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Effect of water bath temperature on physiological parameters and subjective sensation in older people

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Abstract

Aim: In Japan, the incidence of water bathing-related cardiopulmonary accidents among older people is high in winter. The purpose of this study was to investigate alterations in physiological characteristics and subjective thermal sensations of older people when bathing in a cool environment.

Methods: We assessed the skin temperature (ST), rectal temperature (RT), blood pressure (BP), pulse rate (PR), body fluid loss (BFL; sweat and urine), and subjective thermal responses of 11 older healthy male and 10 young male volunteers throughout 42°C and 39°C-bathing in a room at 20°C with 50% humidity.

Results: At 42°C-bathing, the RT during bathing and in the post-bathing period were significantly lower in the older men than in the young, and ST during the post-bathing period decreased gradually in the older men. Systolic BP (SBP) and PR immediately increased just after entering 42°C-water and decreased during bathing in the older men. With the activities of dressing, SBP increased followed by decrease during the post-bathing period. Thus, double product (PR × SBP) increased during the bathing period. Although there was no significant difference in BFL between the older and younger men in 42°C-water, the older men produced significantly less sweat. The older men also reported feeling less warm after 42°C bathing, and feeling less cold during the post-bathing period after 39°C-bathing.

Conclusions: These results suggest that hot water-bathing during cold seasons might induce more serious physiological changes in older people.

Keywords: aging, baths, differential thermal analysis, physiological phenomena

Introduction

Water-bathing is not only a popular recreational activity but is also used in rehabilitation medicine[1]. However, the incidence of water-bathing related cardiopulmonary accidents among older people has been reported to be 4.06/10,000 per year in Japan[2,3] and is correlated with winter season[4,5].

Previous studies have reported physiological responses to water-bathing in older people including an increase of cardiovascular overload[6-8]. However, the bathing style in Japan is very different from that in other countries.

In Japan, 50%–70% of older people bathe in hot water[9] and subjective thermal sensation was reported to become dull with age[10-12.] Several studies have reported age-related differences in physiological responses to the methods and environments involved in bathing in hot water[7,13]. There have been no studies to date that have investigated the effects of hot water-bathing on the physiology and subjective responses of older people, when combined with winter ambient temperatures. Therefore, we aimed to identify alterations in physiological and subjective characteristics of older people in strictly controlled water bathing environments under cool ambient conditions and to provide useful information for older people to undertake whole body water-bathing comfortably and safely, even during the winter.

Methods

Subjects (Table 1)

Eleven older men and 10 younger men participated in the study. The inclusion criteria for the older men were that they were over 65 years of age and were healthy on the basis of a medical check-up. The younger men were to be 20–30 years of age and healthy. Prior to the study, all subjects underwent health evaluations performed by doctors and were shown to be healthy following a normal physical examination, blood pressure (BP<140/90 mmHg), urine examinations, and electrocardiogram. None had a history of cardiovascular or other diseases. The older subjects also underwent blood testing, which revealed no abnormalities. None of the subjects were taking any medication. The experimental protocol was explained to all the subjects and they provided written informed consent. The study was performed according to the requirements of the U.S. Federal Policy for the Protection of Human Subjects (45 CFR, Part 46), which was consistent with the principles of the Declaration of Helsinki. The Ethics Review Committee of Kyushu University approved the study (Approval No. 165).

Experimental Protocol

The study was conducted in the Environmental Adaptation Research Laboratory of Kyushu University during March 2014, to avoid the influence of seasonal changes. In previous surveys concerning the thermal conditions in bathrooms and water temperatures during the winter in areas of Japan, the mean temperatures of dressing rooms, bathrooms, and the water were 10.7–21.0°C, 13.6–22.3°C, and 40–41.4°C, respectively. Thus, we adopted initial water temperatures of 42°C and 39°C, which declined by 1.0–1.5°C after 8 minutes of bathing. In reference experiments, we used an initial water temperature of 39°C declined to 37.5–38°C, which represents a neutral temperature that seldom causes changes in body core temperature.

