Abstract
Maintaining the water content in the human body is necessary to prevent heatstroke on construction sites in the hot sun. As such, determining levels of perspiration for the entire body is important. This study focused on helmets (or hard hats), which are mandatory on construction sites, to develop a wearable helmet device that can measure the amount of perspiration while completing various activities. The results of our experiments indicate the feasibility of measuring whole-body perspiration levels using this device. In addition, we show that the estimated perspiration rate can potentially be used as an index for the earlier identification of heatstroke occurrence compared with the traditional indicator, i.e., a rise in core body temperature.

Keywords: Heatstroke, Perspiration, Measurement, Helmet, Wearable

1. Introduction
The number of fatalities from heatstroke shows an increasing trend over the past 10 years, from one-quarter of the average number of deaths during the mild summer of 2007 to five times the average during the hot summer of 2013.[1] Researchers claimed that if the number of patients that have several days of occupational accident holidays less than three days, are still 100 times more. In addition, heatstroke is expected to become an even greater social problem in the near future as a result of the acceleration of global warming.[2] When comparing different industry types, construction exhibits the highest number of casualties; therefore, heatstroke management risk on construction sites is an important issue.[1]

To limit the risk of heatstroke, the American Conference of Governmental Industrial Hygienists suggests observing the physical condition of workers in high-temperature working environments and advises that, if a worker’s weight decreases by more than 1.5%, they should stop working.[3] Based on this advice, the Ministry of Health, Labor of Japan, and Welfare requires work to be stopped in high-temperature environments, and a break must be taken by individuals if their weight decreases by more than 1.5%.[4]

The ability to effect real-time measurement of the levels of perspiration during activity in the stage before suffering from heatstroke can serve as an effective countermeasure to this condition. However, although perspiration measuring devices and methods already exist,[5, 6] no suitable wearable devices exist that can measure the levels of whole-body perspiration during individual activities and advise on hydration. For example, [17] proposes a wearable perspiration measurement method; however, this technique captures the amount of sweat of the adsorbent connected to an electrode as a change in capacitance and is thus a narrow local perspiration measurement method. Therefore, estimating the amount of whole-body perspiration from the values measured by this research method is difficult. The research in [18] presents an improved version of the ventilation capsule method, which uses the same measurement principle as this study; however, the distance between the two sensors is only 0.3 mm, which...
means they are located close together. Therefore, estimating the amount is difficult. Furthermore, the power supply and pump control were effected from an externally controlled personal computer; therefore, this method could not be applied to the wearable measurement that is the focus of the present research. Based on this background, the purpose of the present research was to develop a device that would solve the problems of existing conventional devices. In addition, this study aimed to confirm whether the whole-body perspiration estimate could be applied as an earlier estimate compared with a rise in core body temperature,[15] which is an effective indicator of heat stroke morbidity.

2. Principle of Perspiration Measurement

First, we improved the ventilation capsule method,[5] which measures the amount of localized perspiration, and we established a method to measure the amount of perspiration of the entire head. The approximate saturated water vapor pressure, $e$ (hPa), at a specific temperature, $t$ (°C), was determined using the Tetens equation [8]:

$$e_{t} = 6.11 	imes 10^{-3} \left( \frac{125.72}{t + 237.3} \right)^{7.562}$$  \quad (1)

Next, the amount of water in the air per unit of volume, $X$ (g/m³), is determined from the relative humidity, RH (%), at that given time:

$$X_{1} = \frac{217 \times e_{t}}{273.15 + t} \times \frac{RH_{t}}{100}$$  \quad (2)

Here, considering an air–fluid system with inflow and outflow airflow rate $F$ (m³/s), $X_{1}$ is the amount of water entering the system, and $X_{2}$ is the amount of water leaving the system per unit of time. The moisture content, $Y$ (g/s), is expressed by the following equation from the mass balance of the system:

$$Y = F \times (X_{2} - X_{1})$$  \quad (3)

Therefore, when airflow rate $F$ is known, and the temperature and relative humidity of the air entering and exiting the system are measured using temperature and humidity sensors, respectively, water content $X_{1}$ and $X_{2}$ in the air per unit of volume can be obtained. From Eq. (1), the amount of evaporated water, $Y$, corresponding to the amount of perspiration per unit of time generated in this air–fluid system can be calculated (Fig. 1).[9]

3. Principle Verification

To construct a wearable device, temperature and humidity sensors were attached to the air inlet and outlet of a commercially available hard hat fitted with a fan. To verify the principle expressed in Eq. (3), the hard hat was placed on a Styrofoam mannequin-head for testing (Fig. 2). To simulate human head perspiration, a wet cloth was attached to the mannequin head. First, to keep the exposure constant, a specific amount (10 g) of water was dropped onto the mannequin head using the surface area of the cloth. The change over time in the weight-loss of the entire mannequin head was measured at 1 min intervals for 15 min using an electronic scale (HT-200, A&D Co.; minimum scale: 0.01 g).

