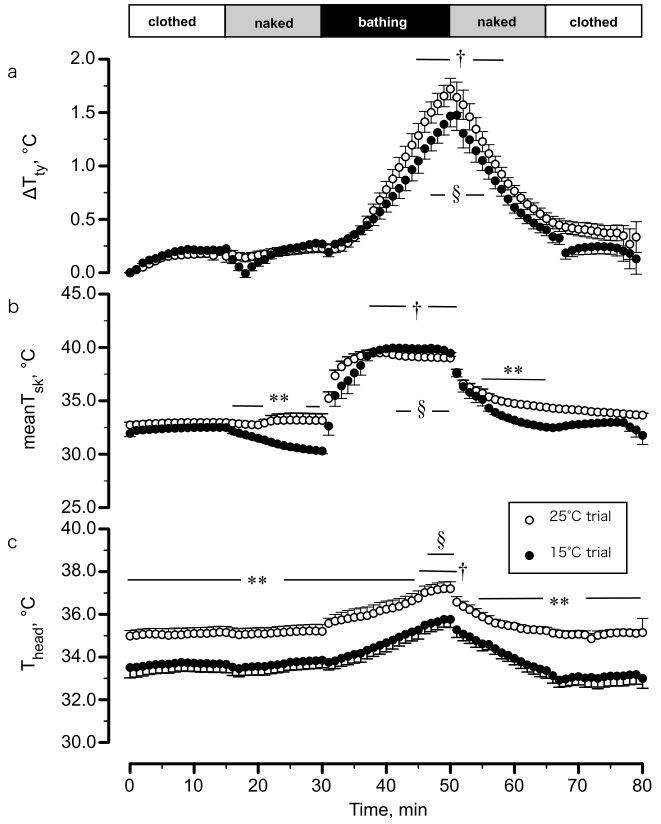

Fig. 1. Change in tympanic temperature from the baseline (ΔT_{ty}, a), mean skin temperature (mean T_{sk}, b), and skin temperature of the forehead (T_{head}, c) in the 25 °C (○) and 15 °C trials (●). Values are presented as mean ± SE. **, $P < 0.01$, 25 °C vs 15 °C trial; †, $P < 0.05$ compared with the baseline in the 25 °C trial; and §$P < 0.05$ compared with the baseline in the 15 °C trial.

respectively).

3.2. Cardiovascular parameters

Fig. 2 shows HR in both trials. HR remained unchanged before bathing in both trials. No difference was observed between the two trials. HR gradually increased from the baseline during bathing period,

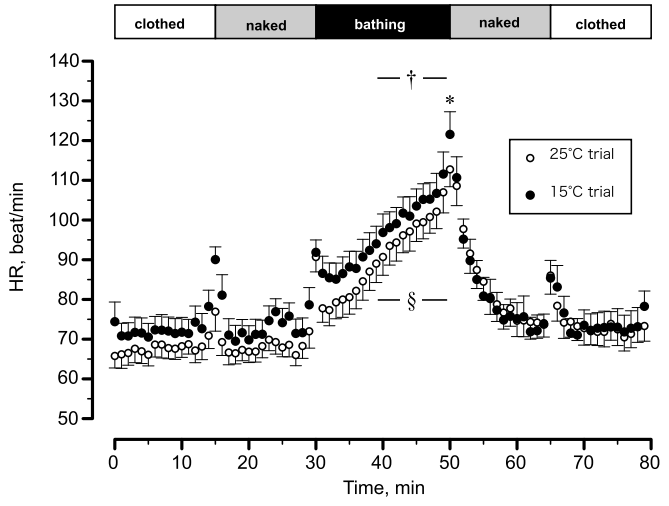

Fig. 2. Heart rate (HR) in the 25 °C (○) and 15 °C trials (●). Values are presented as mean ± SE. *, $P < 0.05$, 25 °C vs 15 °C trial; and †, $P < 0.05$, compared with the baseline in the 25 °C trial; and §$P < 0.05$ compared with the baseline in the 15 °C trial.

