Continuous Observation of Whole-Body Sweating in Exercising Man under Heat Stress

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Wyndham (1973) reviewed many studies on thermoregulation during exercise in a hot environment, and mentioned that in considering such temperature regulation, skin sweating was a factor at least as important as internal temperature and skin temperature.

In the literature, there are few consecutive observations on the rate of body weight loss due to evaporation of skin sweat during exercise. In the present study, the whole-body sweat rate (SR) during bicycle exercise in hot environments was continuously measured using an automatic weight loss indicator.

Experiments

The subjects were three healthy men, who were members of our laboratory staffs. Their age was 27.3 ± 0.5 years, height 169.6 ± 3.7 cm, weight 71.6 ± 3.9 kg and body surface area 1.80 ± 0.12 m^2 (mean ± SEM, respectively). All were untrained and not-thermally acclimated. The experiments were conducted from 9:00 to 10:00 am and the subjects came to the laboratory without breakfast. Experiments on any single individual were performed at the same time of day to avoid any variability attributable to the circadian rhythm of body temperature (Sasaki, 1972; Torii *et al.*, 1986b).

In the first series of experiment, the subjects dressed only in trunks, performed exercise (work exp.) for about 20 min, or remained at rest (control exp.) for 30 min, on a bicycle ergometer (Monark) in a climatic chamber. The climatic chamber was controlled at an ambient temperature (T_a) of 30 or 40°C with a relative humidity (rh) of 45%. The work intensity was 60 Watts, 40% of the maximal aerobic work capacity ($\dot{V}o_{2\,max}$) in each subject. The experiment was carried out from January to early February, and the order of four kinds of experiments conducted was randomized.

In the second experiment, they exercised on a bicycle ergometer for 20 min, and after the exercise they stayed on the bicycle ergometer for over 10 min. All experiments were carried out in a climatic chamber in which the T_a was controlled at 30°C, and rh maintained at a constant 45%. Cycling exercise at a work load the same as for first experiment, 40% of $\dot{V}O_{2\ max}$, was performed repeatedly in February, May, August and October.

Skin sweating at rest and during exercise and recovery was continuously monitored as decrease in body weight throughout the experimental period by a bed balance (J. A. Potter, Model 33B, sensitivity 1.0 g), automatic weight indicator. (Torii *et al.*, 1986a). The best curve was drawn through the weight record for each experiment and the rate of whole-body weight loss was then calculated over 1-min intervals by differentiation of the curve. According to Saltin *et al.* (1970), the balance was calibrated prior to each experiment. Fig. 1 shows an example of a recording of body weight loss during rest, exercise and recovery using the bed scale. Body weight began to decrease 6–8 min after the onset of exercise, and reached a maximal speed obtained after 10–12 min of exercise. Total weight losses at rest and during exercise were approximately 15 g and 70 g, respectively.

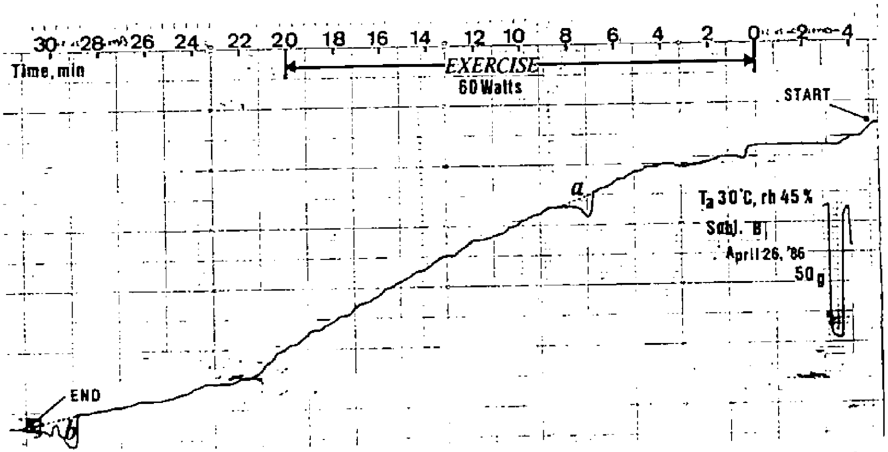

Fig. 1 A recording example (*subject* B) of whole-body weight loss measured by bed scale. After a 5-min of exercise the weight loss increased markedly. A 50 g scale was indicated in the right of a chart. The weight losses were modified at two points, dotted lines, *a* and *b*. The points of *a* and *b* were complemented because a thermocouple sensor dropped and the subject missed his foot from the pedal of a bicycle ergometer, respectively.

