The Effect of Facial Fanning on Thermal Responses during Exercise with a Kendo *Men*

Shinji HAMADA

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1. Introduction

Recently, Nybo et al. [1] reported that the blood flowing through the carotid artery always rises in temperature compared to that flowing through the artery when facial fanning is applied to the faces of subjects during bicycle exercise. According to Jessen and Kuhnen [2], however, experiments showed that while the frontal cutaneous temperature drops as a result of fanning at different temperatures, the brainstem temperature (tympanic temperature) does not. In light of this result, we conducted experiments on subjects to observe any changes in the time-course thermoregulatory response, especially regulatory levels for sweating response and cutaneous blood flow, as well as the drop in tympanic temperature as a result of fanning of the upper bodies of the subjects during bicycle exercise. The results suggested that fanning of the upper bodies during bicycle exercise reduced thermal strain, resulting in successfully ensuring safety and sustained performance during exercise [3]. Nevertheless, the mechanism of vascular constriction and dilation has not been sufficiently researched [4] in order to fully understand the response by the effector organ in autonomic temperature regulation by fan cooling and many issues remaining unsolved.

For this reason, in this study, fanning was selectively applied to the faces of subjects with their heads covered with kendo *men* during repetitive hard exercise to determine the tympanic temperature (T_{ty}) and its effects on the response to peripheral circulatory regulation. In addition, the timing of fanning was discussed and more specifically, a comparison was made between the effects of fanning directly after and in the middle of exercise.

2. Materials and methods

The subject group consisted of ten healthy male students from a national college and a university (age: 18±1 years old, height: 170±1 cm, weight: 63.0±1.1 kg, body surface area: 1.751±0.036 m^2, body fat percentage: 8.8±1.3%, workload: 180±6 watts). They have practiced kendo on a basis of 2-3 hours/day, 6 days/week over five years. In this experiment, they were randomized into two groups; five to the first half (FH) group and the remaining five to the second half (LH) group depending on the timing when fanning was started.

All the subjects were provided with relevant explanations about the objectives and methods of the study and enrolled in the experiment as volunteers with informed consent submitted. Prior to the experiment, they did graded cycle ergometer exercises in an environment with temperatures ranging from 26 to 28 °C (relative humidity (rh): 45%) to determine the parameters including loading level.

Fig.1: The situation of an experiment. All the subjects measured with the bicycle ergometer, after putting a kendo *men* in the climatic chamber.

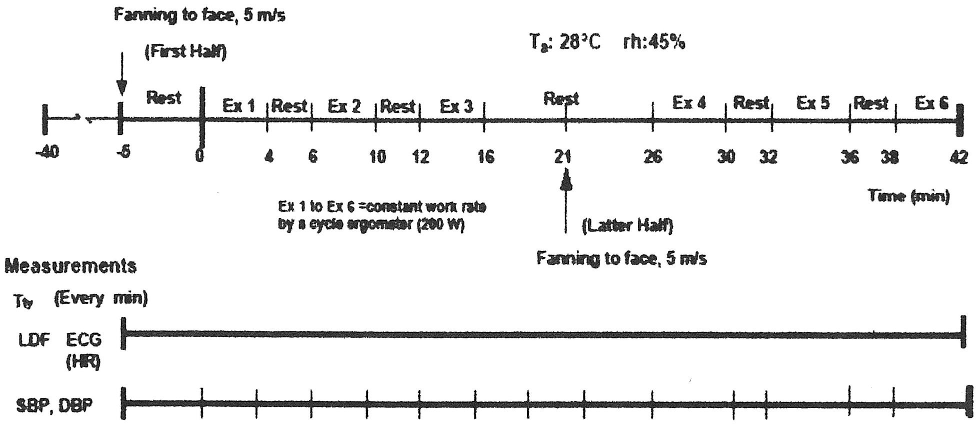

Fig. 2: Experimental protocol. Subjects conducted intermittent-severe cycle exercise (six sets consist of 4 min work [185±6 W]-2 min rest) at an ambient temperature (T_a) of 28°C with relative humidity (rh) of 45%. They received facial fanning (5 m/s) at the first half (FH group) and the latter half (LH group) in the experimental period. We measured continuously tympanic membrane temperature (T_{ty}), systolic (SBP) and diastolic (DBP) blood pressures and a laser-Doppler flowmetry (LDF), and recorded an electrocardiogram (ECG) to determine heart rate (HR).