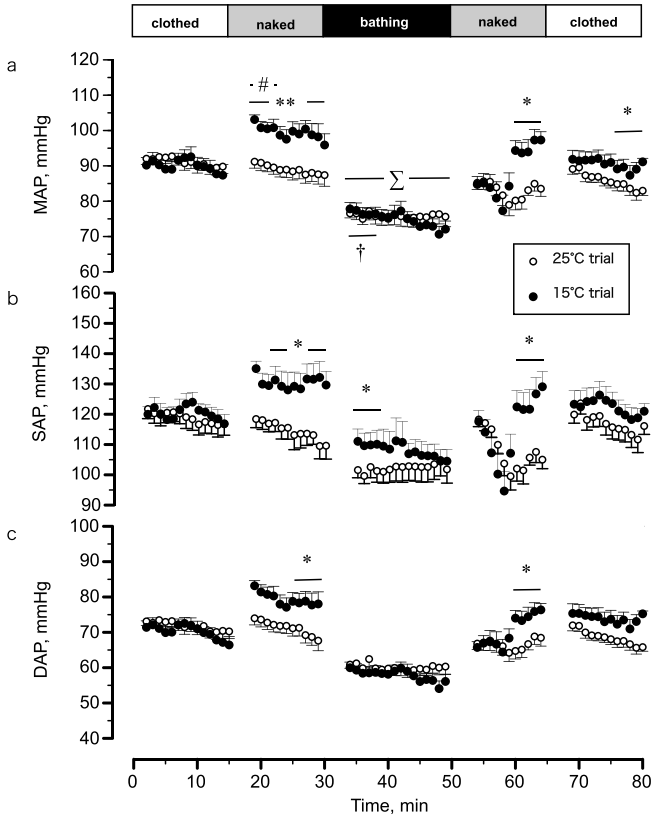

Fig. 3. Mean (MAP, a), systolic (SAP, b), and diastolic arterial pressure (DAP, c) in the 25 °C (○) and 15 °C trials (●). Values are presented as mean ± SE. *, $P < 0.05$, 25 °C vs 15 °C trial; **, $P < 0.01$, 25 °C trial vs 15 °C trial; †, $P < 0.05$ compared with baseline in the 25 °C trial; Σ, $P < 0.05$ compared with naked period before bathing (16–30 min) in the 15 °C trial; and #, $P < 0.05$ compared with baseline in the 15 °C trial.

at 37–50 min (106 ± 5 and 111 ± 5 bpm at the end of period in the 25 °C trial and the 15 °C trial, respectively). HR increased at 51 min (1 min after the end of bathing) by 10 bpm in the 15 °C trial and remained unchanged in the 25 °C trial.

Fig. 3 illustrates MAP (a), SAP (b), and DAP (c) in both trials. There were no differences in SAP, DAP, and MAP between the two trials during both clothed periods (before and after bathing), besides time periods at 76–80 min in MAP. However, MAP, SAP, and DAP in the 15 °C trial became greater than those measured in the 25 °C trial. MAP increased from the baseline at 18–22 min in the 15 °C trial. In the bathing period, MAP became smaller than the values before in the 15 °C trial, although no differences were observed between the two trials. In the 25 °C trial, MAP decreased from the baseline at 35–37 min. However, in the later half of the naked period, MAP, SAP, and DAP were greater in the 15 °C trial than in the 25 °C trial.

Fig. 4 shows CO (a), SV (b), and total peripheral resistance (TPR, c) in the 25 °C and 15 °C trials. In the two trials, CO remained unchanged from the baseline until the start of bathing. The value increased during bathing, which was greater in the 15 °C trial than in the 25 °C trial between 42 and 50 min, with a difference of 1.11 L/min at 50 min. CO returned to baseline levels after the bathing period in both trials. SV remained unchanged throughout the experiment without any difference between the two trials. TPR also remained unchanged from the baseline before bathing in both trials. During bathing, TPR became lower than its baseline level in the 25 °C and 15 °C trials; however, no difference was observed between the two trials. At 68–80 min (after bathing), TPR in the 15 °C trial was greater than that in the 25 °C trial.

Fig. 5 shows %LDF at the chest (%LDF_{chest}, a) and the head (%LDF_{head}, b), and %CVC at chest (%CVC_{chest}, c) and (%CVC_{head}, d) in

