Effect of aging on thermoregulatory and subjective responses during a 15-minute bath at 41 °C

Chihiro Miwa¹, Hiroya Shimasaki¹, Masayasu Mizutani², Yasunori Mori³, Kazunori Maeda³, and Akira Deguchi²

1) Department of Rehabilitation, Faculty of Health Science, Suzuka University of Medical Science, 1001-1 Kishioka-cho Suzuka-shi, Mie, Japan
   TEL: +81-59-383-8991, FAX: +81-59-383-9666
   E-mail: miwa@suzuka-u.ac.jp
2) Oyamada Memorial Spa Hospital
3) Mie Prefecture Health and Environment Research Institute

(received on 17th October, 2019, accepted on 6th April, 2020)

Abstract

The purpose of this study was to clarify the effects of bathing on thermoregulatory and subjective responses in elderly persons compared to those in young persons. Ten young (20.4 years) and 10 elderly (69.7 years) individuals were asked to bathe for 15 minutes in water at 41 °C. Tympanic temperature (Tty) was measured using a thermometer with a thermistor, sweating rate (SR) was measured by a ventilated capsule method, and skin blood flow (SkBF) was measured by laser Doppler flowmetry to assess thermoregulatory responses. Subjective thermal and comfort sensations were evaluated using a seven-point scale. The results showed significant increases in Tty, SR and SkBF in young participants than in elderly participants. In addition, we divided the total bathing period into three time periods and observed later SR and SkBF responses in elderly participants than in young participants. While young participants felt hot and unpleasant during the late time period, elderly participants felt warm and comfortable during the entire duration of bathing. These results demonstrate the thermoregulatory responses due to changes in physical structure and function due to aging during a 15-minute bath at 41 °C in the elderly.

Keywords: Aging, Bathing, Thermoregulation, Subjective response

1. Introduction

The main bathing method in Japan is a “whole body” soak to the shoulders. The various effects on the body depend on the warm temperature, static hydro-pressure, and buoyancy in this style of bathing (Ootsuka 2000). The beneficial effects of bathing in healthy adults include sensations of relaxation and comfort. It was also said that there are other effects such as inducing good-quality sleep or relieving fatigue (Kanda 1995). However, bathing may be harmful to the health of weak elderly persons with disabilities. The estimated nationwide number of deaths during the winter period of 6 months from October is 13,369 in Japan (Suzuki et al 2017). Therefore, it is necessary to determine methods to prevent such bathing accidents in the elderly.

Avoid long bathing times is one of the five points for the prevention of bathing accidents in the elderly (Takahashi 2002). In addition, in elderly persons, the bathing water temperature and bathing duration increases in the winter season compared to those in the summer season (Taylor et al. 1995). Therefore, it is important to determine why the bathing time increases in elderly persons.

Previous studies have reported a smaller increase in the body temperature of elderly participants during bathing compared to that in young participants (Takahashi et al 2007) and elderly individuals have a decreased sensation of changes in temperature (Ono et al 2017). For these reasons, the bathing time of an elderly person tends to be longer. But some studies have reported impaired thermoregulatory control in elderly individuals (Armstrong and Kenney 1993, Holowatz and Kenney 2010, Sagawa et al 1988). In this
study, we have focused on the comparison of bathing time and thermoregulatory responses between elderly and young individuals. Therefore, the purpose of this study was to identify the potential causes of long bathing times in the elderly.

2. Methods

2.1. Study participants

The study participants were 10 healthy young adult men, with a mean age of 20.4 ± 0.5 years, height of 172.5 ± 1.2 cm, weight of 62.5 ± 2.1 kg, body fat percentage by impedance method (HBF-306-A, OMRON) of 18.7 ± 1.2 %, and body surface area of 1.74 ± 0.03 m² and 10 elderly adult men with a mean age of 69.7 ± 0.9 years, height of 162.7 ± 1.5 cm, weight of 66.7 ± 1.0 kg, body fat percentage of 28.2 ± 1.3 %, and body surface area of 1.71 ± 0.02 m². Significant differences were observed between the participants in age (p < 0.001), height (p < 0.001), and body fat (p < 0.001). However, the weight and body surface area did not differ significantly between participants (Table 1). Written informed consent was obtained from all participants after receiving a thorough explanation of the experiment, which was approved by the Ethical Committee of Faculty of Medicine, Aichi Medical College (No. 15001). The young participants were the students of the junior college and the elderly participants attended a culture circle, and they became independent by self-assessment. Three persons in the elderly group were high blood pressure and were regulated with an antihypertensive medicine. The participants did not have diabetes and heart diseases.