For the room temperature appropriate for winter, 10-15°C was thought to be too cold for subjects to wait in for 1 hour while only wearing thin clothing. Therefore, for ethical reasons, we chose to use a room temperature of 20±0.5°C and a relative humidity of 50%, using an automatic controller in the Environmental Adaptation Research Laboratory. Although the water temperature could not be controlled automatically, the initial water temperatures were strictly controlled at 42°C and 39°C. The bathing time of 8 minutes was identified to be the minimum time required for stable skin and rectal temperatures during bathing[11,12].

As shown in Figure 1, after urination, each subject put on short pants, a short-sleeved T-shirt, and a thin sweat suit; then, their body weight (BW) was measured using a precision scale (ID2; Mettler-Toledo Ltd., Port Melbourne, Vic., Australia) and their skinfold thickness was measured on their upper arm, back, and abdomen. Rectal temperature (RT) thermometers were inserted and skin temperature (ST)-sensing electrodes applied. They moved into the climate chamber, which was controlled at 20°C, and sat there for 30 minutes. After removing their T-shirt and sweat suit within 4 minutes, they immersed themselves in the bath up to their armpits for 8 minutes.

After bathing, the ST electrodes were replaced and the subjects sat for 15 minutes, wearing a new set of dry clothing. Immediately after the experiment, BW was measured twice: before and after urination. Using the differences of the BW values before and after the experiment, the body fluid loss (BFL=perspiration and urine weights) was calculated. Each participant bathed at the same time on different days in 42°C and 39°C-water.

Measurement Parameters

Body surface area was calculated using the DuBois-DuBois formula[14]. ST was measured on seven areas of the body (forehead, forearm, hand, abdomen, thigh, leg, and foot) using thermistors (ITPO10-12;Nikkiso-Therm Co., Ltd., Tokyo, Japan) and recorded every minute (LT8A, Gram Corporation, Japan). The Hardy-DuBois formula[15] was used to account for the average ST of the entire body. RT was measured using a thermistor (ITPO10-11;Nikkiso-Therm Co., Ltd.) 12 cm beyond the anus. ST and RT were recorded every 30 seconds on data loggers (LT-8 Series;Nikkiso-Therm Co., Ltd.). BP and PR were measured using an automatic sphygmomanometer (HEM-737;Omron Kyoto, Japan). The amount of perspiration, and the urine that accumulated during the study were calculated (Figure 1).

To subjectively evaluate whole body thermal sensation, we adopted a widely-used 9-point scale designed by the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan in 1979[16]. Thermal comfort was evaluated by a 4-point scale[17].

Statistical Analysis

All data are presented as mean±SD. Differences in basic attributes and subjective sensation after the bathing between the older and younger men were adequately analyzed using the Student's *t*-test and Mann-Whitney U test. Chronological changes in physiological parameters were analyzed using age and time as independent variables, and subcutaneous fat thickness, baseline SBP, and PR as covariates, in analyses of co-variance.

Statistical analyses were performed using SPSS ver. 22.0 (IBM Corp. Chicago, IL, USA). Two-sided p-values of <0.05 and <0.10 were considered significant and tending toward significance, respectively.

Results

Characteristics (Table 1)

There were significant differences in height and body-mass index between the groups. Subcutaneous fat thickness of the upper arm and abdomen tended to be thicker in the older men than in the younger men ($P<0.10$, both).

Rectal Temperature (Figure 2A)

At both 42°C and 39°C, interactions between time and age were found ($P<0.001$, both). In 42°C-bathing, the RT gradually increased in both groups until a significant difference from baseline was reached during bathing. After dressing (18 minutes), the RT of the older people that had increased by 42°C-bathing returned to baseline (4 minutes). Conversely, the RT of the younger men at 42°C-bathing was still significantly higher than baseline during the post-bathing rest-period (18–32 minutes). The RT of the younger men at 39°C-bathing had significantly increased again at 5 minutes after the start of the rest-period.

Skin Temperature (Figure 2B)

An interaction was observed between time and age for both the 42°C and 39°C baths ($P<0.001$, both). During the rest-period after bathing, significant ST elevations were observed in both age groups at both temperatures. Although the younger men maintained significant increases in ST at both temperatures until the end of the experiment, the older men showed smaller increases in ST at 7 minutes after the beginning of the rest-period following 42°C-bathing and at 12 minutes after 39°C-bathing.