To accurately control the airflow of the helmet device with a fan, it was measured using a method conforming to JIS B 3880 and JIS A 1431, and the power supply voltage at the start and end of each experiment was measured. In addition, sensors were arranged in pairs with both a temperature and a humidity sensor attached to the inflow and outflow sides. These sensors demonstrated uniform sensor outputs and were placed where the temperature in the system could be consistently reproduced. The temperature and humidity sensors on both sides were connected to a Raspberry Pi 3, a small personal computer (PC). Data were then collected, with the amount of water loss in the wearable device recorded every minute using an electronic scale. Figure 3 shows the measurement flow.

![Fig. 1 Principle of perspiration measurement.](image1)

![Fig. 2 Experimental setup for verifying the measurement principle with a wearable helmet device.](image2)
To evaluate the repetition error, three iterative experiments were performed, and the results of the regression analysis are shown in Fig. 4. The correlation coefficient, $r$, showed a strong correlation of $r = 0.99$, and the measurement principle in Eq. (3) was confirmed.[9] The temperature during the experiment ranged from 25.4°C to 25.6°C, and the humidity ranged from 55.3% to 54.0%.

4. Helmet Device Development

As the principle was confirmed, we developed a non-restrictive cable-less helmet device. This development was completed by improving a commercially available helmet and fitting it with a fan. A small wireless transmission system was constructed for wirelessly transmitting measurement data to an external PC, and a sensor was mounted on the helmet body; system components other than the sensor were mounted on the brim of the helmet. In this way, the measurement data were automatically transferred to an external PC without a cable. The continuously operated fan provided air conditioning inside the helmet while measuring perspiration levels. The fan used three rechargeable AA batteries as a power source, demonstrated a capacity of 10.8 Wh (3.6 V x 3,000 mAh), demonstrated a fan power of 0.65 W (3.6 V x 0.18 A), and consumed circuit systems such as the wireless transmission of 0.45 W (3 V x 0.15 A); it could operate continuously for approximately 10 hours (i.e., the entire time during a normal day’s work). The weight of the helmet with the fan (567 g) could be reduced to 16 g (a 2.5% weight increase), making it a wearable device that could be comfortable for the user. Figure 5 shows the configuration of the helmet device equipped with the wireless function, and Fig. 6 shows a block diagram of the entire system.
5. Basic Verification Experiment

In the principle verification experiment, the amount of evaporated water was measured using a mannequin head with a cloth attached to the inside of the helmet device. We thought it was necessary to see if the human head would give similar results to the mannequin experiment. Therefore, prior to main experiment, a basic verification experiment was conducted to clarify the relationship between the amount of head perspiration and the amount equivalent to head perspiration, to observe whether it could be accurately measured.

An existing study [19] stated that the method for measuring body-weight with a high-precision electronic platform scale, and measuring the decreased body-weight amount as the volume of whole-body perspiration, has been the most widely used method since ancient times. In [19], first, the amount of local perspiration in each part of the body (forehead, chest, back, thigh) was weighted by the body surface area ratio, and the amount of whole body perspiration was calculated. Then, it is stated that there was a significant linear correlation when the calculated whole body perspiration amount was correlated with the actual weight loss amount. The results indicate a significant linear correlation, which, in turn, indicates that a linear correlation exists between the body surface area at a specific location and the degree of whole-body perspiration. Therefore, in the current study, we present the hypothesis that the amount of whole-body perspiration can be estimated from the amount of evaporated water (equivalent to perspiration) of the entire head, and we set out to prove this.

