An Improved Method for Measurement of Sweat Expulsions during Profuse Sweating

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Summary We present an improved ventilated-capsule method of recording for clear sweat expulsion patterns using nitrogen gas as a carrier gas heated to promote sweat evaporation. With this method, sweat expulsion patterns were more clearly recorded than with the conventional ventilated-capsule method. Taking the derivatives of these recordings of sweating expulsions could eliminate slow fluctuation components in the patterns of sweating. The results indicate that this method is useful in providing more-accurate measurements of sweat expulsion frequencies during profuse sweating.

Key words: sweating, frequency of sweat expulsions, central sudomotor activity.

Sweat is discharged from the sweat gland to the skin surface in a pulsatile fashion. It has been observed that in thermal sweating, each sweat pulse occurs synchronously on different skin areas of the body [1]. The frequency of sweat expulsions (F_{sw} , number of expulsions per min) is known to increase linearly with a rise in body temperature [2]. Recently, microneurography of the activity of the cutaneous sympathetic nerves has revealed sudomotor bursts that correspond to individual sweat expulsions [3]. These observations indicate that the sweat expulsion reflects a centrally controlled sudomotor activity and that the central drive for sweating can be evaluated by measurement of the F_{sw} . Furthermore, the magnitude of the sweat gland's response to the centrally driven sudomotor activity can be estimated from the sweat rate and the F_{sw} . Although F_{sw} is thus an important indicator in the studies of thermophysiology and exercise physiology, one problem remains to be solved: sweat expulsion recording becomes unclear during profuse sweating, making the identification of individual expulsions difficult. This study has developed an improved ventilated-capsule method for more-accurate

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Fig. 1. A schematic of the heated nitrogen gas ventilated sweat capsule for measuring sweat expulsions. (N), nichrome wire; (A), aluminum tube; (P), power supply; [hatched box], insulation.

recordings of individual sweat expulsions during profuse sweating.

Heating the nitrogen gas flowing through a sweat capsule

Sweat expulsion tracings recorded by a conventional ventilated-capsule method have been known to become unclear when the sweat rate increases. This is mainly due to a delayed evaporation of discharged sweat and the sweat remaining on the skin surface. To circumvent this problem, smaller sweat capsules with greater airflow were tested on skin areas with low sweat rates (such as the flexor aspect of the forearm). However, the rate of humidity change determined by the sensor was decreased by a reduction in the size of the capsule or an increase in airflow or both. Our studies, which used various combinations of capsule sizes (covered skin area in cm² (ratio of capsule volume to skin area in cm), 1.1 (1.0); 2.5 (1.1); 5.3 (1.2); 8.0 (1.3); 9.1 (1.4)) and airflow per min (1.0, 1.5, 2.0, 2.5, 3.0 l), revealed that sweat expulsions for an accurate recording of the most appropriate combination of capsule size and airflow was 2.5 cm² and 2.0 l/min. Even with this combination, however, clear tracings of sweat expulsions were not obtained during profuse sweating.

We attempted to overcome this problem by raising the temperature of nitrogen gas (T_{N_2}) flowing through the sweat capsule (Fig. 1), thereby accelerating sweat evaporation under the capsule. We raised the temperature of the gas by heating a small nichrome wire in a 9 cm long aluminum tube on the influent side of the capsule. The capsule and the effluent tube (the distance between capsule and humidity sensor being 50 cm) were thermally insulated and heated by a second nichrome wire to prevent the formation of dew. Thermocouples continuously recorded air temperatures in the capsule and in the humidity sensor. The power voltage supplied to the two nichrome wires was manually controlled to ensure that the capsule and humidity sensor temperatures were the same.

A rise in T_{N_2} might increase thermal discomfort of the subject, which might affect centrally driven sudomotor activity and thereby influence the F_{sw} . Some

subjects felt very hot and unpleasant when the temperature exceeded 50°C, but they felt no discomfort when T_{N_2} was kept below 45°C for 1 h. Therefore we always kept T_{N_2} at 45°C in our study.

Derivatives of sweat expulsion patterns

A second difficulty in obtaining an accurate F_{sw} measurement is the slow fluctuation components in the sweating recording. To exclude them, we took the derivatives of sweat expulsion patterns by a differential amplifier (Nihon Kohden, ED601G; differential time constant, 50 ms).

Application

The effectiveness of our method was tested on six healthy male volunteers from 21 to 28 years of age.