Hemodynamics (Figure 3)

For the PR changes, the interactions between age and time were significant at 42°C (P<0.001), but not at 39°C. In the older men, there was a significant increase of PR at the beginning of water-bathing (4 minutes) and at the end of the water-bathing (12 minutes) compared with the PR at the initial resting-period (0 minutes) (77±4 and 71±7 vs. 64±8 bpm, P<0.05). Also in the younger men, PR at the beginning and the end of water-bathing (4 and 12 minutes) increased significantly compared with the initial resting-period (83±10, p<0.05, 86±12, P<0.01 vs. 73±12 bpm). At the beginning of the post-water bathing rest-period (18 minutes), the PR in both ages returned to the values of the initial rest-period.

Interactions between age and time were also seen for the SBP (42°C: P<0.001, 39°C: P<0.001). In the older men, the SBP at the beginning of the bathing-period was significantly increased compared with that during the initial resting-period (42°C: +21±17 mmHg, 39°C: +17±8 mmHg; P<0.001, both). In contrast, there were no significant effects in the younger men at the beginning of the bathing-period (4 minutes) under either condition. During bathing, the decrease in SBP observed 4 minutes after the start of the bathing was –30±15 mmHg at 42°C and –28±10 mmHg at 39°C for the older men, and –6±8 mmHg at 42°C and –8±9 mmHg at 39°C for the younger men. A comparison of SBP during the initial resting-period (0 minutes) and at the beginning of the post-bathing resting-period (18 minutes) of the 39°C bathing revealed a significant difference, with the older men showing a +15±9 mmHg change (*P*<0.001) and the younger men a +8±7 mmHg change (*P*<0.05). Chronological changes in diastolic BP were also analyzed under both thermal conditions, but there was no correlation between age and time.

In the double product (DP: PR × SBP; Figure 3C), an interaction between time and age was observed during the 42°C-bathing (*P*<0.05). During the 39°C-bathing, time was the only significant causal factor (*P*<0.01). In the older men, DP was significantly increased at the beginning of the bathing-period (4 minutes) (+3120±1317 bpm･mmHg, *P*<0.001), but during bathing it returned to baseline.

Body Fluid Loss

There were no significant differences in the amount of BFL between each group under both bathing conditions. In the younger men, the amount of perspiration differed significantly depending on water temperature (42°C: 128.5±46.7 g, *P*<0.01; 39°C: 85.4±19.0 g, *P*<0.01). Perspiration in the older men at 42°C was significantly lower (91.6±34.0 g, *P*<0.05), but this was not the case at 39°C (84.9±17.8 g) compared with the younger men. Urine production for each age and water temperature were as follows: older men, 135.6±127.2 g (42°C), 109.0 ±81.5 g (39°C); younger men, 71.8±55.3 g (42°C), 103.2 ±86.9 g (39°C).

Subjective sensitivity (Figure 4)

For the end of the bathing, the younger men at 42°C felt significantly hotter than those at 39°C (2.5±0.5 vs 1.7 ±0.5 points, $P<0.05$), whereas the difference did not observe in the older men. At the start of resting-period after the bathing, a significant bath temperature dependent differences observed in the both groups (younger: 1.1±1.2 vs -1.2 ±1.5 points, $P<0.05$; older: 0.5±0.8 vs -0.4 ±1.0 points, $P<0.05$). At the 15 minutes after the start of resting-period, a significant bath temperature dependent differences also observed in the younger men (0.1±0.9 vs -1.1 ±0.9 points, $P<0.05$). Furthermore, there were significant age-depended differences in the subjects at 39°C (-1.1±0.9 vs -0.1±0.8 points, $P<0.05$), but not in the subjects at 42°C.

For the thermal comfort, a significant difference observed in the younger men at the end of the bathing (0.0±0.0 vs 0.4±0.5 points, $P<0.05$), whereas the difference did not observe in the older men.