In this experiment, the amount of water evaporation (the amount of head perspiration) discharged from the helmet device attached to the human head was adsorbed with a phosphorus pentoxide ($P_2O_5$) adsorbent, which exhibited strong water absorption characteristics. The weight of the adsorption sheet was measured with an electronic scale every 3 minutes. The amount of head-perspiration (evaporated water content) measured by the helmet device was recorded wirelessly every minute on an external PC.

Prior to the experiment, the high-precision electronic platform scale shown in Table 1 was calibrated. Additionally, as in [6], subjects were asked to enter the experimental room environment, which demonstrated a temperature of $30 \pm 1 ^\circ C$ and a humidity of $35 \pm 10\%$, 30 min before initiating the experiment so that their body could adapt to the environment. Then, the measurements begun.

To reduce the effect of ineffective perspiration on the body’s surface, which is considered a major cause of measurement errors, subjects were asked to wear cotton-based shirts and trousers; these were removed when weighing and sweat on the body’s surface. After wiping, I weighed only with my underwear and helmet. The amount of weight-loss was measured every 6 min using the precision electronic platform scale.

We measured for a period of 15 min and compared that results. Figure 7 shows the experimental flow of the basic verification applied in this study.

Figure 8 shows the correlation between the cumulative amount of water adsorbed on the scale and the cumulative head-perspiration amount measured by the helmet device. Similar to [19], which directly measured the amount of perspiration on other parts of the human body such as the forehead, correlation coefficient $r$ indicated a strong correlation ($r = 0.97$), and the degree of perspiration equivalent increased monotonically and linearly over time. Accordingly, researchers confirmed that the helmet device could accurately measure the amount equivalent to perspiration on the head and that the measurement principle was valid for human subject measurements.

6. Human Verification Experiment

The basic verification experiment found that the amount

| Equipment | Model number/feature/specification |
|-----------|-----------------------------------|
| Helmet    | Manufacturer: Toyo Safety Co., Ltd. |
|           | Model number: 394 F Windy Helmet    |
|           | Weight: 567 g                       |
|           | Blower built-in helmet (fan motor adopted) |
|           | Fan motor power consumption: 3.6 V × 0.18 A |
| Inflow/outflow temperature and humidity sensors | Manufacturer: Alps Company |
|          | Model number: HSHCAL 101B           |
|          | · Capacitive digital temperature and humidity sensor |
|          | · Adopt a paired sensor with uniform sensor output and place the sensor in the most reproducible location |
|          | · For the sensor output method, select the I2C bus output method that is resistant to noise |
| High-precision electronic platform | Manufacturer: Shinko Electronics Co., Ltd. |
|          | Model number: FJ-150K                |
|          | Minimum display: 1 g                 |
|          | Reproducibility ($\sigma$): 0.7 g    |
| PC        | Equipment: Raspberry Pi Zero/W       |
|          | Wireless system Wi-Fi                |
|          | Weight: 16 g                        |
|          | System power consumption: 3 V × 0.15 A |
| Battery   | Three AA batteries                  |
|          | Power capacity: 3.6 V × 3 Ah         |
|          | (shared with helmet fan power supply) |
equivalent to head perspiration could be accurately measured with the developed helmet device. Next, by increasing the number of participants, a human verification experiment at rest was conducted.

The experimental method was almost the same as the basic verification experiment, but the measurement time was 30 min, the temperature was $30^\circ$C $\pm 0.5^\circ$C, and the humidity was $37\% \pm 11\%$. As in the basic experiment, in order for their bodies to adapt to the environment, participants entered the room 30 min before starting the measurements. Figure 10 shows the experimental flow of the resting participant verification experiment. The experimental environment is shown in Fig. 9.
7. Human Verification Experiment Results and Discussion

A total of 18 subjects (N = 10) participated in the experiment. They were aged between 20 and 22 years, with short-to-long hair. Table 2 summarizes the participant information and the measurement results. Figure 11 and Fig. 12 show examples of the cumulative weight-loss over time in the human experiment and the equivalent cumulative head-perspiration amount weight measured by the helmet device.

The volume of perspiration varied among the participants, and, following an existing report,[3] the measurements varied significantly for each participant, depending on various factors, such as the day and season. However, both cumulative weight-loss and cumulative head-perspiration amount increased gradually over time, even when fluctuations were present in, e.g., the amount of hair and measurement time. To study this in greater detail, regression analysis was performed on all the data collected from the 18 participants for cumulative weight-loss and cumulative head-perspiration equivalent weight. Figure 13 shows the results of these data. The accumulated weight-loss was assumed to correspond to the amount of whole-body perspiration as per the slope of the graph in Fig. 13. Under the environmental conditions, P is expressed in terms of Q by the following equation:

\[ P(g) = 20.4 \times Q(g) \]  

where \( P(g) \) is the amount of whole-body perspiration, and \( Q(g) \) is the cumulative head-perspiration equivalent weight.