Several days later, the subjects did bicycle ergometer exercises putting kendo *men* in a climatic chamber at 28 °C (rh: 45%). The experiment was run from 11 a.m. to 2 p.m. over July and August. The experiment protocol defined the conditions: 1) the subjects being put in the above environmental conditions for 40 minutes or more, 2) remaining still while mounted on the bicycle ergometer for ten minutes, 3) doing the first and second half ergometer exercises; in the first half, four minutes exercise + two minutes rest repeated three times and in the latter half, the same course repeated three times, between which ten minutes rest being given (42 minutes in total) (Fig. 2). The pedal rotating speed was set to 50 revolutions/ minute. In the FH group, fanning was applied by selectively blasting air against the faces of the subjects at 5 m/s in window velocity using a blower (Koito Industries) for 21 minutes starting from the time point before the beginning of the exercise to the time point when the first part was finished. In the LH group, fanning was applied for 21 minutes starting from the time point after the completion of the first half to the time point when the second part was finished. The subjects wore short-sleeved training shirts (upper body) and training tights (lower body) to avoid the influence of fanning on parts of the body other than the face during exercise. With no limitation put on breakfast, they ate their usual morning meal and joined the experiment three hours after eating.

The parameters for time-course measurement included : tympanic temperature (T_{ty}) as body core temperature, skin blood flow (LDF), systolic blood pressure (SBP) and diastolic blood pressure (DBP). For T_{ty} measurement, a thermistor with a soft sp when tmistor measurement, a thermistor with a soft spring coiling was used. T_{ty} was measured when the tip of the thermistor sensor came in contact with the tympanic membrane and plotted out on the recording sheet every one minute by a thermistor temperature-measuring device. LDF was continuously measured by means of a laser-Doppler blood flow measuring device that was attached to the skin surface of the left forearm with double-sided tape. The deviation (% of baseline) from the LDF at rest was assumed to be an indicator of skin blood flow. SBP and DBP were measured using an automated blood-measuring device. With a compression garment attached to the right arm of the subject, the SBP and DBP values at rest, exercise and recovery were measured at intervals of two or four minutes.

At the same time, the heart rate (HR) was recorded on an electrocardiogram by means of precordial leads and the 20 second R-R interval was measured and converted into value/minute. The mean arterial pressure (MAP) was calculated by using the formula (SBP+2 x DBP)/3. Cutaneous vascular conductance (CVC) was calculated by dividing the LDF value by the MAP value (LDF/MAP). The rate of pressure product (RPP) was obtained by multiplying the HR value by the SBP value (HR×SBP).

The Data was expressed in terms of average values and standard errors. For statistical processing, the *t*-test with