Discussion

Our results show that for the older men experiencing whole body water-baths at 39°C or 42°C, with an air temperature of 20°C: 1) at both water temperatures, ST decreased gradually after bathing; 2) RT were significantly lower than those of the young at both water temperatures during and after bathing; 3) SBP, PR, and DP immediately increased after entering a 42°C-bath. A biphasic change in SBP was observed, because it decreased while bathing, increased during the post-bathing dressing-period, and then decreased gradually during the post-bathing rest-period; 4) the amount of BFL was not significantly different from the young, but the amount of perspiration generated at 42°C was significantly smaller; 5) thermal sensation after the bathing-period and cold sensation 15 minutes after a 39°C-bath were impaired versus the young.

Thermoregulation

In our study, the older men showed a significant decreases in ST during the post-bathing rest-period, and had a lower RT than the younger men. Older people are known to have an increase in age-related arterial stiffness, vascular endothelial dysfunction, and a reduction in vasodilator substances such as nitric oxide, and/or a loss in biological utilization capacity[18,19]. These alterations attenuate vasodilatation and decrease blood flow, resulting in impaired maintenance of RT and ST after hot water-bathing[7]. Vasoconstriction of skin capillaries might also occur to prevent a decrease in core temperature in the cold environment. The observed difference in the subcutaneous fat layer, which tended to be thicker in the older than the younger men, might also contribute to the lower skin temperature of the older group[20]. Thus, the skin temperatures of the obese older men might be influenced by thicker subcutaneous fat layer.

The amount of perspiration in the older men was significantly lower during 42°C water-bathing. It has been reported that core body temperature is closely related to skin blood flow and the perspiration response[19,21]. Increases in skin blood flow due to vasodilatation are generated as part of a thermoregulatory response to heat stress[19]. Skin blood flow and/or perspiration in response to heat stress have previously been reported to be lower in the older people[22,23.] We speculated that in the older men, the impaired increase in RT might be responsible for the decrease in perspiration. In addition, alterations in function of the parasympathetic innervation of the sweat glands have been reported[24,25] and Ferrer *et al.*[26] showed a significant age-related decrease in sweat gland density in the palms and the legs.

Hemodynamics

The previous study on older people bathing at 40°C reported rapid increases in SBP while the subjects were changing clothes and resting in a room at 10–20°C[12]. In a survey of Japanese winter bathing habits, subjects reported using dressing rooms at 10–20°C and bathing rooms at 13–22°C[13]. Based on these data, we planned to use a room temperature of 15°C, but ethical considerations meant that we set the ambient temperature at 20°C.

The PR of both groups was significantly increased during 42°C-bathing. Chishaki *et al.*[27] also reported PR increases at the start of 41°C-bathing under a 27°C room temperature, which suggested that these increases in PR might be caused by activation of the sympathetic nervous system in response to a reduction in BP caused by peripheral vasodilation resulting from hot water-bathing.

A significant increase in DP was observed at the beginning of the 42°C-bathing period among the older men. Chiba *et al.*[28], reproducing winter conditions with water baths at 40-42°C and ambient temperatures of 18-20°C, also reported increases in DP among the older men after water-bathing. As a result, the cardiac overload resulting from water-bathing in winter is greater than at other times of year, especially in older people.

Subjective sensations

In our study, at the completion of the rest period after a 39°C water-bath, they showed little awareness of cold. Previous studies have reported an increase in the threshold for cold sensation among older people[10,11], and there is a possibility that the lack of awareness of a cold post-bathing environment could result in accidents.

Limitations

First, a consideration of safety concerns led us to set the ambient temperature to 20°C. Second, we set the bathing time to 8 minutes, since it was identified to be the minimum time required for skin and rectal temperatures to become stable during bathing. Third, the number of subjects studied was relatively small and type II statistical errors may therefore influence the interpretation of our data. The range of ages in the older men was limited from 66 to 75 years. We included only the healthy older men and the older people with hypertension, diabetes mellitus, obesity, and other diseases were excluded. Thus, our interpretations cannot be directly applied to the very old, the older men with various diseases, and women. It is therefore necessary to continue to accumulate knowledge and expertise.