At this time, the correlation coefficient \( r \) was 0.75, and a sufficient correlation was found between \( P \) and \( Q \).[9]

In this experiment, based on existing studies,[18, 19] we entered the experimental environment 30 min before con-

Table 2  Participant information and measurement results.

| Person | Sex | Age | Height [cm] | Weight [kg] | Cumulative weight-loss [g] | Cumulative head-perspiration equivalent weight [g] |
|--------|-----|-----|-------------|-------------|--------------------------|-----------------------------------------------|
| A      | Male | 22  | 174         | 74.8        | 60.0                     | 2.93                                           |
| B      | Male | 32  | 160         | 46.2        | 78.0                     | 4.54                                           |
| C      | Male | 22  | 165         | 59.1        | 75.0                     | 3.59                                           |
| D      | Male | 22  | 165         | 59.8        | 110.0                    | 3.89                                           |
| E      | Male | 22  | 176         | 61.3        | 43.0                     | 1.93                                           |
| F      | Male | 22  | 172         | 88.8        | 97.0                     | 2.42                                           |
| G      | Male | 20  | 169         | 55.7        | 39.0                     | 2.15                                           |
| H      | Male | 22  | 173         | 52.4        | 27.5                     | 2.26                                           |
| I      | Male | 20  | 169         | 76.4        | 96.0                     | 6.83                                           |
| J      | Male | 22  | 168         | 88.3        | 111.4                    | 6.13                                           |

Fig. 11  Cumulative weight-loss and cumulative head-perspiration equivalent weight (Person A).

Fig. 12  Cumulative weight-loss and cumulative head-perspiration equivalent weight (Person B).
ducting measurements, to allow the body to adapt to the environment. After this period, the time to the extent that the risk of contracting heat stroke does not increase. The experiment time was 30 min. Even when the experiment continued for 30 min or more under a high environmental temperature (as in this experiment), perspiration continued keeping the body temperature constant until the initial symptoms of heatstroke were exhibited by the mechanism of human body temperature regulation. It is considered to be promoted,[14] and the correlation in Fig. 13 is expected to continue being maintained.

The head-to-body surface area ratio is approximately 7.2%,[10] but the ratio of cumulative weight-loss to the cumulative head-perspiration equivalent weight with this device is approximately 5.0%. The cumulative head-perspiration amount was lower, due to the water loss from water vapor in breath exhalation, ineffective perspiration [11] remaining on the scalp, and the fixed band of the helmet as a film of water. Accordingly, researchers considered that the amount of whole-body perspiration could be estimated from the amount of head perspiration.

8. Human Verification Experiment during Activity

Since good results were obtained in the human verification experiments while participants were at rest, verification experiments were performed on males aged 26 to 65 using the newly developed helmet device under actual working conditions.[12] The experimental yard is shown in Fig. 14. The top and sides of the yard received partial sunlight and had open windows, and the temperature and humidity were similar to an outdoor environment. The experiment was conducted in August. During the experiment, the ambient temperature was 30°C to 34°C, the wet-bulb globe temperature (WBGT) was 27°C to 29°C, the humidity was 53% to 73%, and no wind or air conditioning occurred.

The preparations and procedures for the experiment will now be described. To simulate the daily routine of a construction worker, we requested that each subject wear work clothes and our prototype perspiration helmet as
shown in Fig. 5. The subject was required to walk for 30 min on a circular course at the test facility as shown in Fig. 14. A controlled walking speed of approximately $1.43 \pm 0.1$ m/s (2.8 MTEs equivalent) was maintained, which is considered a typical walking speed.[13] For both experiments (resting and walking), the quantity of perspiration from the subject’s head was measured by the helmet and transmitted wirelessly in 1 min intervals to an external PC and stored. The walking subject rested every 10 min, and their weight was measured using an electronic precision scale. We recorded any weight loss and compared this with the amount of head perspiration. During weighing, to eliminate any external effects of perspiration, the subject removed their work clothes and wiped the perspiration from the rest of their body. The high-precision electronic precision scale used is the same as that used in the previous report. Figure 15 shows the experimental flow.