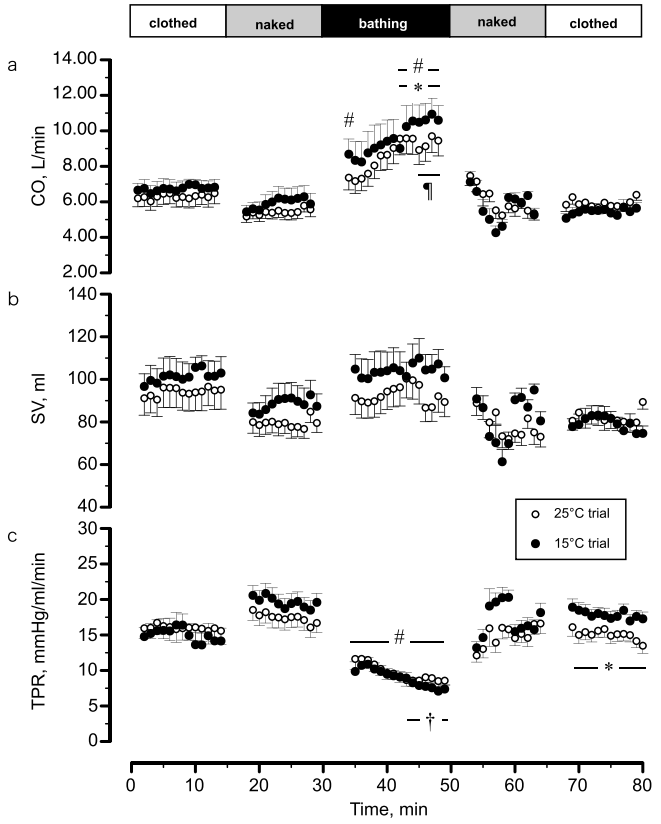

Fig. 4. Cardiac output (CO, a), stroke volume (SV, b), and total peripheral resistance (TPR, c) in the 25 °C (○) and 15 °C trials (●). Values are presented as mean ± SE. *, $P < 0.05$, 25 °C vs 15 °C trial; †, $P < 0.05$ compared with baseline in the 25 °C trial; ¶, $P < 0.05$ compared with the time point before bathing (28–30 min) in the 25 °C trial; and ♯, $P < 0.05$ compared with the time point before bathing (28–30 min) in the 15 °C trial.

both trials. Each value remained at its baseline level before bathing. During bathing, $\%LDF_{head}$ and $\%LDF_{chest}$ in the 15 °C trial became greater than those in the 25 °C trial at 46–52 and 32–52 min, respectively (440 ± 45% and 635 ± 37% at end of bathing, respectively). Percent LDF_{chest} in the 15 °C trial was greater than baseline between 47 and 50 min. Both values returned to their baseline levels after bathing without any difference between the two trials.

During bathing, $\%CVC_{chest}$ in the 15 °C trial became greater than the baseline at the time period d 44–50 min (678.53 ± 55.57% and 463.24 ± 51.52 at 50 min, respectively). At 53–60 min (naked period after bathing), $\%CVC_{chest}$ was greater in the 15 °C trial. There was no significant difference in $\%CVC_{head}$ from the baseline and between both trials.

3.3. Thermal sensation and change in body weight

Fig. 6 illustrates changes in thermal sensation of the periphery (a) and whole body (b). The rating for the periphery was lower in the 15 °C trial than in the 25 °C trial at 20, 30, 55, and 65 min (naked period before and after bathing). During bathing, the rating became greater than the baseline at 35 and 50 min in the 15 °C trial and at 50 min in the 25 °C trial. However, there were no difference between the two trials.

The rating for the whole body in the 15 °C trial was lower than that in the 25 °C trial at 15–30 min (naked period before bathing). During bathing on both trials, the rating values increased from the baseline at 35 and 50 min in the 15 °C trial and 50 min in the 25 °C trial; however, no differences between the two trials were observed.

The reduction of body weight was observed in both trials without any differences.

4. Discussion

The present study was to evaluate the risks of hot-water bathing by experiments mimicking bathing behavior. In addition, we examined if the temperature of bath room affects thermal and cardiovascular responses and thermal perception. The present study had important findings such as: i) increase in blood pressure before bathing when being naked at 15 °C, ii) reduction of blood pressure immediately after hot-water immersion, iii) increase in core temperature, and greater skin blood flow during the immersion with the augmentations in 15 °C trial, and iv) abrupt increase in heart rates after bathing in the 15 °C trial.

4.1. Cold stress before bathing

When participants were fully clothed, room temperature of 15 °C had no effect on measured parameters besides decrease in T_{head} (Fig. 1c). After participants took off clothes, mean T_{sk} gradually decreased (Fig. 1b) with an increase in blood pressure in the 15 °C trial (Fig. 3). It has been reported that whole-body cold stress (i.e. decreased mean skin and/or core temperature) elicits reflex increase in efferent skin sympathetic nerve activity (Charkoudian, 2010; Greaney et al., 2015; Holowatz and Kenney, 2010), evoking skin vasoconstriction and subsequent reductions in skin blood flow to minimize heat loss. Because T_{ty} did not change before bathing in the 15 °C trial, decrease in skin temperature may be a factor for the increase in blood pressure.