During exercise (work exp.), SR increased at 30 and 40°C, especially in subjects exercising at 40°C. SR during exercise increased with working time (Figs. 2 and 3). The pattern of seat loss has been previously reported (Torii, *et al.*, 1983; Torii *et al.*, 1984). SRs during exercise were significantly higher at 40°C than at 30°C (Fig. 4). During rest (control exp.), SR was maintained constant the throughout experimental period for 27 min in the two different environments, but the sweating speed was significantly different between 30 and 40°C.

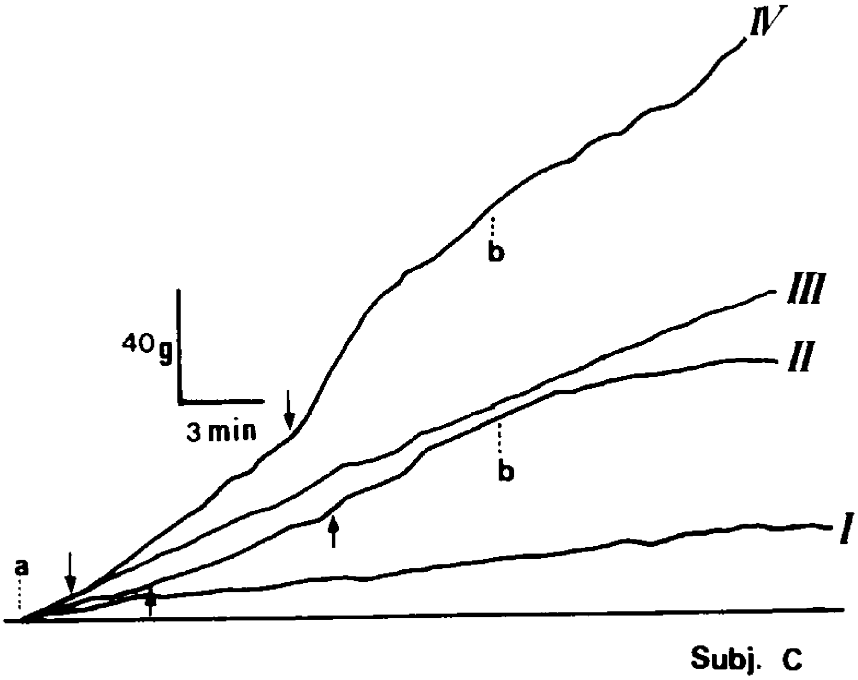

Fig. 2 Curves of sweating loss at rest [control] ext.] and during exericese and recovery [work exp.] at different thermal conditions of 30 and 40°C. *Subject*, C. I: control exp. at 30°C, II: work exp. at 30°C, III: control exp. at 40°C, IV: work exp. at 40°C. a: work started, b: work stopped. Arrows writing by the closed line were indicated the point of sweating increase.