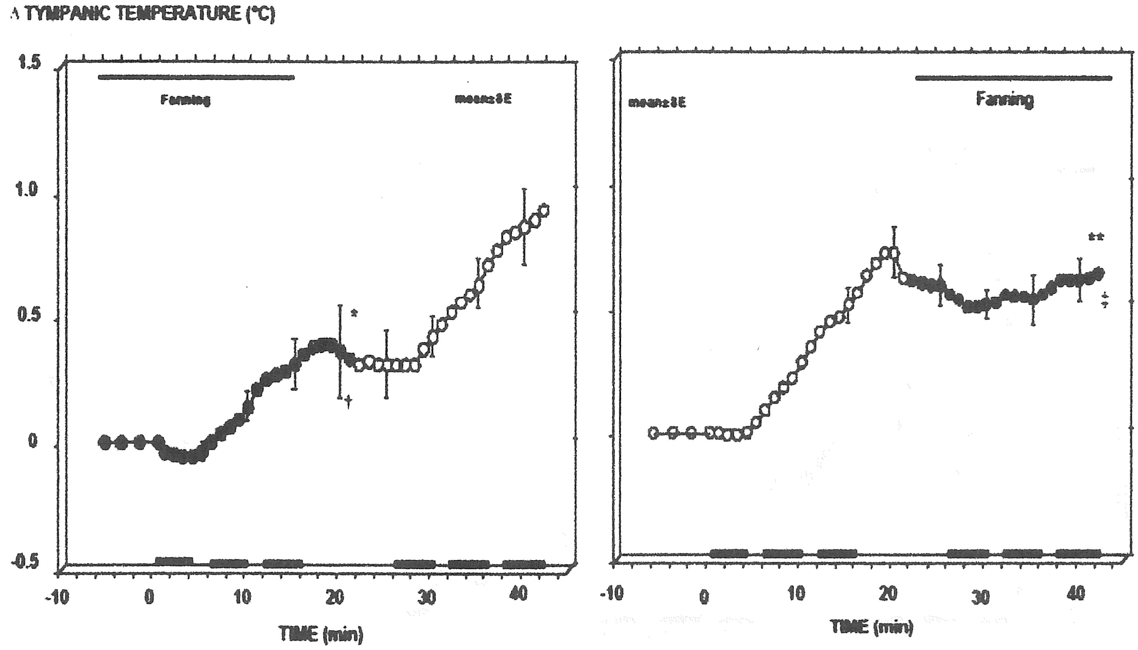

Fig. 3: Change of tympanic temperature (ΔT_{ty}) in intermittent-severe work with and without facial fanning. The data are mean±SE. Six horizontal bars indicate working period at the bottom. Closed and open circles indicate trials with and without fanning, respectively. Left panel (FH group, n=5) and right panel (LH group, n=5). * In the FH, with *vs.* without fanning, $F[1,41]=36.744$, $P=0.0001$. ** In the LH, with *vs.* without fanning, $F[1,41]=15.582$, $P=0.0003$. †, In the 1st session, with vs. without fanning, $F[1,41]=4.899$, $P=0.0329$. ‡, In the 2nd session, with *vs.* without fanning, $F[1,41]=137.0$, $P=0.0001$

average values considered in each of the groups was used, while one-way analysis of variance without considering average values was used for processing time-course changes.

3. Results

Although T_{ty} increased gradually from 36.63±0.08 °C after the beginning of the exercise, the increase was controlled to 37.03±0.18 °C (0.4 °C increase) in the FH group, to which fanning was applied in the first half of the exercise. After the completion of fanning, it did not drop at rest with an increase up to 37.58±0.13 °C, a 1 °C increase from the baseline, during the subsequent exercise. In the LH group, to which fanning was applied in the second half of the exercise, T_{ty} increased gradually from the baseline of 37.08±0.2 °C after the beginning of the exercise and up to 37.8±0.13 20 minutes after, a 0.7 °C increase from the baseline. After the beginning of fanning, the increase in T_{ty} was controlled even during exercise to 37.82±0.24 °C, the same temperature as before the beginning of fanning. On the other hand, a significant difference in time-course change of ΔT_{ty} was observed between the first and second half portions both in the FH ($F[1,41]=36.744$, $P=0.0001$) and LH ($F[1,41]=15.582$, $P=0.0003$) groups. This suggested that fanning controlled the increase in T_{ty}. During the first half exercises, the maximum T_{ty} value was 0.39±0.14 °C in the FH group and 72±0.1 °C in the LH group. The difference in T_{ty} between both the groups was 0.33 °C; T_{ty} was significantly lower in the FH group than in the LH group ($F[1,41]=4.899$, $P=0.0329$).

After resting, the time-course change in ΔT_{ty} during the second half portion was 0.93±0.14 °C in the FH group with no fanning applied, while it was 0.64±0.1 °C in the LH group with fanning applied. The difference in ΔT_{ty} was significant between both the groups ($F[1,41]=137.0$, $P=0.0001$) (Fig. 3).

In regulation of body temperature, especially in high body temperatures during exercise, the head and face play an important role [5]. In this experiment, with the head covered, air was blasted against the face starting from two different points; at the same time as the beginning of the exercise and in the middle of the exercise. In the FH group with fanning applied in the first half of the exercise, the