To assess body core temperature, we used infrared thermometry at tympanic temperature. However, the value seemed to be affected by the room temperature. Therefore, we used ΔT_{ty} to estimate thermal load to the body core. We verified that ΔT_{ty} is not influenced by the room temperature, comparing rectal temperature and T_{ty} during exercise (unpublished data). The difference in ambient temperature of 10 °C (25 °C vs. 15 °C) results in T_{ty} of 0.3 ± 0.1 °C; however, change in T_{ty} was well correlated to that of rectal temperature (changes in T_{ty}/changes in rectal temperature = 0.9; n = 10, p = 0.03).

Greaney et al. (2017) showed that a decrease in skin temperature during cold exposure was well correlated with a reduction of CVC of the skin vessels and an increase of blood pressure. However, in the 15 °C trial, $\%CVC_{head}$ and $\%CVC_{chest}$ remained unchanged before bathing (Fig. 5c and d). A possible reason for this difference may be the lower baseline value of mean T_{skin} in the present study (Fig. 1b; mean T_{skin} of 32.2 °C compared to that of 34.0 °C in the study by Greaney et al.). Another possibility is that we assessed LDF at the head and chest, aiming to evaluate the systemic control of the skin vessels (i.e. where hot water did not directly affect) and the influence of local temperature on the skin vessels (i.e. where hot water directly affected), respectively. It was reported that skin vascular response to cold is smaller in the chest, compared to the periphery (Matsuda-Nakamura et al., 2015). However, these results may suggest that vascular beds, other than the skin vessels assessed in the present study, could be involved in the increase of blood pressure.

Thermal perception of the whole body and periphery was well linked with mean T_{sk} (Figs. 6 and 1b) as previously reported by Frank et al. (1999). In addition, both body core and skin temperature contribute to thermal comfort and autonomic responses in humans. Because no difference in T_{ty} was observed in the 15 °C trial (Fig. 1a), the increase in blood pressure and the cold sensation of the whole body and periphery may be caused by a reduction of skin temperature.

4.2. Responses at the first 5 min of bathing

Immediately after immersing in hot water, mean T_{sk} tended to increase than its baseline in both trials, and reached a similar level (Fig. 1b). Percent LDF_{chest} in the 15 °C trial was greater than that in the 25 °C trial, but no change was observed in $\%CVC_{head}$ between the two trials (Fig. 5a and d). It was reported that there is a functional relationship between local skin temperature and skin blood flow which is