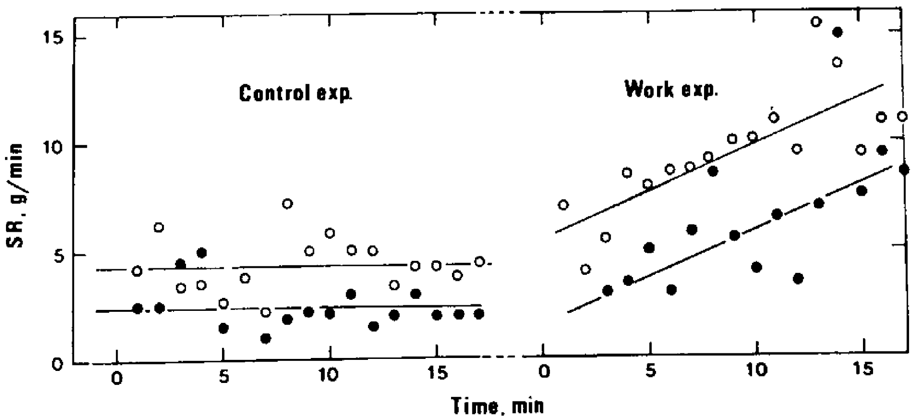

Fig. 3 Time course of sweat rate (SR) at rest [Control exp.] and during exercise [Work exp.] at ambient temperatures of 30 (●) and 40°C (○). *Subject*, A. The regression equations of working time against SR in the right panel are as floows: 30°C; $Y=0.43X+1.8$, $r=0.619$ ($p<0.01$), 40°C; $Y=0.42X+5.6$, $r=0.775$ ($p<0.01$)

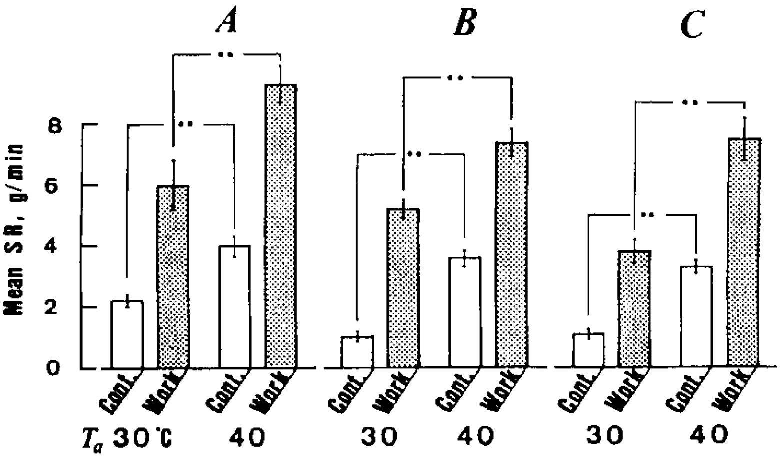

Fig. 4 Mean SR (±SEM) at rest [Control exp., $n=27$] and exericise [work exp., $n=17$] at ambient temperatures (T_a) of 30 and 40°C. Asterisks denote significant difference, 30°C *vs.* 40°C (**$p<0.01$, by paired t-test).

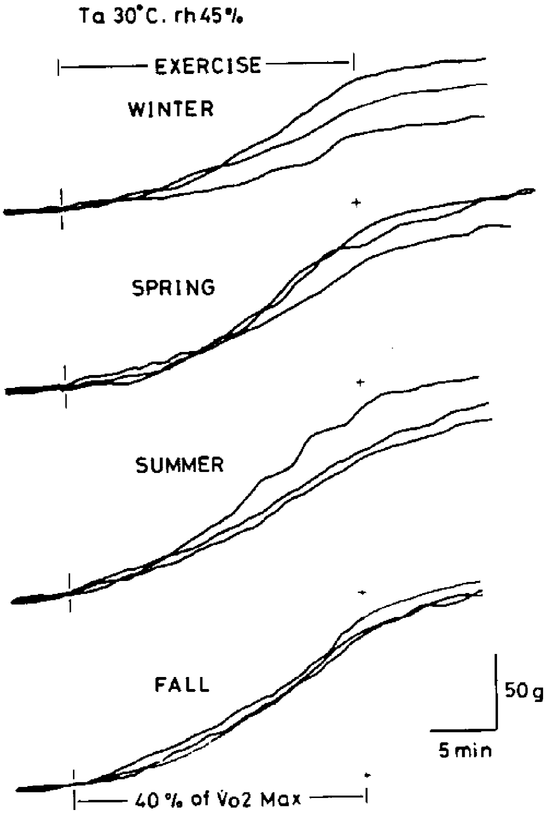

Fig. 5 Courves of sweating loss at given work intensity of $\dot{V}o_2$ max, 60 Watts in various seasons. In each season three curves were indicated the results of subjects, A, B, and C, respectively.