Each subject wore only shorts and sat for about 40 min in a relaxed position in a room with a temperature of 27°C and a relative humidity of 35%. During this time, three cylindrical acrylate sweat capsules and five thermocouples were attached to each subject. Sweat expulsions were recorded simultaneously at two 2.5 cm² skin areas close to each other on the flexor aspect of the left forearm. F_{sw} was calculated from these recordings. The two capsules covering the forearm skin areas were ventilated with dry nitrogen gas at a rate of 2.0 l/min. T_{N_2} in one of these capsules was kept at 45°C; the other capsule was not thermally controlled. The third sweat capsule was attached to the chest and covered a 9.1 cm² area of skin for measurement of the local sweat rate ($\dot{m}_{sw}$). The sweat capsule on the chest was ventilated with unheated dry nitrogen gas at a rate of 2.5 l/min. The effluent gas humidity from each capsule was sensed continuously with a capacitance hygrometer (Vaisala, HMP133Y) and recorded simultaneously on a pen recorder and a data recorder. The hygrometer output for F_{sw} measurement was processed through a low-pass filter (NF electronic instruments, FV664; cut-off frequency, 1.00 Hz and above) for noise elimination.

Esophageal temperature (T_{es}) and skin temperatures at the chest, upper arm, thigh, and calf were monitored with thermocouples. Mean skin temperature ($\bar{T}_{sk}$) was calculated with the weighting formula proposed by Ramanathan [4]. Mean body temperature ($\bar{T}_b$) was calculated by the following equation: $\bar{T}_b = 0.9 \times T_{es} + 0.1 \times \bar{T}_{sk}$.

After resting on a bicycle ergometer (Monark, 829E) for 5 min, the subjects began cycling at 360 kpm/min for another 5 min period, which was followed by a 30 min exercise at 720 kpm/min.

Figure 2 is a typical example of results from an experiment. T_{N_2} in the heated condition was maintained at $45.0 \pm 1.0^\circ\text{C}$. T_{N_2} in the unheated condition rose to $31.5 \pm 1.0^\circ\text{C}$, from $27.0 \pm 0.5^\circ\text{C}$, by a rise in local skin temperature. Consequently, the saturated vapor pressure in the heated condition (68–76 mmHg) was about twice as much as in the unheated condition (33–37 mmHg). Figure 2, A and B, shows tracings of the patterns of sweating in the unheated and heated conditions.

Fig. 2. Simultaneous recordings of patterns of sweating under the unheated condition (A) and the heated condition (B) and the derivative of sweat expulsions calculated from record B (C). T_{N_2} , nitrogen gas temperature within sweat capsule; $\bar{T}_b$, mean body temperature; T_a , ambient temperature; RH, relative humidity.

It is evident that the tracing of each sweat expulsion under unheated conditions is not as clear as under heated conditions. These tracings show that the identification of individual expulsions becomes easier and that the reliability and objectivity of measured F_{sw} rise when the influent gas in a capsule is heated. Although it was difficult to count F_{sw} when the chest sweat rate was about $0.7 \text{ ml}/(\text{cm}^2 \cdot \text{min})$ and higher in an unheated condition, counting F_{sw} was easy when the rate was greatly increased ($\sim 1.0 \text{ ml}/(\text{cm}^2 \cdot \text{min})$) in a heated condition. Figure 2C shows a tracing of the derivative thus recorded sweat expulsions in the heated condition. The slow fluctuation components in the patterns of sweating could be eliminated if the derivative was taken, which would make the counting of F_{sw} much easier. When F_{sw} is measured, however, reference to the original sweating trace should be made.

It has been reported that local sweating responses are affected by local skin

Fig. 3. Relationships between $\dot{m}_{SW}$ and $\bar{T}_b$ (A), F_{SW} and $\bar{T}_b$ (B), and $\dot{m}_{SW}$ and F_{SW} (C) during a subject's exercise (720 kpm/min). Each plot represents the average value for every 2 min. $\dot{m}_{SW}$, local sweat rate at the chest; $\bar{T}_b$, mean body temperature; F_{SW} , frequency of sweat expulsion.

temperatures [5–8]. This raises a possibility that heating carrier gas by our method may affect local sweating, thereby generating a reactive error in the measured F_{sw} . The increase in sweat production rate by local heating is caused by the facilitation of transmitter release at the neuroglandular junction or an increase in sensitivity in the glandular cell to transmitter substances or both [8]. Thus, the effect of local heating on sweating is largely limited to the local area unless a large area of skin is heated. Therefore, the effect of local heating on F_{sw} by the present method is not significant. Recording by our method exhibited no difference in the F_{sw} between heated and unheated conditions, and F_{sw} was in the range of 5 to 30 per min, observed during normal exercise [9, 10].

Figure 3A, B, and C are examples of the relationship that exists between $\dot{m}_{sw}$ and $\bar{T}_b$, F_{sw} and $\bar{T}_b$, and $\dot{m}_{sw}$ and F_{sw} . A significant positive correlation was found in each of the relationships in 6 subjects ($p < 0.01$). These results conform well with previous reports [2, 9].

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