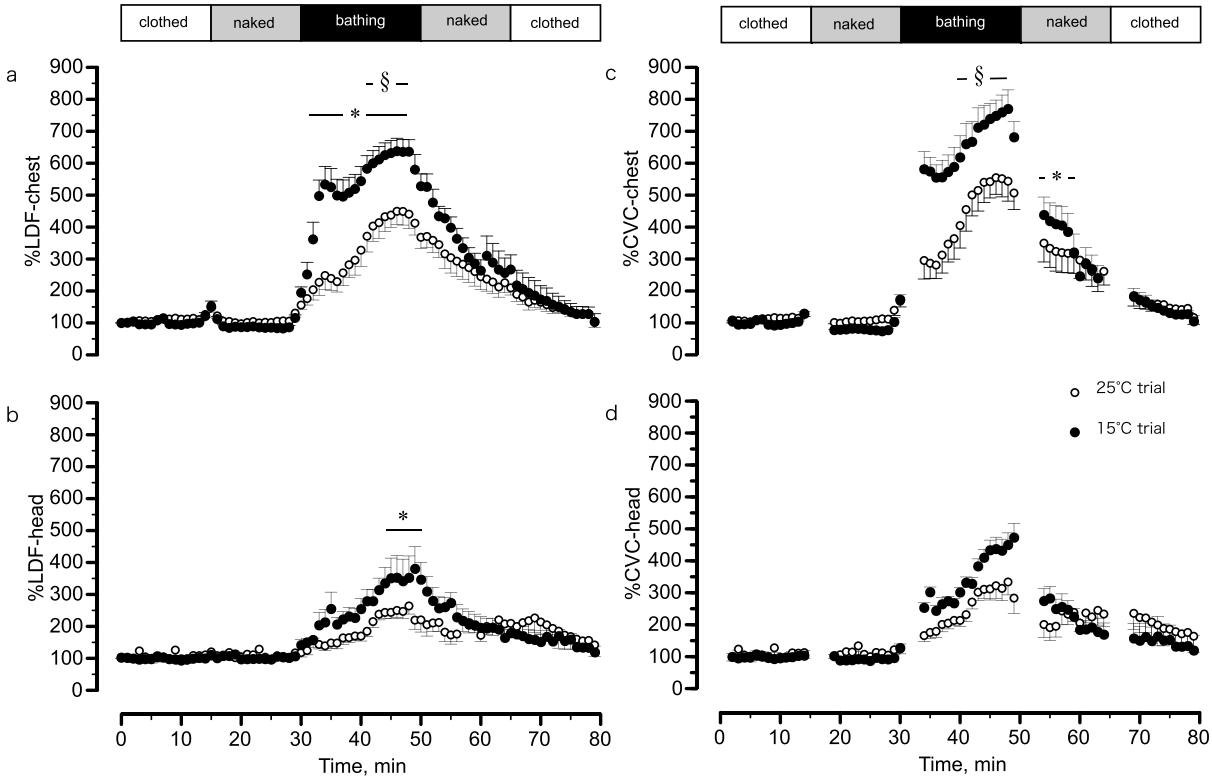

Fig. 5. Percent change of laser-doppler flow from the baseline at the chest (%LDF_{chest}, a) and head (%LDF_{head}, b) and % change of cutaneous vascular conductance from the baseline at the chest (%CVC_{chest}, c) and head (%CVC_{head}, d) in the 25 °C (○) and 15 °C trials (●). Values are presented as mean ± SE. *, $P < 0.05$, 25 °C vs 15 °C trial; §, $P < 0.05$ compared with baseline in the 15 °C trial.

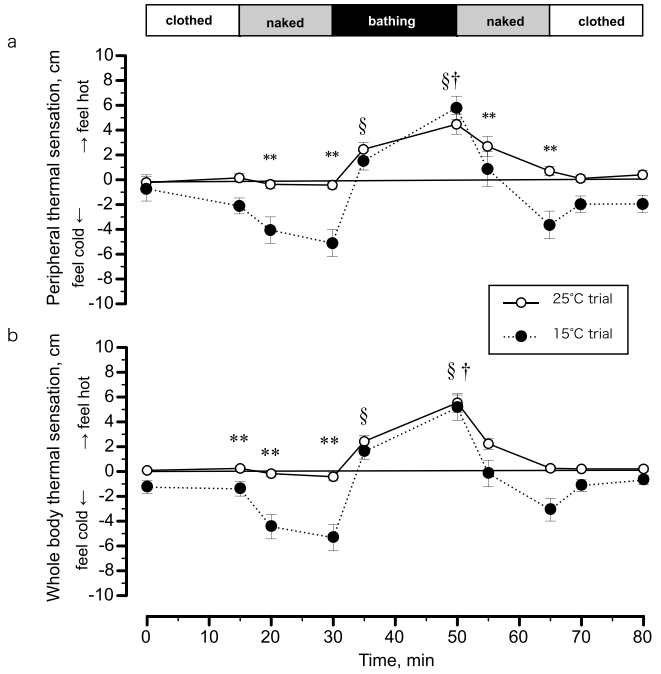

Fig. 6. Peripheral thermal sensation (a) and whole-body thermal sensation (b) in the 25 °C (○) and 15 °C trials (●). Values are presented as mean ± SE. **, $P < 0.01$, 25 °C vs 15 °C trial; §, $P < 0.05$ compared with baseline in the 15 °C trial; and †, $P < 0.05$ compared with baseline in the 25 °C trial.

maintained after sympathetic blockage (Golay et al., 2004; Wenger et al., 1986). Therefore, obtained results may suggest that the increase in %LDF_{chest} was directly influenced by local temperature.

It remains unclear why the increase of %LDF_{chest} was greater in the 15 °C trial than in the 25 °C trial (Fig. 5a). Minson et al. (2001) reported that heating the skin at 42 °C elicited an increase in skin blood flow within the first 5 min of heating, followed by a prolonged secondary plateau which was reached ~20–30 min into heating (thermal hyperemia). In addition, they demonstrated that the initial peak was predominantly the result of a sensory nerve axon reflex, which appeared to elicit vasodilation via both nitric oxide (NO) and endothelium-derived hyperpolarizing factors. Therefore, the heating of cold skin may have augmented the sensory response and resulted in greater hyperemia.

Greater reduction of blood pressure (MAP of 23 mmHg from the level prior to bathing) was observed in the 15 °C trial (Fig. 3a). SV and CO did not decrease during this period (Fig. 4a and b). Thus, the reduction may be due in part to an elevation of skin blood flow (Fig. 5a and b). Previous studies (Carter et al., 2014) reported that water immersion to the neck level increased central blood volume and cardiac output (i.e. Starling's law of the heart). However, the influence of water pressure to the body may have been smaller in the present study due to lower immersion level (i.e. subclavian level).