In summer, as soon as the subjects started muscular work, onset of sweat secretion was observed in all cases. However, in winter, it did not increase noticeably until after a few minuts (Fig. 5). Mean SR during execise was significantly higher in summer than in winter (Fig. 6).

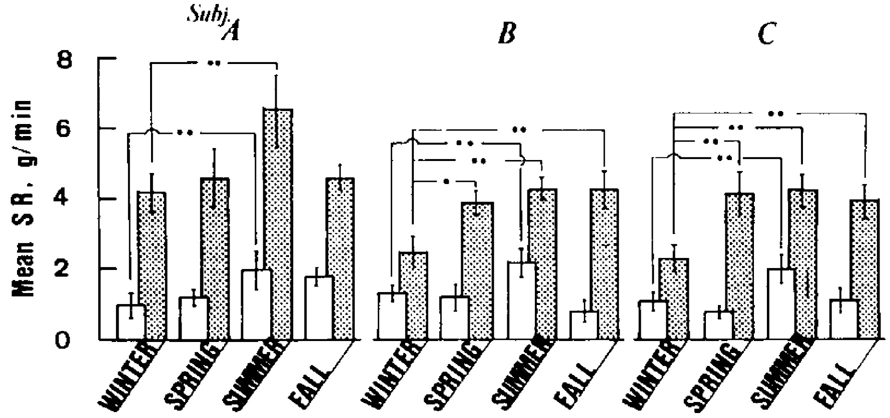

Fig. 6 Mean SR (±SEM) at rest [open column, $n=10$] and during exercise [shaded column, $n=20$] in winter, spring, summer and fall. Asterisks denote significant difference from winter ($^{*}p<0.05$, $^{**}p<0.01$, by paired t-test).

Discussion

During exercise, heat flows with a temperature gradient from the muscles to the environment (Nadel, 1979b). However, when the environmental temperature is higher than the skin temperature, heat transfer occurs from the environment to the internal body (Gagge *et al.*, 1938). Thus, sweat production and evaporation play an important role in the regulation of body temperature during muscular work, especially in a hot environment, i.e., in the cooling of the skin and blood. Evaporation of 100 g of sweat secreted from the body surface results in a 1°C fall in mean body temperature in a 70-kg man (Nadel, 1979a). A number of methods or techniques for measurement of sweat have been developed in the field of thermal physiology (See review, Kuno 1956).

In the present study, whole-body sweating rate (SR) during exercise in two hot environments was continuously measured using an automatic weight loss indicator. At 40°C or in the summer, SR immediately inceased as soon as exercise started. Mean SR at 40°C or in the summer was higher than that at 30°C or in the winter, respectively (Figs. 4 and 6).

Van Beaumont and Bullard (1963) found, in local skin sweating, that evaporation of the sweat from the calf and forearm serially measured using resistance hygrometry during bicycle exercise (1000 kgm·min^{-1}) in a heat (T_a, 37.5°C) showed a sharp increase in the sweating rate within a few seconds after commencement of exercise. On the other hand, Saltin *et al.* (1970)

continuously measured whole-body sweating as weight loss during exercise at an ambient temperature of 30°C (rh, 45%). In our present results, the sweating pattern agreed with theirs.

Kuno's monograph (1956) contains a review of studies which have been made on variations in the rate of sweating on different parts of the body. The data variables refer to only a number of small areas of a few cm^2 scattered over the surface of the body. These data imply that a parallel relationship exists between the whole-body sweat and the local sweat rate. Thus the determination of thermal balance during exercise from local skin sweating has been unsuitable. To determine the thermoequilibrium during muscular work, heat production and the process of heat loss, especially evaporation, must be estimated. However, Ogawa (1981) has indicated that the determination of skin sweating by means of a scale is very difficult under certain conditions, *e.g.*, a hot, humid environment, or during severe and/or prolonged muscular work. Furthermore, Ogawa *et al.* (1984) have attempted to calculate the evaporation due to skin sweating by subtracting dripping sweat from whole-body sweating.