2.2. Bathing facilities

The experimental bathroom was composed of a unit bathroom and an adjacent dressing room. The unit bathroom had dimensions of 1,400 × 1,750 × 2,040 (height) mm with a bathtub (1,300 × 800 × 500 mm in depth and the full volume 520 L) and a washing space (1,350 × 800 × 2,130 [height] mm). The dressing room was 2,080 × 1,930 × 2,510 (height) mm. Both rooms were equipped with sufficient air conditioning.

2.3. Procedures

The study participants were asked to report to the experimental bathing area twice at a designated time of 9:00, 11:00, 13:00, or 15:00 on separate days, at the same time of day in both instances for two months from May to July. Intervals of more than 48 hours were set between the experimental bathing sessions. The participants arrived 30 minutes before the experiment while wearing swimming suits, and their body weights were measured for 10 minutes. Then, probes and sensors were applied to each individual for 30 minutes. The participants stayed for 1 hour at room temperature (RT) of 23 °C and relative humidity (RH) of 50 in a controlled environment and at the bathroom same temperature and humidity. The participants were requested to wear swimming trunks and to sit in the dressing room (defined as the rest period) for 5 minutes. Then, they moved to the bathroom and bathed on separate days, bathing at 41 °C for 15 minutes (defined as the task period). The water level of the bath was at nipple level. After exiting the bathtub, the participants received a towel dry and rested in the dressing room for 5 minutes (defined as the recovery period). The evaluated task was bathing at 41 °C. Because we wanted to recapitulate the real-life bathing experience we did not maintain the water temperature by adding hot water whilst bathing, therefore the bathing water temperature decreased naturally. The participants’ body weights were measured before and after bathing.

2.4. Measurements

Tympanic temperature (Tty) was measured using a highly precise deep-tissue thermometer, with thermistors with a precision of 0.01 °C (ST-21S; Sensor Technica Co. Ltd.) to determine core temperatures each minute in the right ear, while the sweating rate (SR) was measured at the left (non-immersed) arm by a ventilated capsule method (SKD 2000; Skinos Co. Ltd.). Skin blood flow (SkBF) at the left (non-immersed) forearm was measured using laser Doppler flowmetry (ALF-21; Advance Co. Ltd.). We measured the participants’ weight before and after the experiment with a precision of 20 g using a weighing scale (AD-6205; Table 1. Basic characteristics of the young and elderly participants

| Variable          | Young (n=10)      | Elderly (n=10)     |
|-------------------|-------------------|--------------------|
| Age, y            | 20.4 ± 0.5        | 69.7 ± 0.9 (p<0.001) |
| Height, cm        | 172.5 ± 1.2       | 162.7 ± 1.5 (p<0.001) |
| Weight, kg        | 62.5 ± 2.1        | 66.7 ± 1.0 (p=0.09) |
| Body fat, %       | 18.7 ± 1.2        | 28.2 ± 1.3 (p<0.001) |
| Body surface area, cm² | 1.74 ± 0.03       | 1.71 ± 0.02 (p=0.50) |

Data are shown as mean ± standard error (mean ± SE) and differences between the young and the elderly are represented by p-values.
A&D Co. Ltd.). As the ambient temperature can affect tympanic temperature, we covered the participants’ ears with cotton after inserting the tympanic temperature sensor.

Temperature was measured using a thermometer (TR-76Ui; T&D Co. Ltd.), while the humidity was measured using a hygrometer (TR-72wf; T&D Co. Ltd.) in the dressing room. We measured the water temperature with a thermometer (TR-50U2; T&D Co. Ltd.) every minute.

Ratings of thermal and comfort sensations were assessed every 5th minute during the rest period: at 0 minutes (just after bathing), and at the 5th, 10th, and 15th minute during the task period; and at the 5th minute during the recovery period. Subjective thermal sensation (7: very hot, 6: hot, 5: slightly hot, 4: neutral, 3: slightly cold, 2: cold, and 1: very cold) and comfort sensation (7: very comfortable, 6: comfortable, 5: slightly comfortable, 4: neutral, 3: slightly unpleasant, 2: unpleasant, and 1: very unpleasant) were evaluated using seven-point scales.