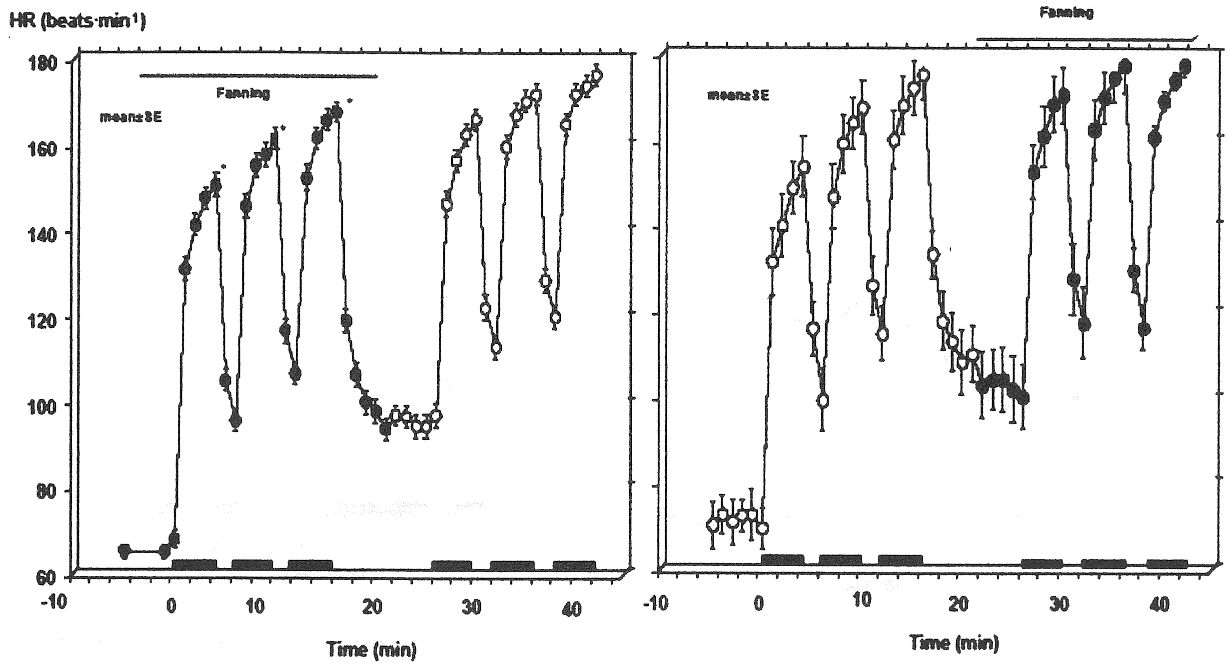

Fig. 4: Heart rate (HR) in intermittent-severe work with and without facial fanning. The data are mean±SE. Six horizontal bars indicate working period. Closed and open circles indicate trials with and without fanning, respectively. * Significantly different, 1st work *vs*. 4th work, 2nd work *vs*. 5th work or 3rd work *vs*. 6th work. Left panel (FH group, n=5) and right panel (LH group, n=5).

increase in T_{ty} was held to a low level. In the LH group with fanning applied in the second half, the mechanism of body temperature regulation was prominently observed. This suggested fanning could effectively control the increase in T_{ty} by controlling the up-regulation of evaporative heat release through sweating on the face in the latter half. For this reason, hereafter, fanning will be referred to as fan cooling. The venous blood derived from the scalp and the face flowing into the cranium has an
the scalp and the face flowing into the cranium has an effect on the time-course change in T_{ty} [6]. In another part of our experiment, fanning of the upper body including the head and the face decreased the skin temperature of the forehead from 35 °C to 31 °C. In this case, sweat was evaporated from the face [3]. This suggested that the flow of the blood derived from the face into the cranium was involved in controlling the increase in T_{ty} even with dysfunctional scalp.

HR at rest was 65±1 beats·minute^{-1} in the FH group and 69±4 beats·minute^{-1} in the LH group, demonstrating that in both groups, HR prominently increased during exercise and prominently decreased at rest. No significant difference was observed in time-course change in HR between the FH and LH groups (Fig. 4). HR in the FH group (Fig. 4, left), however, was 150±2, 161±3 and 167±2 beats·minute^{-1} during the three repetitive exercises in the first half and in the second half after the completion of fanning, it increased up to 165±2, 172±2 and 176±2 beats·minute^{-1} (in each case, $P<0.05$, *t*-test). Note that this type of change was not observed in the LH group (Fig. 4, right). Accordingly, no significant difference was observed in the LH group with fanning applied in the second half compared to the case with no fanning applied.