The roles of temperature regulation during exercise under heat stress have been discussed elsewhere (Torii *et al.*, 1984; 1985; 1986a). Robinson (1974) suggested that the neuromuscular reflex, at least, takes part in the control of sweating during the initial stage of exercise. An increase in the sweat rate may be stimulated by non-thermal factors. The mechanism of skin sweating, however, is still a matter of controversy, although many studies have been made of thermal physiology during muscular work in the heat (Nadel, 1979b; Nielsen, 1981; Gisolfi and Wenger, 1984; Sawka, 1988).

References

Kuno, Y., (1956) *Human perspiration*. C. C. Thomas, Springfield.

Gagge, A. P., C.-E. A. Winslow, and L. P. Herrington (1938) The influence of clothing on the physiological reactions of the human body to various environmental temperatures. *Am. J. Physiol.*, 124: 30–50.

Gisolfi, C. V. and C. W. Wenger (1984) Temperature Regulation during exercise: old concepts, new ideas. *Exercise Sport Sci. Rev.*, 12: 339–372.

Nadel, E. R. (1979a) Temperature regulation. *In: Sports Medicine and Physiology*, ed. by R. H. Strauss, pp. 130–146, W. B. Saunder Co., Philadelphia.

Nadel, E. R. (1979b) Control sweating rate while exercising in the heat. *Med. Sci.. Sports*, 11: 31–35.

Nielsen, B. (1981) Exercise and temperature regulation. *In: Advances in Physiological Sciences, Vol. 32, Contributions to Thermal Physiology* (Satellite Symposium of the 28th International Congress of Physiological Science, Précs, Hungary 1980), eds by Z. Szeléyi and M. Székly, pp. 537–544. Akadémikai Kiadó, Butapest.

Ogawa, T. (1981) Heat dissipation-Evaporation, *In: Thermal Physiology*. ed. by T. Nakayama, pp. 34–55, Rikohgakusya, Tokyo (In Japanese).

Ogawa, T., M. Asayama, J. Sugenoya, H. Fujimatsu, T. Miyagawa, and Y. Terai (1984) Temperature regulation in hot-humid environments, with special reference of hidromeosis. *J. Therm. Biol.*, 9: 121–125.

Robinson, S. (1974) Physiology of muscular exercise. *In: Medical Physiology Vol. 2*, ed. by V. Mountcastle, pp. 1273-1304, C. V. Mosby, St. Louis.

Saltin, B., A. P. Gagge, and J. A. J. Stolwijk (1970) Body temperatures and sweating during thermal transients caused by exercise. *J. Appl. Physiol.*, 28: 318-327.

Sasaki, T. (1972) Circadian rhythm in Body temperature, *In: Advances in Climatic Physiology*, eds by S. Itoh, K. Ogawa, and H. Yashimura, pp. 50-67, Igakushion, Tokyo.

Sawka, M. N. (1988) Physiological responses to acute exercise-heat stress, *In: Human Performance Physiology and Environmental Medicine at Terrestrial Extremes*, eds by K. B. Pandolf, M. N. Sawka, and R. R. Gonzalez, pp. 97-151, Benchmark Press, Indianapolis.

Torii, M., M. Yamasaki, S. Tsuzuki, and T. Sasaki (1983) Whole body sweat rate during exercise in the heat environment. *J. Human Ergol.*, 12: 99-102.

Torii, M., M. Yamasaki, and T. Sasaki (1984) Thermoregulatory responses of the initial stage of bicycling in a heat environment. *J. Physical Fitness Japan*, 33: 98-104 (In Japanese).

Torii, M., M. Yamasaki, and T. Sasaki (1985) Seasonal variation of sweating rate caused by exercise during thermal transient. *J. Human Ergol.*, 14: 53-56.

Torii, M., M. Yamasaki, and T. Sasaki (1986a) Effects of heat stress on temperature regulation in initial exercise. *J. Human Ergol.*, 15: 3-12.

Torii, M., M. Yamasaki and T. Sasaki (1986b) Circadian variation of thermoregulatory responses in exercising men at two different work loads. *Jpn. J. Biometeor.*, 23 (Suppl): 14.

Van Beaumont, W. and R. W. Bullard (1963) Sweating: its rapid responses to work. *Science*, 141: 643-646.

Wyndham, C. H. (1973) The physiology of exercise under heat stress. *Ann. Rev. Physiol.*, 35: 193-220.