Weight was measured with a precision of 20 g using a weighing scale (AD-6205; A&D Co. Ltd.).

### 2.5. Statistical analysis

The results are expressed as the means ± standard error (mean ± SE). We confirmed that each measurement item had a normal distribution before performing various analyses using the Shapiro-Wilk test. A unpaired t-test was used for age, height, weight, body fat, and changes in weight after the bathing for comparisons between young and elderly participants. Difference between young and elderly participants were assessed by two-way repeated-measures analysis of variance (ANOVA), and post-hoc testing via Bonferroni’s method was used in the comparisons between the 5th minute rest period and the values measured every minute during the task and recovery periods, for Tty, SR, SkBF and thermal and comfort sensations. Pearson correlations were used to examine the relationships between the amount of changes in Tty and SR, SkBF, and between subjective sensations (thermal and comfort sensations) and objective parameters (Tty, SR, and SkBF) during bathing. P-values < 0.05 were considered statistically significant. IBM SPSS Statistics version 24.0 was used for statistical analyses.

### 3. Results

#### 3.1. Changes in bathing water temperature

After bathing with a water level at nipple level, the mean bathing temperatures decreased from 41.22 ± 0.12 °C at the start of the bathing to 40.29 ± 0.11 °C at the end.

#### 3.2. Changes in tympanic temperature during bathing (Fig. 1)

In young participants, the Tty increased from 36.68 ± 0.07 °C during the rest period to 37.19 ± 0.10 °C at the end of the task period. In contrast, in elderly participants, Tty increased from 36.48 ± 0.07 to 36.78 ± 0.08 °C. Two-way repeated measures ANOVA showed significant differences in Tty between young and elderly participants (p = 0.048). A significant increase was observed in the end of 3 minutes of the task period (13th min: p = 0.023, 14th min: p = 0.006, 15th min: p = 0.001) and the 1st and 2nd of recovery period in young participants (1st min: p = 0.003, 2nd min: p = 0.012), and in the recovery period in elderly participants (1st min: p = 0.004, 2nd min: p = 0.008, 3rd min: p = 0.012, 4th min: p = 0.02, 5th min: p = 0.038). The Tty increases after 15 minutes of bathing were 0.51 ± 0.08 °C in young participants and 0.30 ± 0.04 °C in elderly participants, respectively, and the increase in young participants was larger than that in elderly participants (p = 0.036).

#### 3.3. Changes in sweating rate during bathing (Fig. 1)

In young participants, the SR increased from 0.05 ± 0.02 mg/cm²/min during the rest period to 1.49 ± 0.14 mg/cm²/min at the end of the task period. In contrast, in elderly participants, SR increased from 0.04 ± 0.02 to 0.69 ± 0.14 mg/cm²/min. Two-way repeated measures ANOVA showed a significant difference in SR between young and elderly participants during bathing (p < 0.001). A significant increase was observed from the 4th minute (p = 0.046) to the end of the recovery period in young participants (p < 0.001), and 5 minutes of task period (11th min: p = 0.01, 12th min: p = 0.006, 13th min: p = 0.001, 14th and 15th min: p < 0.001), the recovery for 1 minute in elderly participants (p = 0.042). The increases in SR after 15 minutes of bathing were 1.44 ± 0.14 mg/cm²/min in young participants and 0.65 ± 0.14 mg/cm²/min in elderly participants, respectively, with a larger increase in young participants than in elderly participants (p = 0.001).

#### 3.4. Changes in skin blood flow during bathing (Fig. 1)

In young participants, SkBF increased from 1.88 ± 0.35 mL/100 g tissue/min during the rest period to 9.87 ± 1.01 mL/100 g tissue/min at the end of the task period. In contrast, in elderly participants, the SkBF increased from 2.12 ± 0.54 to 6.16 ± 1.09 mL/100 g tissue/min. Two-way repeated measures ANOVA showed significant differences in SkBF between young and elderly participants during bathing (p = 0.036). A significant increase was observed from the 7th minute (p = 0.02) to the end of the task period (p < 0.001) in young participants; however, significant change was observed for
only last 2 minutes of task period in elderly participants (14th min: p = 0.028, 15th min: p = 0.011). The SkBF increases after 15 minutes of bathing were 7.99 ± 0.73 and 4.04 ± 1.21 mL/100 g tissue/min in young and elderly participants, respectively, with a larger increase in young participants than in elderly participants (p = 0.012).