Conclusions

Our study implies that if the room temperature is much lower than 20°C, as is the case in genuine Japanese bathrooms in winter, the increase in SBP and DP could be greater than that observed in this study. Older subjects did not complain of excessively hot during hot water-bathing or cold after being in a cool room, while the young subjects complained about both. This indicates that the subjective thermal sensation of older people is not dependable for the prediction of risk from bathing. It is necessary for older people themselves, their caregivers, and healthcare providers to pay more attention to low bathroom temperatures and high water temperatures to prevent physiological stress and accidents during bathing.

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Disclosure Statement

None

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Figure legends

Figure1: Experimental protocol

ST, skin temperature; RT, rectal temperature; PR, pulse rate; BP, blood pressure

Figure 2: Alterations in physiological parameters

(A) Change in rectal temperature. n=6 older people, n=7 young men. Values are mean±SD, *p<0.05, **p<0.01, ***p<0.001 vs. 4 min.

(B) Change in mean skin temperature. n=9 older people, n=8 young men. Values are mean±SD. *p<0.05, **p<0.01, ***p<0.001 vs. 18 min.

Figure 3: Alterations in cardiovascular parameters

(A) Change in pulse rate (PR). n=11 older people, n=10 young men. Values are mean±SD. *p<0.05, **p<0.01, ***p<0.001 vs. 0 min.

(B) Change in systolic blood pressure (SBP). n=11 older people, n=10 young men. Values are mean±SD.*p<0.05, **p<0.01, ***p<0.001 vs. 0 min.

(C) Change in double product (SBP × PR). n=11 older people, n=10 young men. Values are mean±SD. *p<0.05, ***p<0.001 vs. 0 min.

Figure 4: Thermal sensation comfort scores

n=11 older people, n=10 young men. *p<0.05 and †p<0.1.

Figure 1, Ono et.al.

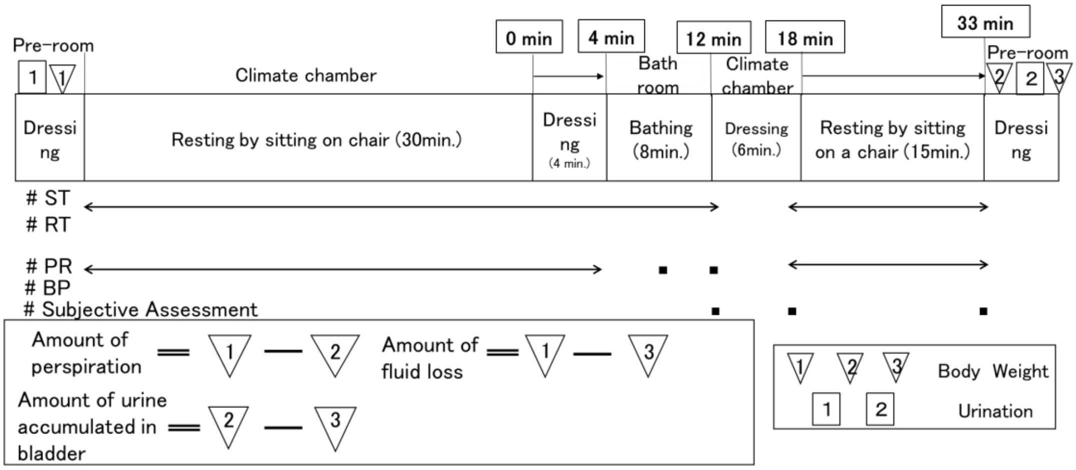
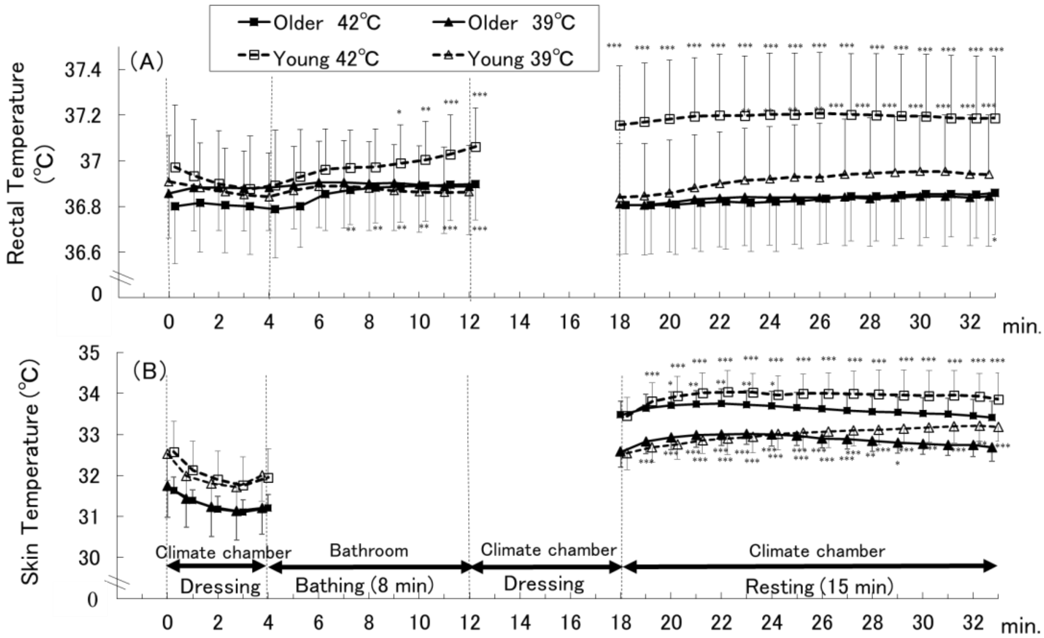