4.3. Responses to 20-min bathing

Bathing for 20 min induced a gradual increase of T_{ty} without further increase in mean T_{skin} (Fig. 1a). T_{head} also increased during the bathing period in both trials (Fig. 1c). In the 15 °C trial, %CVC_{chest} became greater than the baseline (Fig. 5c). The result may suggest that the increase in body core temperature decreased the skin vascular tone during bathing.

It has been reported that, during water immersion to the neck level, body heat was balanced (i.e. basal metabolism vs. conductive heat loss to the water) at water temperature of 32 °C (Yamazaki et al., 2000). Such greater increase in T_{ty} within a short period may show a strong suppression of heat loss during bathing, causing an imbalance between heat loss and production and the rapid increase of T_{ty} during bathing

time in both trials (Fig. 1a).

HR increased with CO during bathing (Figs. 2 and 4a), which may reflect the increase in T_{ty} and $\%LDF_{chest}$ (Figs. 1a and 5a). Hyperthermia per se increases HR (Jose et al., 1970). In addition, thermoregulatory increase in skin blood flow may have also contributed to the elevation of HR and CO.

Participants felt hot at the whole body and periphery during bathing (Fig. 6). Although T_{head} remained lower in the 15 °C trial (Fig. 1c), the results may indicate that facial skin temperature does not affect much thermal perception during bathing.

4.4. Responses after bathing

Mean T_{sk} decreased after bathing and returned to the baseline level at the end of bathing series (Fig. 1b). The reduction was slower in the 25 °C trial. Percent CVC_{chest} also decreased in the same manner as mean T_{sk} (Fig. 5c). HR in both trials decreased to the baseline level within 10 min after end of bathing time (Fig. 2). However, in the 15 °C trial, HR transiently increased within 1 min after bathing, which may indicate a stronger baroreflex control in the 15 °C trial. When participants move out of water, sudden change of posture and loss of water pressure to the lower body may induce baroreflex control to maintain blood pressure. Such control might also be detected by reductions in $\%CVC_{chest}$ and $\%CVC_{head}$, reflecting vasoconstriction; however, $\%CVC_{chest}$ was higher in the 15 °C trial when compared with the 25 °C trial (Fig. 5c). Therefore, greater HR may be necessary to compensate the difference. In fact, MAP became similar between the two trials after bathing period (Fig. 3a).

4.5. Possible risks during bathing in cold environment

It was reported that sudden reduction of blood pressure of > 20 mmHg could induce discomfort, dizziness, and fainting (Ricci et al., 2015; Taneja et al., 2008). Therefore, as observed in the present study, the period for which a naked person moves to a hot water in a cold environment is a critical moment.

The time length of the 15-min naked period may have been too long compared to actual bathing behavior. Therefore, we might overestimate the risk during bathing in a cold environment. However, the length differs among individuals, and the increase of blood pressure in the cold was observed immediately after putting of clothes. Therefore, the time length of the naked period may not be a sole factor increasing the risk.

Another risk is staying in a hot water for more than 10 min. Core body temperature increases by 1 °C from the baseline, and CO elevates (Figs. 1a and 3a). More importantly, a cold environment augments the increase in skin blood flow, which does not contribute to thermoregulation in a hot water. In a cold room, participants felt colder outside of hot water; however, the cold room did not affect the thermal perception in hot water. Therefore, cold is not a factor making people stay longer in hot water or to need a higher water temperature.

The last possible risk may be prompted when a person moved out of hot water. Blood pressure is maintained by baroreflex control, decreasing blood distribution to the skin. However, when a person bathe in a cold room, further compensatory response (i.e. HR increase) is needed. This may be because of greater skin blood flow at the end of the bathing period in a cold environment. Without the compensatory mechanism by the HR increase, dizziness or fainting may occur.

To lessen the risks during bathing, four strategies are suggested: i) keep ambient temperature of dressing room and bath room higher, ii) warm well skin before bathing, iii) avoid bathing hot water (> 41 °C) for longer period (> 10 min), and iv) move slowly when getting out of hot water.

5. Conclusion and perspectives

In the present study, we conducted an experimental exam of physiological and psychological changes during bathing in younger people. Greater cardiovascular, thermoregulatory, and psychological changes were observed, which could be potential risks during bathing. Elderly people are generally weak in cardiovascular adjustment, thermoregulation, and thermal perception. Therefore, the risks we observed in the present study may be augmented in elderlies. Further studies are necessary to clarify the risks and mechanisms in elderly people.

