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Thermal Imaging of Exercise-Associated Skin Temperature Changes in Trained and Untrained Female Subjects

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Abstract—Heat dissipation during sport exercise is an important physiological mechanism that may influence athletic performance. Our aim was to test the hypothesis that differences exist in the dynamics of exercise-associated skin temperature changes between trained and untrained subjects. We investigated thermoregulation of a local muscle area (muscle–tendon unit) involved in a localized steady-load exercise (standing heels raise) using infrared thermography. Seven trained female subjects and seven untrained female controls were studied. Each subject performed standing heels raise exercise for 2 min. Thermal images were recorded prior to exercise (1 min), during exercise (2 min), and after exercise (7 min). The analysis of thermal images provided the skin temperature time course, which was characterized by a set of descriptive parameters. Two-way ANOVA for repeated measures detected a significant interaction ($p = 0.03$) between group and time, thus indicating that athletic subjects increased their skin temperature differently with respect to untrained subjects. This was confirmed by comparing the parameters describing the speed of rise of skin temperature. It was found that trained subjects responded to exercise more quickly than untrained controls ($p < 0.05$). In conclusion, physical training improves the ability to rapidly elevate skin temperature in response to a localized exercise in female subjects.

Keywords—Infrared thermography, Heels raise, Blood flow, Thermoregulation, Sedentaries–athletes.

INTRODUCTION

The thermo-regulatory system of human body has the task to maintain a constant temperature despite the variations caused by environmental conditions and/or physical work. The control of heat exchange between human body and the environment is essential for body temperature regulation. The tegumentary apparatus (skin) has the fundamental role of regulation of heat exchange through conduction, convection, radiation, and evaporation.[2,15] The activation of body compensatory vasoregulation occurs during muscles activity, through reduction of blood flow in the splancnic region and tegumentary apparatus. Intense exercise causes heat production in the core structures and activates muscles,[5] with a consequent massive transfer of warmer blood from the internal to the superficial parts of the body. Thus, the vasoconstriction in these regions increases blood flow in the muscular areas while the muscle blood volume remains constant. The blood volume in the internal and periferical parts of the body decreases. In this condition we can observe an increase of the venous return and the cardiac output.[15,20]

The effect of physical exercise on skin blood flow has been previously studied and reviewed by Johnson[8] and Kenney and Johnson.[10] They found that the modifications of cutaneous blood flow (CBF) during exercise is linked to the individual grade of vasodilation and vasoconstriction. As a consequence, the CBF influences the skin temperature depending on modification caused by exercise. Johnson[8] and Robinson[16] observed that at the beginning of the exercise the demand of blood flow to working muscles caused a briefly skin vasoconstriction, but as the body core temperature raises, the thermal regulatory processes predominate and the skin vessels dilate, increasing heat dissipation through the skin, essentially by irradiation and evaporation.[12] Frietzsche and Coyle[5] showed that the CBF is higher in endurance athletes than in untrained subjects during exercise. As a result, a higher fitness level is associated to a higher CBF. It stands to

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reason to hypothesize that trained subjects have a better thermoregulation than untrained ones.

Usually, cutaneous temperature is estimated by averaging values of the cutaneous temperature recorded in predetermined regions of interest (ROI) by contact temperature probes, but since many years several group of research tried to use infrared thermography (IRT) to measure these values.[3,15,19] IRT is a non-invasive technique that visually represents the whole process during and after exercise. This device allows quantitative and precise evaluation of the spatial distribution and time evolution of cutaneous temperature, allowing data recording rate up to 100 Hz. IRT is widely used for medical diagnostic analysis[11] and is becoming increasingly used to record variations of cutaneous temperature linked to physical exercise.

Using this technique Merla *et al.*[15] studied thermoregulation during and after the exercise in runners as well as Torii *et al.*[18] and Zontak *et al.*[20] for bicycle ergometer, and Ludwig *et al.*[13] for breathing exercise. Some differences of heating in different parts of the body with relation to specific swimming style were found by Zaïdi *et al.*[19] The above-mentioned studies used IRT to investigate the alterations of skin temperature across various parts of the body following various modalities of exercise (such as running or cycling) involving various muscle groups. Only few studies, such as those by Ferreira *et al.*[3] and Bertmaring *et al.*,[1] have addressed the evaluation of thermoregulation during localized exercise. Apart from a preliminary report by Merla *et al.*,[14] none have assessed the time profiles of skin temperature before, during, and after exercise in trained as compared to untrained subjects.