Figure 2, Ono et. al.



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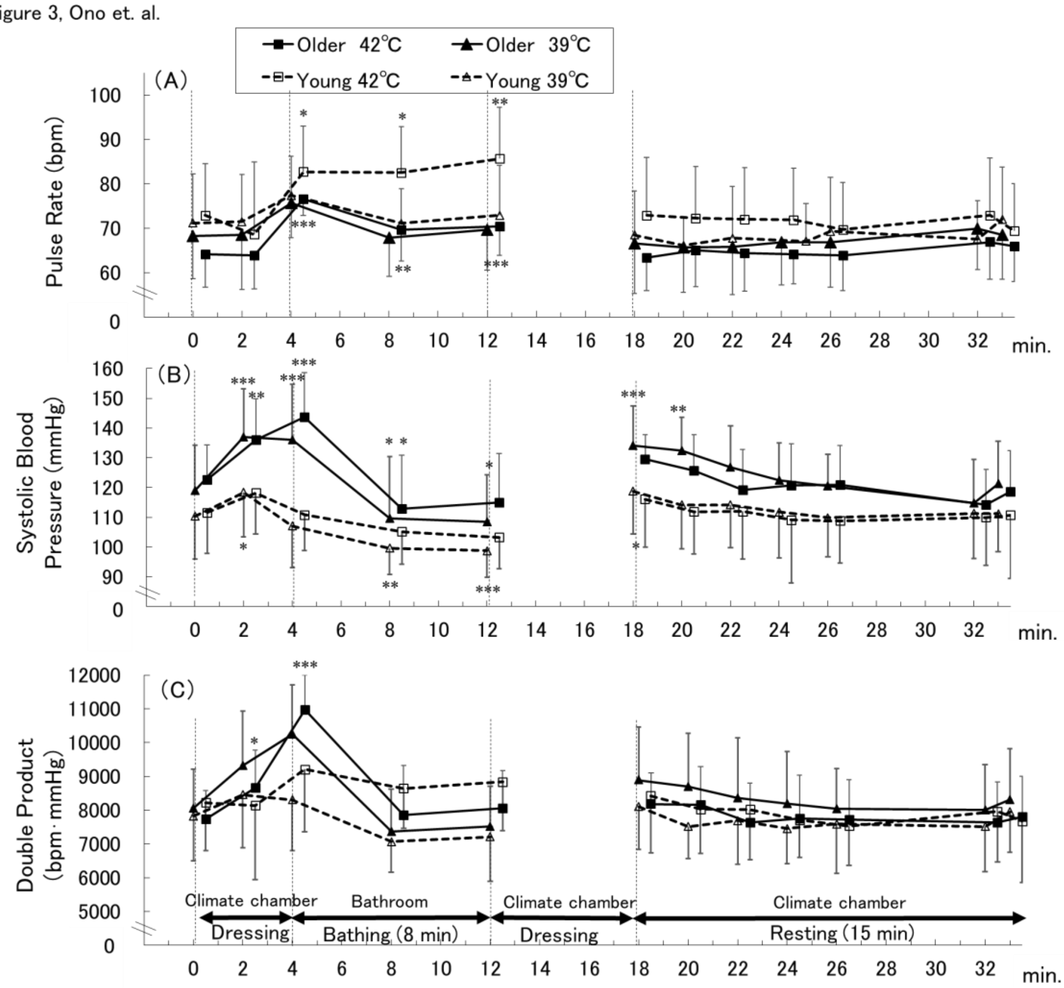