9. Results and Discussion of Human Verification Experiments during Activity

General information on each subject and perspiration quantities at 30 min intervals are given in Table 3. Figure 16 plots the relationship between the cumulative weight-loss of the subjects and their total head perspiration. The slope of the graph shows whole-body perspiration amount $P(g)$ represented by Eq. (5) when the head-perspiration equivalent amount is $Q(g)$.[12]

$$P(g) = 23.1 \times Q(g) \quad (5)$$

The regression coefficient in (5) was slightly higher during experiments in which the subject walked compared with resting, and the magnifications were calculated at 20.4 [9] and 23.1,[12] respectively. The Magnification difference was assumed to have been due to undertaking light exercise (walking) in a warm environment, which possibly led to an increase in water exhalation. Additionally, an increase was found in the amount of ineffective perspiration [11] from the head of the subject.

A satisfactory correlation was obtained where $r = 0.87$. For the temperature range of 30°C, and 30°C to 34°C, for subjects aged 20 to 22 and 26 to 65 years, and based on exercise type (resting or walking) ([9] and,[12] respectively), a higher correlation was obtained at rest than in [9] ($r = 0.75$), despite significant changes in simulated working conditions. In the warm environment, both cumulative weight-loss and head perspiration more than doubled; therefore, the correlation coefficient at the time of walking was considered to have been better than when at rest because of the consistent rate of perspiration.[12]

Multiple regression analyses were performed to analyze

| Person | Sex | Age | Height[cm] | Weight[kg] | Cumulative weight-loss [g] | Cumulative head-perspiration equivalent amount [g] |
|--------|-----|-----|------------|------------|--------------------------|-----------------------------------------------|
| K      | Male| 26  | 168        | 67.1       | 204                      | 15.4                                         |
| L      | Male| 31  | 172        | 68.1       | 275                      | 8.4                                          |
| M      | Male| 37  | 173        | 62.2       | 215                      | 4.2                                          |
| N      | Male| 38  | 170        | 55.9       | 122                      | 5.5                                          |
| O      | Male| 42  | 179        | 88.1       | 298                      | 14.1                                         |
| P      | Male| 44  | 170        | 68.4       | 329                      | 19.5                                         |
| Q      | Male| 45  | 186        | 97.4       | 259                      | 12.6                                         |
| R      | Male| 58  | 160        | 67.4       | 203                      | 10.4                                         |
| S      | Male| 65  | 171        | 75.5       | 189                      | 5.5                                          |

Fig. 16 Cumulative weight-loss and cumulative head-sweating equivalent amount.
The factors in the environment that demonstrated a strong impact on cumulative weight-loss, as shown in Table 4. The variance confirmed that the estimated value of cumulative weight-loss, using a significance ($F$) of 0.05 or less, could be described statistically. Researchers determined that the cumulative weight-loss was significantly affected by the elapsed time, ambient temperature, and cumulative head-perspiration. Time [14] and ambient temperature [15] during cardiovascular activity are known to affect perspiration. The correlation coefficient between the estimated cumulative weight-loss and the actual cumulative weight-loss was $r = 0.97$. Calculating head perspiration was found to be more accurate than calculating whole-body perspiration. In addition, researchers discovered that weight-loss could be estimated more accurately (Fig. 17) using this technique.[12]

10. Relationship between Perspiration Change and Core Body Temperature Change

To examine the relationship between changes in core body temperature,[7] which are considered an important indicator of heatstroke, as well as changes in perspiration, the core body temperature of eight participants was simultaneously measured during the human verification experi-

### Table 4  Multiple regression analysis results.

| Regression statistics                  |       |
|----------------------------------------|-------|
| Multiple correlation R                 | 0.971 |
| Standard error                         | 23.302|
| Number of observations                 | 45    |

Analysis of variance table(P<0.05)

|                        | Degree of freedom | Fluctuation   | dispersion | Dispersion ratio | Significant F |
|------------------------|-------------------|---------------|------------|------------------|---------------|
| Regression             | 11                | 299,393,100   | 27,217,555 | 50.128           | 2.26E-17      |
| Residual error         | 33                | 17,917,878    | 542,966    |                  |               |
| Total                  | 44                | 317,310,978   |            |                  |               |