RPP (x 10^3) at rest was 8.2±0.2 in the FH group and 9.5±1.0 in the LH group. In the FH group, at the completion of exercise in the first half, it increased up to 34.7±1.9. After resting, with no fanning applied in the second half, it increased up to 38.4±1.6, with no significant difference being observed between these values. The LH group had similar results as those in the FH group even with fanning applied in the second half.

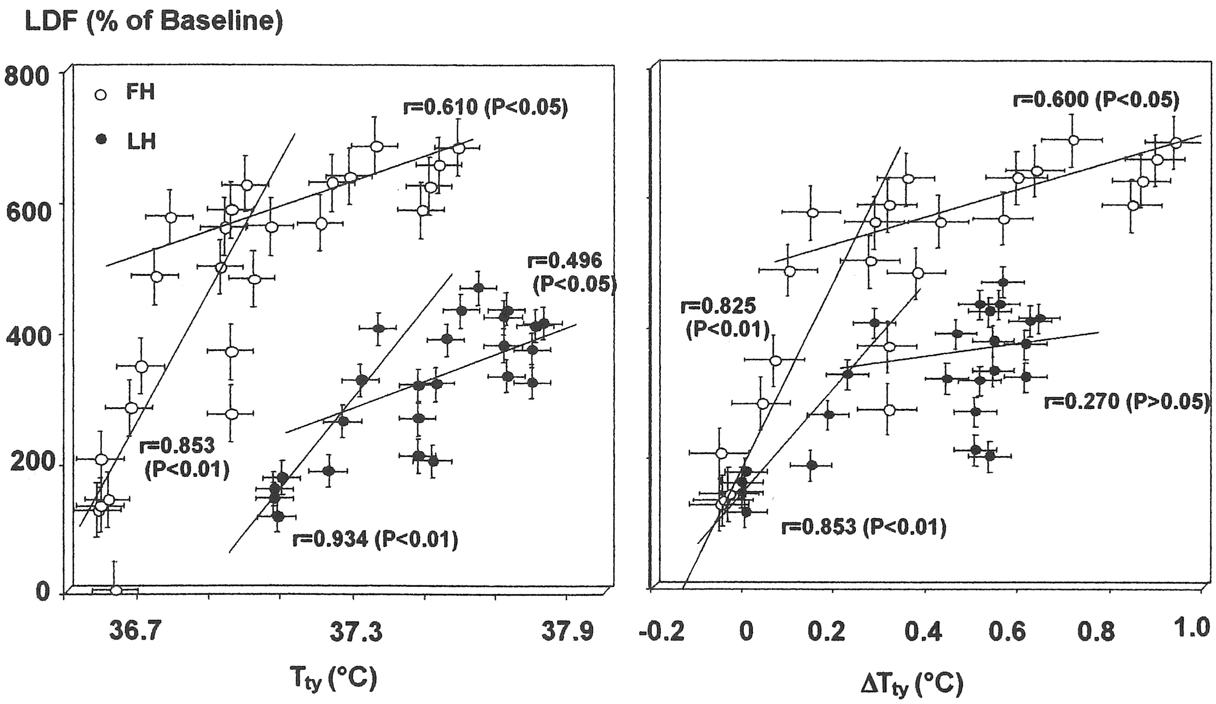

Fig. 5: Relationship between tympanic temperature (T_{ty}, left) and change of tympanic temperature (ΔT_{ty}, right) and relative value of a laser-Doppler flow (LDF) in intermittent-severe work with and without facial fanning. The data are mean±SE. Closed and open circles indicate trials with and without fanning, respectively.

The comparison of RPP (x 10^3) in the first half between the FH and LH groups, however, showed that it was significantly lower in the FH group during exercise and at recovery. This suggested that the increase or decrease is determined by the timing of fanning (whether it is started from the beginning of exercise or not). The MAP value had a similar result to the RPP result, indicating that fan cooling is effective in reducing the load involved with circulatory regulation during exercise. Continuous fanning starting from the beginning of exercise is important to reduce the load involved with the circulatory regulating system.