Aim of this study was to investigate the influence of physical fitness on exercise-associated skin temperature changes. Trained and sedentary female subjects were studied. We focused on a specific muscle area (muscle–tendon unit) involved in a steady-load localized exercise (2-min standing heels raise). Since we were interested in obtaining a detailed portrait of the skin temperature dynamics, IRT images were taken prior the initiation of the exercise, during the exercise as well as for 7 min after the cessation of the exercise. Our hypothesis was that exercise can induce differences in the trends of skin temperature between trained and untrained subjects.

MATERIALS AND METHODS

Subjects

We considered two groups of female subjects: one of trained and one of sedentary subjects. The group of trained was composed by seven athletes, selected from a synchronized swimming team that took part in Spring Italian Synchronized Swimming National Championship [age = 18.43 ± 0.75 years; body weight = 54.57 ± 2.29 kg; height = 1.62 ± 0.01 m; body mass index (BMI) = 20.76 ± 0.68 kg/m^2]. They trained for at least five sessions per week, 2.30 h per session. The choice of a team of synchronized swimming, almost exclusively a female sport, permitted to have an high interindividual homogeneity of anthropometric characteristics and training conditions.

Seven sedentary female subjects were randomly selected from a list of volunteers belonging to the student population of the State University of Milan (age = 20.14 ± 0.46 years; body weight = 54.29 ± 2.17 kg; height = 1.66 ± 0.03 m; BMI = 19.64 ± 0.70 kg/m^2). No statistical difference was found between the age, height, weight, BMI of the two groups. All participants were non smokers, and without cardiovascular or pulmonary diseases. They had not assumed drugs or medications with a potential effect on cardiovascular and thermoregulatory functions during the 2 months prior the tests.

The Ethical Committee of the State University of Milan approved this study. After a thorough explanation of the protocol that was going to be used, the subjects, or the parents of the underage ones, accepted informed written consent to participate in this study.

Experimental Protocol

In a preliminary test aimed to find out the appropriate exercise duration, the subjects performed their maximum number of repetitions of heels raise exercise without overload (using a metronome to standardize the pacing). We chose heels raise exercise because both groups weren't used to perform it and thus it could be considered as an unspecific exercise for both groups. Sedentaries and athletes performed the exercise in about 2–2.30 min. Hinging on this preliminary evaluation, we decided to set the duration of the exercise to 2 min in order to allow completion of the exercise to all subjects.

Subjects observed this standard preliminary protocol for infrared thermal imaging measurements: they abstained from assuming alcoholic or caffeine-containing products for a 4-h period prior to the start of the experiment; they removed body hair on legs that were clean and without cosmetics products before the measurements in order to obtain the most representative thermal images of skin temperature.

After being acclimated to the room climate conditions (temperature 22–23 °C; relative humidity 60 ± 5%; no direct ventilation and constant intensity of light) for

15 min before the exercise, the subjects performed heels raise exercise without overload for 2 min.

The pace of movement was set with a metronome in order to standardize the number of repetitions: in 1 s the subjects raised up heels as high as possible, and during the following second they lowered heels back to the starting position (Fig. 1).

All the thermal images were shot (frame rate 0.05 Hz) at the same instant during the exercise, i.e., when the subjects heels re-achieved the starting position with heels on the floor.

All the tests were performed in the late morning period in order to limit possible effects due to circadian rhythm variations.

Thermographic Analysis

Thermal imaging records temperature of objects without any contact with their surface by detecting infrared radiation emitted following the Stefan–Boltzmann law. It can be written for a real body with an emissivity value ε:

$$E = \varepsilon_{\lambda,\theta,T}\sigma T^4 \tag{1}$$

where E is the energy emitted per unit area and per unit time (Wm^{-2}), ε is the emissivity that depends on the wavelength λ, the angle θ and on temperature T (K), and $\sigma = 5.6693 \times 10^{-8}\ \mathrm{W\,m^{-2}\,K^{-4}}$ is the Stefan–Boltzmann constant.