Acknowledgement

This study was partly supported by Tanita Co., Inc., Japan. The authors declare that there is no conflict of interest.

References

Boldt, L.-H., Fraszl, W., Röcker, L., Schefold, J.C., Steinach, M., Noack, T., Gunga, H.-C., 2008. Changes in the haemostatic system after thermoneutral and hyperthermic water immersion. Eur. J. Appl. Physiol. 102, 547–554. https://doi.org/10.1007/s00421-007-0620-7.

Carter, H.H., Spence, A.L., Pugh, C.J.A., Ainslie, P., Naylor, L.H., Green, D.J., 2014. Cardiovascular responses to water immersion in humans: impact on cerebral perfusion. Am. J. Physiol. Integr. Comp. Physiol. 306, R636–R640. https://doi.org/10.1152/ajpregu.00516.2013.

Charkoudian, N., 2010. Mechanisms and modifiers of reflex induced cutaneous vasodilation and vasoconstriction in humans. J. Appl. Physiol. 109, 1221–1228. https://doi.org/10.1152/japplphysiol.00298.2010.

Chiba, T., Yamauchi, M., Nishida, N., Kaneko, T., Yoshizaki, K., Yoshioka, N., 2005. Risk factors of sudden death in the Japanese hot bath in the senior population. Forensic Sci. Int. 149, 151–158. https://doi.org/10.1016/j.forsciint.2004.04.085.

Faul, F., Erdfelder, E., Lang, A.-G., Buchner, A., 2007. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav. Res. Methods 39, 175–191. https://doi.org/10.3758/BF03193146.

Frank, S.M., Raja, S.N., Bulcao, C.F., Goldstein, D.S., 1999. Relative contribution of core and cutaneous temperatures to thermal comfort and autonomic responses in humans. J. Appl. Physiol. 86, 1588–1593. https://doi.org/10.1152/jappl.1999.86.5.1588.

Golay, S., Haeberli, C., Delachaux, A., Liaudet, L., Kucera, P., Waeber, B., Feihl, F., 2004. Local heating of human skin causes hyperemia without mediation by muscarinic cholinergic receptors or prostanoids. J. Appl. Physiol. 97, 1781–1786. https://doi.org/10.1152/japplphysiol.00814.2003.

Greaney, J.L., Kenney, W.L., Alexander, L.M., 2017. Neurovascular mechanisms underlying augmented cold-induced reflex cutaneous vasoconstriction in human hypertension. J. Physiol. 595, 1687–1698. https://doi.org/10.1113/JP273487.

Greaney, J.L., Stanhewicz, A.E., Kenney, W.L., Alexander, L.M., 2015. Impaired increases in skin sympathetic nerve activity contribute to age-related decrements in reflex cutaneous vasoconstriction. J. Physiol. 593, 2199–2211. https://doi.org/10.1113/JP270062.

Holowatz, L.A., Kenney, W.L., 2010. Peripheral mechanisms of thermoregulatory control of skin blood flow in aged humans. J. Appl. Physiol. 109, 1538–1544. https://doi.org/10.1152/japplphysiol.00338.2010.

Holowatz, L.A., Santhanam, L., Webb, A., Berkowitz, D.E., Kenney, W.L., 2011. Oral atorvastatin therapy restores cutaneous microvascular function by decreasing arginase activity in hypercholesterolaemic humans. Physiol. Soc. J Physiol 589, 2093–2103. https://doi.org/10.1113/jphysiol.2010.203935.

Jeleazcov, C., Krajinovic, L., Münster, T., Birkholz, T., Fried, R., Schüttler, J., Fechner, J., 2010. Precision and accuracy of a new device (CNAP™) for continuous non-invasive arterial pressure monitoring: assessment during general anaesthesia. Br. J. Anaesth. 105, 264–272. https://doi.org/10.1093/BJA/AEQ143.

Jose, A.D., Stitt, F., Collison, D., 1970. The effects of exercise and changes in body temperature on the intrinsic heart rate in man. Am. Heart J. 79, 488–498. https://doi.org/10.1016/0002-8703(70)90254-1.

Matsuda-Nakamura, M., Yasuhara, S., Nagashima, K., 2015. Effect of menstrual cycle on thermal perception and autonomic thermoregulatory responses during mild cold exposure. J. Physiol. Sci. 65, 339–347. https://doi.org/10.1007/s12576-015-0371-x.