3.5. Relationship between tympanic temperature and sweating rate, and tympanic temperature and skin blood flow during bathing (Figs. 2, 3, 4)

In the analysis of thermoregulatory responses over time, we observed relationships between the amount of change in Tty and SR, and between Tty and SkBF during bathing. Equilateral correlations were observed for relationships in both young (p < 0.001) and elderly
Effect of aging on thermoregulatory and subjective responses during a 15-minute bath at 41 °C

Furthermore, we analysed the relationships between the magnitudes of changes in Tty and SR, and in Tty and SkBF every 5 minutes during bathing. A significant equilateral correlation between Tty and SR was observed for 5 minutes of the first (p = 0.014), middle (p < 0.001), and late periods (p = 0.002) in young participants. However, in elderly participants, significant equilateral correlations were observed only in the late period (p < 0.001). A significant equilateral correlation between Tty and SkBF was observed for 5 minutes of the first (p < 0.001) and middle periods (p < 0.001), but not in the late period in young participants. A significant correlation was observed for SR in the late period (p = 0.007) in elderly participants.
Fig. 5. Changes in subjective thermal and comfort sensations during a 15-minute bath at 41 °C. The filled and open circles indicate the elderly and the young, respectively. The error bar indicates standard error. The graph shows scores for “subjective thermal sensation” (left), and “comfort sensation” (right). *p < 0.05, **p < 0.01: vs. rest period (for 5 minute).

Fig. 6. Relationships between the absolute value of thermal sensation and tympanic temperature, skin blood flow, and sweating rate during a 15-minute bath at 41 °C. The upper panels show the young, the lower panels show the elderly.

Fig. 7. Relationships between the absolute value of comfort sensation and tympanic temperature, skin blood flow, and sweating rate during a 15-minute bath at 41 °C. The upper panels show in the young, the lower in the elderly.
3.6. Changes in subjective thermal and comfort sensations during bathing (Fig. 5)

Two-way repeated measures ANOVA showed significant differences in thermal and comfort sensations between young and elderly participants during bathing (p < 0.001). In young participants, the thermal sensations were as follows: just after bathing, they became “slightly warm” (p = 0.045) and at the 5th (p < 0.001), 10th (p < 0.001), 15th minute (p < 0.001) their sensations changed to “hot”. However, there was no significant change in elderly participants. In young participants, the “comfortable” sensation moved to “unpleasant” during bathing and after the 15th minute the sensation was “slightly unpleasant” (p = 0.045). However, in elderly participants, the sensation was immediately “comfortable”, and was maintained until the 10th minute of the task (0 min: p = 0.028, 5th min: p = 0.012, 10th min: p = 0.028).

3.7. Relationship between subjective sensations and objective parameters during bathing (Figs. 6 and 7)

We analysed the relationships between the magnitudes of changes in subjective sensations (thermal and comfort sensations) and objective parameters (Tty, SkBF, and SR) during bathing. Significant equilateral correlations were observed between thermal sensation and objective parameters in young participants (Tty: p = 0.04, SR: p = 0.001, SkBF: p = 0.001); however, no significant relationship was observed in elderly participants. In contrast, a significant negative correlation was observed between comfort sensation and objective parameters in young participants (Tty: p = 0.002, SR: p = 0.004, SkBF: p = 0.013). However, a significant correlation was not seen in elderly participants.

3.8. Changes in body weight during bathing

Body weight loss after bathing was 208.00 ± 27.35 g and 120.00 ± 27.48 g in young and elderly participants, respectively. Significant differences were observed between young and elderly participants (p = 0.036).

4. Discussion

In Japan, there is generally a bathtub in the home, and many Japanese people customarily take a bath daily. A number of studies have examined the influence of bathing on bodily functions and psychological changes. Ohnaka et al. (1995), Miwa et al. (1999), and Hashiguchi et al. (2002) examined changes in thermoregulatory and cardiovascular functions during 40 °C or 41 °C bathing, reporting body temperature increases and blood pressure fluctuation. However, the impact on the body is severe and may lead to sudden death during bathing. Regarding deaths while bathing, there are a number of risk factors, particularly in elderly persons.