LDF reached 624±94% during the second exercise in the first half in the FH group and then decreased to 176±60%. In the second half, it increased up to 680±105%. On the other hand, in the LH group, it reached 464±101% in the first half and then decreased to 57±19%. During exercise with fanning applied in the second half, the increase in LDF was controlled to 430±99%. Regardless of fanning, LDF was higher in the FH group than in the FH group. For T_{ty}-LDF, a significant correlation was observed in both groups. Both in the FH and LH groups, the sensitivity to T_{ty}-LDF correlation deteriorated (% of Baseline·°C^{-1}). It appeared in the vicinity of 37.1-37.3 °C of T_{ty} in both groups (Fig. 5, left). For ΔT_{ty}-LDF, no significant correlation was observed in the LH group with a sensitivity of 0.3 °C (Fig. 5, right).

In this experiment, no significant difference was seen in decreased skin blood flow as a result of fan cooling. According to our previous reports [3], in respect to air blasting against the upper body, a significant decrease was observed in skin blood flow. On the other hand, the results of this experiment showed that selective fan cooling of the face had less effect, leading to a limited effective range to be considered. For body core temperature-skin blood flow during exercise, sensitivity to this correlation was deteriorated or reduced. This leads to the gentle gradient of a regression curve (skin blood flow, ml·100 ml^{-1}·minute^{-1}·°C^{-1}). Some studies have reported that this point is in the vicinity of the deep body temperature 38 °C (esophageal temperature) [7]. This may be caused by non-thermal factors including the individual physical properties of the subjects, fluctuation in arterial blood pressure of blood flow involving the circulatory function and neurogenetic variation in vasoconstrictive capacity.

Similarly in our experiment, sensitivity to the tympanic temperature- skin blood flow correlation reduced in the vicinity of 37.1-37.3°C. In our previous studies at 30°C (rh,45%), sensitivity to the tympanic temperatur-skin blood flow correlation during 40 minutes of moderate exercise was reduced in the vicinity of 37.5°C. Although no direct comparison can be made between the previous studies using the esophageal temperature as the body core temperature and this study using the tympanic temperature, the fundamental mechanism for appearance might be identical between them.

In this experiment, bicycle exercise was done intermittently with a heavy load. Accordingly, it may be considered that in addition to the factors other than the aforementioned thermal factors, the signal input from the muscle mechanoreceptor controls the regulation response (control over the increase in blood flow) [8].

CVC increased up to 6.04±1.35% of Baseline·$mmHg^{-1}$, then decreased to 2.18±0.55% of Baseline·$mmHg^{-1}$ and finally increased up to 6.23±1.42% of Baseline·$mmHg^{-1}$ in the FH group with no fanning applied. On the other hand, in the LH group with no fanning applied, it increased up to 3.76±1.06% of Baseline·$mmHg^{-1}$, then decreased to 1.01±0.57% of Baseline·$mmHg^{-1}$ and finally increased up to 3.67±1.14% of Baseline·$mmHg^{-1}$ by fanning applied in the second half. It increased during exercise in both groups and decreased at rest, with no significant difference being observed.

Fan cooling of the face with the head covered starting from the beginning of the exercise controls significant increases in the parameters including tympanic temperature, heart rate, average arterial blood pressure and cardiovascular strain excluding skin blood flow and cutaneous vascular conductance.

This suggests that thermal and cardiovascular strain is controlled, resulting in effective control over the increase in brain temperature (reduced fatigue) and the improvement of physical exercise [9].

4. Conclusion

1. The increase in tympanic temperature was effectively controlled by fan cooling throughout the first and second half exercises. The effect of fanning was higher in the first half than in the second half.
2. The heart rate was significantly lower in the first half of the exercise and in the accompanying recovery period than in the second half in the FH group.
3. The cardiovascular strain and average arterial blood pressure was significantly lower in the first half in the FH group than in the LH group.
4. No significant difference in skin blood flow was observed between the groups, however, a tympanic temperature and skin blood flow correlation was observed. Sensitivity to the correlation was reduced in the vicinity of 37.3 °C.
5. Cutaneous vascular conductance gradually increased during exercise and decreased in the recovery period, with no significant difference being observed between the groups.
6. These findings suggest that fan cooling of the face during exercise while putting a kendo *men* is effective in successfully sustaining cardiovascular regulating function when it is started at the beginning of the exercise and continued, rather than in the middle exercise.

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