Minson, C.T., Berry, L.T., Joyner, M.J., 2001. Nitric oxide and neurally mediated regulation of skin blood flow during local heating. J. Appl. Physiol. 91, 1619–1626. https://doi.org/10.1152/jappl.2001.91.4.1619.

Nilsson, G.E., Tenland, T., Oberg, P.A., 1980. Evaluation of a laser Doppler flowmeter for measurement of tissue blood flow. IEEE Trans. Biomed. Eng. BME 27, 597–604. https://doi.org/10.1109/TBME.1980.326582.

Ono, J., Hashiguchi, N., Sawatari, H., Ohkusa, T., Miyazono, M., Son, S., Magota, C., Tochihara, Y., Chishaki, A., 2017. Effect of water bath temperature on physiological parameters and subjective sensation in older people. Geriatr. Gerontol. Int. 17, 2164–2170. https://doi.org/10.1111/ggi.13053.

Pall, M.L., 2009. Do sauna therapy and exercise act by raising the availability of tetrahydrobiopterin? Med. Hypotheses 73, 610–613. https://doi.org/10.1016/J.MEHY.2009.03.058.

Ramanathan, N.L., 1964. A new weighting system for mean surface temperature of the human body. J. Appl. Physiol. 19, 531–533. https://doi.org/10.1152/jappl.1964.19.3.531.

Ricci, F., De Caterina, R., Fedorowski, A., 2015. Orthostatic hypotension. J. Am. Coll. Cardiol. 66, 848–860. https://doi.org/10.1016/j.jacc.2015.06.1084.

Stephens, D.P., Aoki, K., Kosiba, W.A., Johnson, J.M., 2001. Nonnoradrenergic mechanism of reflex cutaneous vasoconstriction in men. Am. J. Physiol. Circ. Physiol. 280, H1496–H1504. https://doi.org/10.1152/ajpheart.2001.280.4.H1496.
Takehara, H., Yanese, T., Nishikawa, K., Murakami, K., 2001. On the residential consciousness and interest in bathing. J. Home Econ. Jpn. 52, 1005–1013. https://doi.org/10.11428/jhej1987.52.1005.
Taneja, I., Medow, M.S., Glover, J.L., Raghunath, N.K., Stewart, J.M., 2008. Increased vasoconstriction predisposes to hyperpnea and postural faint. Am. J. Physiol. Circ. Physiol. 295, H372–H381. https://doi.org/10.1152/ajpheart.00101.2008.
Wenger, C.B., Stephenson, L.A., Durkin, M.A., 1986. Effect of nerve block on response of forearm blood flow to local temperature. J. Appl. Physiol. 61, 227–232. https://doi.org/10.1152/jappl.1986.61.1.227.
Yamazaki, F., Endo, Y., Torii, R., Sagawa, S., Shiraki, K., 2000. Continuous monitoring of change in hemodilution during water immersion in humans: effect of water temperature. Aviat. Space Environ. Med. 71, 632–639.
Yatsuzuka, H., Inoue, T., Mae, M., Moro, Y., 2013. Actual state of bathing facilities and thermal environment in bathrooms in winter. J. Environ. Eng. (Transactions AIJ) 78, 489–496. https://doi.org/10.3130/aije.78.489.

Yuta Masuda is a Ph.D. student in the Graduate School of Human Sciences, Waseda University, Japan. He received a master's degree of sports science in 2016 from Waseda University. His research interest is heat tolerance during exercise in a hot environment.

Shuri Marui is an assistant professor in the Faculty of Human Sciences, Waseda University, Japan. She received Ph.D. degree from Waseda University in 2018. She studies about thermoregulation of females and the gender difference.

Issei Kato is a master student in the Graduate School of Human Sciences, Waseda University, Japan. He completed a bachelor's degree in human science in 2018. His research focus is cardiovascular responses to extreme environment on sports fields.

Mayuka Fujiki is a undergraduate student in the Faculty of Human Sciences, Waseda University, Japan. Her research interest is application of wearable device to sports activities for the safety.

Mariko Nakada is a undergraduate student in the Faculty of Human Sciences, Waseda University, Japan. Her research focus is thermal perception and behavioral thermoregulation.

Kei Nagashima M.D., Ph.D. is a professor of the Faculty of Human Sciences, Waseda University. He has long studied for thermal and body fluid physiology. He also worked as a general surgeon. His recent interest is to clarify a mechanisms involved in heat acclimation and acclimatization from the whole body to molecules.