Chiba et al. (2005) and Suzuki et al. (2017) reported that cold during the winter season was a dangerous risk factor for bathing accidents. However, no study has focused on bathing time and thermoregulatory responses compared between elderly and young individuals. This study examined the thermoregulatory response of young and elderly participants during a 15-minute bath at 41 °C. We measured Tty, SR, and SkBF as objective indexes and thermal and comfort sensations as subjective indexes.

In this study, Tty, SR and SkBF were increased significantly in both young and elderly participants. We divided the total bathing period into three periods and examined the relationships between the increase in Tty and those of SR and SkBF. A significant equilateral correlation was observed between Tty and SR during the late period in elderly and young participants. The relationship between Tty and SkBF in elderly participants was observed in the late period, similar to the relationship between Tty and SR. Regarding the thermal sensation, young participants felt hot, and gradually felt unpleasant, while elderly participants felt warm and comfortable throughout the bathing. Significant relationships were seen between the physiological and subjective reactions in young participants during bathing, but they were not seen in elderly participants.

The increase in Tty seen in elderly participants was less than that seen in young participants during the 15-minute bath at 41 °C. This may be due to the higher body fat volume in elderly individuals than in young individuals (Cheung et al. 2000, Kachiba-Uscckio and Crucza 2011, Pandolf et al. 1988, Petrofsky and Laymon 2009). The volume of fat in the human body increases with age (Buford et al. 2012, Crawford et al. 2016, Yoon et al. 2018). An increase in the volume of the fat reduces the conduction of heat from the outside (Petrofsky and Laymon 2009). The increase in Tty during bathing was lower in young participants than in elderly participants with higher fat volumes and the hyperthermic suppressant effect of the volume of fat increases delayed sweating and vessel vasodilation as a thermoregulatory function.

Another factor may be related to the influence of aging. Delayed sweating in the elderly may be due to an increased threshold temperature for sweating (Foster et al. 1976, Inoue et al.1999a, Kenny and Fowler 1988), a decrease in sweating signals due to reduced thermo-reception of the skin (Inoue 1996), or decrease in sudomotor nerves (Inoue et al. 1999b). We measured sweating at the left forearms in this study. Local differences in sweat glands have been associated with aging, and the extremities may be attributed partly to decreased regional sweat gland function, including in the forearm in the elderly (Inoue 1996).

There are several possible explanations for the
decreased angiectatic reaction during bathing in elderly participants compared to young participants. Cardiac output and warmed blood circulation decreases (Rowell 1974, Johnson 2010), there is little blood vessel density, temperature-dependent neuromodulation function decreases (Grassi et al. 2003, Holowatz et al. 2003, Minson et al. 2002), and there is limited blood vessel endothelial expansion to enable NO release (Holowatz et al. 2003, Minson et al. 2002). In addition, elderly individuals have a smaller physical fluid volume than younger individuals (Kenny et al. 1990, Nadel et al. 1980).

The subjective change during bathing differed between elderly and young participants. Elderly participants did not feel that 41 °C was hot. During the 15-minute bath, body temperature did not increase as much in elderly participants compared to that in young participants, and elderly participants are reported to have low sensitivity to warm temperatures (Ono et al. 2017, Taylor et al. 1995). The temperature at which the elderly feels comfortable bathing, the young find unpleasant (Taylor et al., 1995). Thus, the elderly is rarely influenced by high temperature bathing; hence, the elderly may bathe for extended periods at high temperatures. Accidents resulting from long bathing duration may be due to bathing promoted changes in circulation.

We studied the changes at every 5 minutes during bathing at 41 °C for 15 minutes. The time frame is important for changes observed during bathing in the elderly (Miwa et al. 1999). A significant equilateral correlation was seen between Tty and SR in young participants during bathing for 15 minutes. This suggested that sweating occurred throughout the 15 minutes of bathing at 41 °C in young participants. In contrast, sweating was seen in elderly participants during bathing after 10 minutes. It is that sweating during 41 °C bathing becomes more difficult with increased age. Vasodilatation of the skin occurred according to a rise in Tty in young participants after bathing for 10 minutes, but it was not seen afterwards for 5 minutes. In the young, vasodilatation at 41 °C might reach equilibrium at 10 minutes. An equilateral correlation was seen between vasodilatation and the rise of Tty in elderly participants after 10 minutes. The time was similar for the sweating phenomenon of bathing. It is the result that body temperature does not rise during bathing until around 10 minutes in the elderly.