Multiple regression equation (The objective variable is the cumulative weight loss)

|                         | coefficient     | Standard error | t      | P-value |
|-------------------------|-----------------|----------------|--------|---------|
| Section                 | −1,900.513      | 907.590        | −2.094 | 0.044   |
| Equivalent amount of head perpiration | 9.540 | 1.746 | 5.465 | 0.000 |
| Body temperature        | 19.346          | 18.326         | 1.056  | 0.299   |
| Age                     | −0.237          | 0.516          | −0.460 | 0.649   |
| Height                  | 0.168           | 1.829          | 0.092  | 0.927   |
| Body weight             | 0.760           | 1.104          | 0.688  | 0.496   |
| Head circumference      | 2.558           | 3.397          | 0.753  | 0.457   |
| Hair                    | 13.190          | 11.134         | 1.185  | 0.245   |
| Exercise habits         | −0.095          | 7.045          | −0.014 | 0.989   |
| Elapsed time            | 4.886           | 0.752          | 6.502  | 0.000   |
| Temperature             | 27.111          | 12.985         | 2.088  | 0.045   |
| Humidity                | 0.869           | 2.097          | 0.414  | 0.681   |

Fig. 17  Multiple regression equation estimation results (cumulative weight-loss).
The core body temperature was measured using a VitalgramCT (Aforce Sense Co., Ltd). It was mounted on the left side of the participant under the ribs at the recommended mounting area and calibrated subcutaneous fat at this area and measured core body temperature. Figure 18 shows the time elapsed, the measured cumulative weight-loss, and the core body temperature.

During the 30 min measurement in this experiment, the increase in the amount of perspiration was significant compared with the increase in the core body temperature, and similar results were obtained in a previous study.[14]

In,[14] the amount of perspiration increased at the same time as exercise, but skin temperature and core body temperature did not increase for approximately 10 min; furthermore, at the start of exercise, the amount of perspiration preceded the increase in core body temperature and skin temperature. Researchers reported that perspiration increased within a very short time. Conventionally, as a morbidity index of heatstroke, a marked increase in core body temperature was reported at the onset of severe heatstroke.[16] Since an increase in the amount of perspiration can be measured faster than measuring body temperature, the amount of perspiration may represent a more effective index.

In the future, we aim to verify that sufficient perspiration measurement accuracy will be obtained even in harsher heat environments and workloads and that this will be effective for use in heatstroke risk management. To put this into practical use, we plan to study a method for more reliably capturing the risk of heatstroke by using it in combination with other sensing information.

11. Conclusion

To prevent heatstroke in construction site conditions in the hot sun, maintaining the correct water level in the body is necessary. Therefore, ascertaining the amount of whole-body perspiration is important. We focused on a typical worker’s protective helmet, as these are mandatory on construction sites, and developed a wearable helmet device that could measure perspiration. The measurement principle was first derived using a moisture material balance. Then, a system was developed to measure the amount of perspiration inside the helmet by attaching temperature and humidity sensors to the air inflow and outflow sections of the helmet, which was equipped with a fan. We were able to demonstrate the measurement principle using this equipment.

Next, after developing the helmet device, which was also equipped with wireless functionality, and confirming the human verification test while subjects were at rest, further verification tests were conducted in an environment similar to that of true working conditions. Cumulative weight-loss from whole-body perspiration was 23.1 times the equivalent amount of cumulative head-perspiration with the helmet device. Additionally, the correlation coefficient was \( r = 0.87 \). This is a sufficient correlation than at rest the relationship \( r = 0.75 \) was confirmed.

Multiple regression analysis showed that cumulative weight-loss was significantly affected by activity time and temperature, as well as by the cumulative head-perspiration amount. Additionally, \( r \) was 0.97; researchers found that by introducing these values into the estimation formula, the integrated weight-loss corresponding to whole-body perspiration could be more accurately estimated.
During the verification of this experiment, core body temperature was also measured to determine whether measuring perspiration from the body as a whole would serve as an effective index for predicting the incidence of heatstroke. The results suggested that, during the early stages of exercise, changes in whole-body perspiration were more pronounced compared with increases in core body temperature. This may be effective as an early morbidity estimation index for heatstroke.

Lastly, this experiment was conducted with the approval of a public review for Suwa University of Science Ethics Review Committee (approval number no. 16, 18).

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