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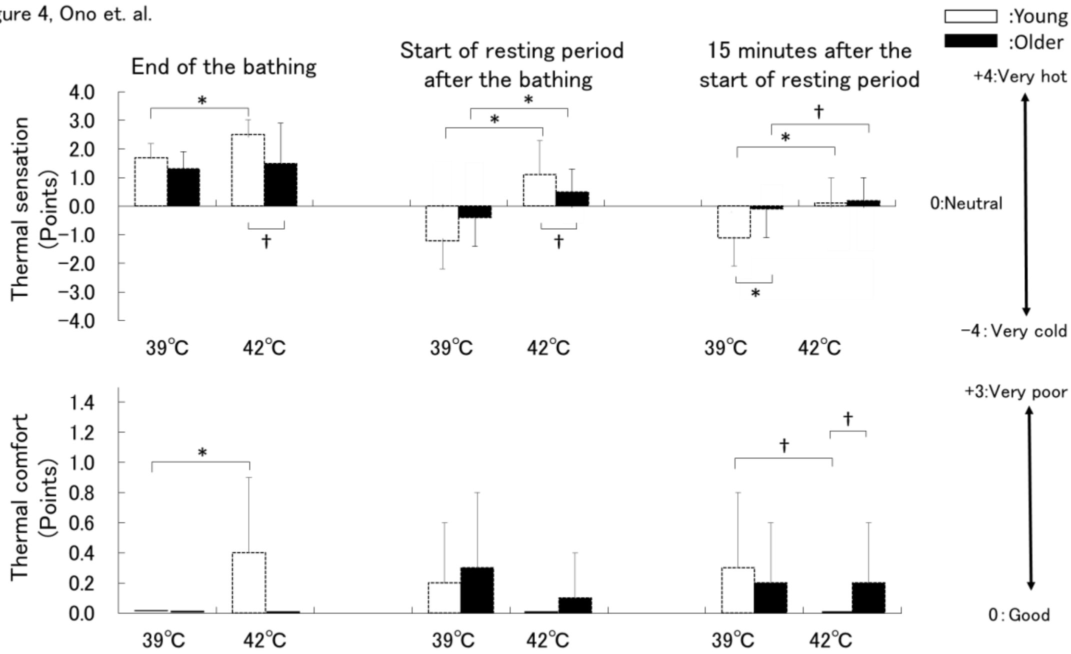

Table 1 Subject characteristics

	Older（n=11）	Young (n=10)	t-test
Age (years)	69.5 ± 2.9	24.1 ± 1.8	-
Age range (min-max)	66–75	22–27	-
Height (m)	1.66 ± 0.07*	1.72 ± 0.05	p= 0.027
Weight (kg)	62.8 ± 10.0	59.8 ± 7.1	p= 0.432
BMI (kg/m^2)	22.7 ± 2.2*	20.1 ± 2.5	p= 0.026
Body surface area (m^2)	1.70 ± 0.16	1.70 ± 0.11	p= 0.900
Subcutaneous fat thickness			
upper arm (mm)	13.1 ± 2.0	11.7 ± 2.4	p= 0.084
back (mm)	20.1 ± 5.9	17.3 ± 6.3	p= 0.305
abdomen (mm)	16.3 ± 4.8	12.8 ± 4.0	P= 0.079

BMI, body mass index
* ; *P*<0.05 vs. younger men