There are few relationships between physiological reactions and psychological changes in elderly people. We try to end bathing when we feel unpleasant as soon as body temperature rises due to the hot water. The change in sensation from warm to uncomfortable was not seen in bathing at 41 °C for 15 minutes in elderly participants. Therefore, bathing time in the elderly tends to be longer than that in the young.

Weight change after bathing was lower in elderly participants than in young participants. This may be due to the larger volume of sweat generation while bathing in the young than in the elderly.

5. Study Limitations

1. The number of study participants in this study was small, at only 10 per group. Further investigation with a larger number of participants is required.
2. Because the height and volume of fat differed between participants, we were not able to clearly determine whether these results were influenced by aging.

6. Conclusions

We examined thermoregulatory function and subjective responses during a 15-minute bath at 41 °C in young and elderly individuals. In the elderly, the physiological changes were slower and psychological changes were more extreme in comparison with the young, and differences were seen in the timing of these reactions. Elderly persons are at a risk for bathing accidents due to bathing for long periods of time.

Acknowledgments

This study was supported in part by a research scholarship from the DENSO Corporation and we would like to thank Editage (www.editage.com) for English language editing.

References

Armstrong, C.G., Kenney, W.L. (1993) Effects of age and acclimation on responses of aged men to heat exposure. J Appl Physiol 75 (5): 2162-2167.

Buford, T.W., Lott, D.J., Marzetti, E., Wohlgemuth, S.E., Vandenborne, K., Pahor, M., Leeuwenburgh, C., Manini, T.M. (2012) Age-related differences in lower extremity tissue compartments and associations with physical function in older adults. Exp Gerontol 47 (1): 38-44.

Cheung, S.S., McLellan, T.M., Tngalia, S. (2000) The thermophysiology of uncompensable heat stress. Physiological manipulations and individual characteristics. Sports Med 29 (5): 329-359.

Chiba, T., Yamauchi, M., Nishida, N., Kaneko, T., Yoshizaki, K., Yoshioka, N. (2005) Risk factor of sudden death in the Japanese hot bath in the senior population. Forensic Sci Int 149 (2-3): 151-158.

Crawford, R.J., Filli, L., Elliott, J.M., Nanz, D., Fischer, M.A., Marcon, M., Ulbrich, E.J. (2016) Age- and level-dependence of fatty infiltration in lumbar paravertebral muscles of healthy volunteers. AJNR 37 (4): 742-748.

Foster, K.G., Ellis, F.P., Doré, C., Exton-Smith, A.N.,
Effect of aging on thermoregulatory and subjective responses during a 15-minute bath at 41 °C

