1. Introduction

Currently, a device exists that is capable of measuring localized perspiration by humans,[1] however, there is currently no wearable device to measure whole-body perspiration. We have developed a helmet that can measure perspiration. It was found that it is possible to estimate whole-body perspiration from the measurements obtained from head perspiration.[2] In this study, as with previous reports,[2] under a warm working environment equivalent to the actual working environment and at various ages, we confirmed whether the total amount of perspiration could be estimated from the measurement of head perspiration using the developed helmet device. We report that it was possible in this study.

2. Experimental Procedure

To simulate the daily routine of a construction worker, we requested a subject to wear work clothes and our prototyped perspiration helmet [2] as shown in Fig. 1. The subject had to walk for 30 minutes on a circular course at the test facility, as shown in Fig. 2.

A controlled walking speed of approximately $1.43 \pm 0.1$ m/s was maintained, which is considered a typical walking speed.[3] For both experiments (resting and walking), the amount of perspiration from the subject’s head was measured by the helmet and transmitted using Wi-Fi every one minute to an external PC, and stored. The walking speed...
subject also rested every 10 minutes and their weight was measured on an electronic precision scale. We recorded any weight loss and compared with amount of head perspiration measured by our helmet. During the weight measurements, the subject removed his work clothes and wiped off any perspiration except their head to eliminate external effects of perspiration. The electronic scale same as the one used in [2].

3. Results and Discussion
A. Results and discussion of regression analysis

General information on each subject and the perspiration quantities at the 30 minutes intervals are given in Table 1. Figure 3 plots the relationship between the cumulative weight loss of the subjects and the total amount of head perspiration of each. From the slope of the graph, it was found that the whole-body perspiration amount \( P \) (g) is represented by the formula (1) when the head perspiration equivalent amount is \( Q \) (g).

\[
P(g) = 23.1 \times Q(g) \tag{1}
\]

The regression coefficient in (1) was slightly larger during the experiment where the subject was walking, compared to at rest, calculated at 20.4 [2] and 23.1, respectively. This is assumed to be due to the light exercise (walking) in a warm environment. Theoretically, this leads to an increase in exhaled water from an increase in exhalation volume. Also, there is an increase in the amount of ineffective perspiration [4] from the head of the subjects.

A satisfactory correlation, \( r \), was obtained where \( r = 0.87 \). For the temperature range 30°C and 30°C–34°C, subject age 20–22 years and 26–65 years, and exercise type (resting or walking), despite significant changes in simulating working conditions, a higher correlation was obtained at rest than in [2] \( r = 0.75 \). Since both the accumulated weight loss and the amount of head perspiration more than doubled in the warm environment. It is considered that the correlation coefficient at the time of walking was better than that at rest due to stable continuation of perspiration.

B. Results and discussion of the multiple regression analysis

Multiple regression analysis on the cumulative weight loss was performed to analyze which factors in the environment have a strong impact on the cumulative weight loss, as shown in (Table 2). From the variance, it could be verified that the estimated value of the cumulative weight

| Person | sex | age | height [cm] | weight [kg] | Cumulative weight loss [g] | Cumulative head perspiration equivalent amount [g] |
|--------|-----|-----|-------------|------------|----------------------------|----------------------------------|
| A      | male | 26  | 168         | 67.1       | 204                        | 15.4                             |
| B      | male | 31  | 172         | 68.1       | 275                        | 8.4                              |
| C      | male | 37  | 173         | 62.2       | 215                        | 4.2                              |
| D      | male | 38  | 170         | 55.9       | 122                        | 5.5                              |
| E      | male | 42  | 179         | 88.1       | 298                        | 14.1                             |
| F      | male | 44  | 170         | 68.4       | 329                        | 19.5                             |
| G      | male | 45  | 186         | 97.4       | 259                        | 12.6                             |
| H      | male | 58  | 160         | 67.4       | 203                        | 10.4                             |
| I      | male | 65  | 171         | 75.5       | 189                        | 5.5                              |

Fig. 3 Cumulative weight loss and cumulative head perspiration.
loss, using a significance F of 0.05 or less, can be described statistically. It was determined that the accumulated weight loss was significantly affected by the elapsed time, the ambient temperature, and the accumulated head perspiration. It is known that time of [5], and ambient temperature [6] during cardiovascular activity impacts perspiration. Following these factors, there was a tendency for the t value of the amount of hair to be high. It is conceivable that the perspiration area of the head may increase due to the large amount of hair, and it is thought about quantity of head perspiration increasing, but as a result of having analyzed a comparison in consideration of this factor, as for the influence, this influence is extremely small, and it is considered that the factors of the cumulative amount of head perspiration, the elapsed time, and the temperature are dominant in estimating the amount of perspiration in the whole body. The correlation coefficient between the estimated cumulative weight loss and the actual cumulative weight loss is \( r = 0.97 \). It was found that it is more accurate to calculate head perspiration compared to whole-body perspiration. Furthermore, it was found that weight loss could be estimated more accurately (Fig. 4) using this technique.

According to these results, the perspiration helmet developed in this study was able to estimate the whole-body perspiration amount more accurately, even in an

| Table 2 | Multiple regression analysis results. |
|---|---|
| Regression statistics |  |
| Multiple correlation R | 0.971355816 |
| Standard error | 23.30163063 |
| Number of observations | 45 |

| Analysis of variance table (P < 0.05) |  |
|---|---|
| Degree of freedom | Fluctuation | dispersion | Dispersion ratio | Significant F |
| Regression | 11 | 299393.1001 | 27217.55456 | 50.12754953 | 2.26294E-17 |
| Residual error | 33 | 17917.87767 | 542.96599 |
| total | 44 | 317310.9778 |

| Multiple regression equation (The objective variable is the cumulative weight loss) |  |
|---|---|
| Coefficient | Standard error | t | P-value |
| Section | −1900.51284 | 907.5902594 | −2.094020755 | 0.044019194 |
| Equivalent amount of head perspiration | 9.540058633 | 1.745768462 | 5.46467578 | 4.67956E-06 |
| Body temperature | 19.3451066 | 18.3258817 | 1.055638739 | 0.298800773 |
| Age | −0.23712645 | 0.515803861 | −0.45972213 | 0.648730179 |
| Height | 0.168316708 | 1.829286205 | 0.092021233 | 0.927244629 |
| weight | 0.759843137 | 1.104022236 | 0.688249849 | 0.496105488 |
| Head circumference | 2.557906111 | 3.387434493 | 0.752893431 | 0.456851681 |
| Hair | 13.18963395 | 11.13457067 | 1.84587288 | 0.24462346 |
| Exercise habits | 0.095273659 | 7.04570986 | −0.013522681 | 0.989292215 |
| elapsed time | 4.886217052 | 0.751547448 | 6.501541672 | 2.22166E-07 |
| temperature | 27.11123282 | 12.98517867 | 2.087589822 | 0.04407688 |
| Humidity | 0.869124668 | 2.097164762 | 0.414428415 | 0.681242035 |

Fig. 4 Estimated results based on the multiple regression equation (cumulative weight loss).
actual working environment during random activities. In addition, this experiment was conducted with the approval of the public review for Suwa University of Science Ethics Review Committee (approval number No18).

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