Weiner, J.S. (1976) Sweat responses in the aged. Age Ageing 5 (2): 91-101.
Grassi, G., Seravalle, G., Turri, C., Bertinieri, G., Dell’Oro, R., Mancia, G. (2003) Impairment of thermoregulatory control of skin sympathetic nerve traffic in the elderly. Circulation 108 (6): 729-735.
Hashiguchi, N., Ni, F., Tochihara, Y. (2002) Effects of room temperature on physiological and subjective responses during whole-body bathing, half-body bathing and showering. J Physiol Anthropol Appl Human Sci 21 (6): 277-283.
Holowatz, L.A., Houghton, B.L., Wong, B.J., Wilkins, B.W., Harding, A.W., Kenney, W.L., Minson, C.T. (2003) Nitric oxide and attenuated reflex cutaneous vasodilation in aged skin. Am J Physiol Heart Circ Physiol 284 (5): H11662-H11667.
Holowatz, L.A., Kenney, W.L. (2010) Peripheral mechanisms of thermoregulatory control of skin blood flow in aged humans. J Appl Physiol 109 (5): 1538-1544.
Inoue, Y. (1996) Regional differences in age-related decrements of the cutaneous vascular and sweating responses to passive heating. Eur J Appl Physiol 74 (1-2): 78-84.
Inoue, Y., Havenith, G., Kenney, W.L., Loomis, J.L., Buskirk, E.R. (1999a) Exercise- and methylcholine-induced sweating responses in older and young men: effect of heat acclimation and aerobic fitness. Int Biometeorol 42 (4): 210-216.
Inoue, Y., Shibasaki, M., Ueda, H., Ishizashi, H. (1999b) Mechanisms underlying the age-related decrement in the human sweating response. Eur J Appl Physiol 79 (2): 121-126.
Johnson, J.M. (2010) Exercise in a hot environment: the skin circulation. Scand J Med Sci Sports 20 (Suppl3): 29-39.
Kaciba-Uscciko, H., Gruca, R. (2011) Gender differences in thermoregulation. Curr Opin Clin Nutr Metab Care 4 (6): 533-536.
Kanda, K. (1995) Effects of bathing following sleep in the elderly and young people. Bull Inst Public Health 44 (3): 401-404.
Kenney, W.L., Fowler, S.R. (1988) Methylcholine-activated eccrine sweat gland density and output as a function of age. J Appl Physiol 65 (3): 1082-1086.
Kenney, W.L., Tankersley, C.G., Newswanger, D.L., Hyde, D.E., Puhl, S.M., Turner, N.L. (1990) Age and hypohydration independently influence the peripheral vascular response to heat stress. J Appl Physiol 68 (5): 1902-1908.
Minson, C.T., Holowatz, L.A., Wong, B.J., Kenney, W.L., Wilkins, B.W. (2002) Decreased nitric oxide- and axon reflex-mediated cutaneous vasodilation with age during local heating. J Appl Physiol 93 (5): 1644-1649.
Miwa, C., Matsukawa, T., Iwase, S., Sugiyama, Y., Mano, T., Sugeno, N., Yamaguchi, H., Kirsch, K.A. (1994) Human cardiovascular responses to a 60-min bath at 40 degrees C. Environ Med 38 (1): 77-80.
Nadel, E.R., Fortney, S.M., Wenger, C.B. (1980) Effect of hydration state of circulatory and thermal regulations. J Appl Physiol 49 (4): 715-721.
Ohnaka, T., Tochihara, Y., Kubo, M., Yamaguchi, C. (1995) Physiological and subjective responses to standing showers, sitting showers, and sink baths. Appl Human Sci 14 (5): 235-239.
Ono, J., Hashiguchi, N., Sawatari, H., Ohkusa, T., Miyazono, M., Son, S.Y., Magota, C., Tochihara, Y. (2017) Effect of water bath temperature on physiological parameters and subjective sensation in older people. Geriatr Gerontol Int 17 (11): 2164-2170.
Ootsuka, Y. (2000) Physiology of the bathing. J Int Med 10 (10): 830-834.
Pandolf, K.B., Cadarette, B.S., Sawka, M.N., Young, A.J., Francesconi, R.P., Gonzalez, R.R. (1988) Thermoregulatory responses of middle-aged and young men during dry-heat acclimation. J Appl Physiol 65 (1): 65-71.
Petrofsky, J.S., Laymon, M. (2009) Heat transfer to deep tissue: the effect of body fat and heating modality. J Med Eng Technol 33 (5): 337-348.
Rowell, L.B. (1974) Human cardiovascular adjustments to exercise and thermal stress. Physiol Rev 54 (1): 75-159.
Sagawa, S., Shiraki, K., Yousef, M.K., Miki, K. (1988) Sweating and cardiovascular responses of aged men to heat exposure. J Gerontol 43 (1): M1-M8.
Suzuki, M., Shimbo, T., Ikaga, T., Hori, S. (2017) Sudden death phenomenon bathing in Japan – Mortality data. Circ J 81 (8): 1144-1149.
Takahashi, R. (2002) Prevention of the bathing accident in the elderly person -Five points-. Expert Nurse 18: 22-24. (in Japanese)
Takahashi, Y., Ohnaka, T., Tochihara, Y., Nagai, Y., Ito, H., Yoshitake, S. (2007) Environmental and behavioral conditions of bathing among elderly Japanese. J Physiol Anthropol Appl Human Sci 26 (2): 235-240.
Taylor, N.A., Allsopp, N.K., Parkes, D.G. (1995) Preferred room temperature of young vs aged males: the influence of thermal sensation, thermal comfort, and affect. J Gerontol A Biol Sci Med Sci 50 (4): M216-M221.
Yoon, M.A., Hong, S.I., Ku, M.C., Kang, C.H., Ahn, K.S., Kim, B.H. (2018) Multiparametric MR Imaging of age-related changes in healthy thigh muscles. Radiology 287 (1): 235-246.