The emissivity value was set to 0.97, in keeping with the value of human skin emissivity reported by Jones and Plassmann.[9] We wish to stress that, when applying IRT to the human body, the noise due to environmental irradiation in far IR band (10 μm) is in general low because of both the reflectance value of skin ($R = 3\%$) and the temperature of subjects, about ten degrees above the environmental one.

Finally, it is worth emphasizing that non contact measurements avoid any local alterations of heat exchanges mechanism through skin, its surrounding, and body core, and free the subjects from physical and psychological constrictions. Source of artificial or natural heat by radiation was avoided in order to reduce IR radiation noise.

Thermal images were recorded during 1 min of pre-exercise to determinate basal temperature, 2 min of exercise, and 7 min of recovery-time. Thermal image sequences of the surface of the subject's calves were recorded by a 14-bit digital infrared thermal camera (AVIO, TVS-700, 320 × 240 Microbolometric Array; 8–14 μm spectral range; 0.07 °C thermal resolution; and 35 mm lens). Recordings were made using a digital frame grabber with a rate of one image per 20 s. During the trials the subjects were dressed in swimsuit, and were set 3 m from the thermocamera to permit the complete exposure of the posterior region of the legs and of consequence the best recording of the temperature calves. As regarding to the calibration procedure, the subjects were placed in front of a uniform background with a constant temperature ($T =$ 24.86 ± 0.20 °C).

The images of the sequence were then corrected from temperature shift due to the periodic self-calibration of the sensor using an area with a constant temperature (in the background) and analyzed with a dedicated software for thermal images elaboration

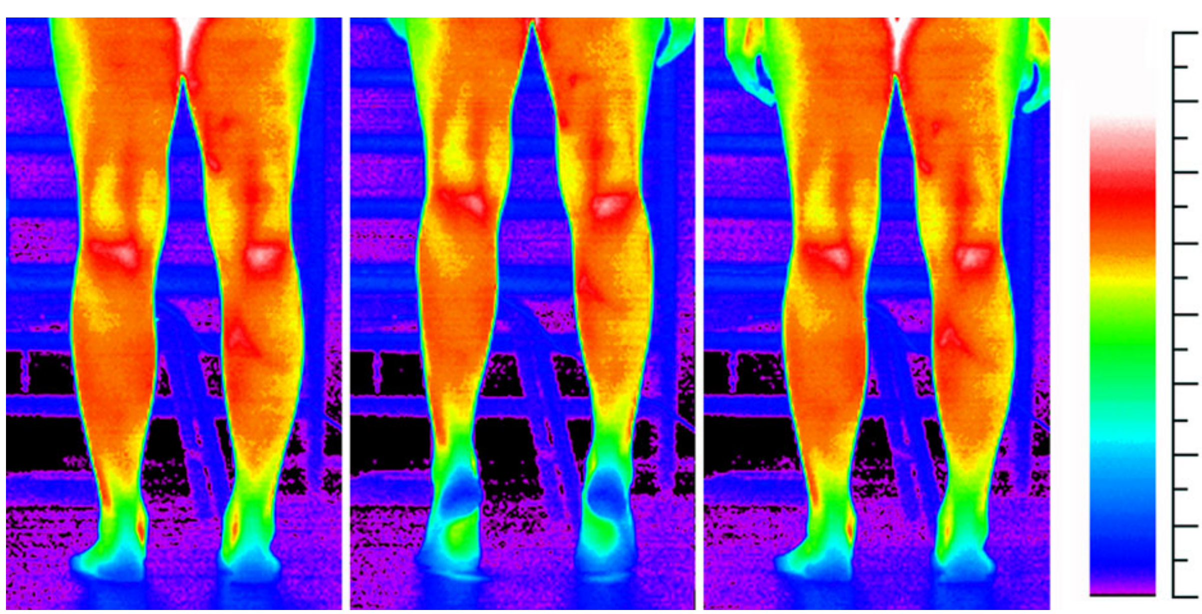

FIGURE 1. Thermal images of one repetition of standing calf raise exercise performed by an athlete.

(GRAYESS® IRT Analyzer, Version 4.8). In order to avoid the operator dependency of the ROI selection process, the following procedure was set-up to obtain a reliable temperature of the calves surface. One region including all the muscles involved in exercise was selected for each calf. For each calf inside this area, the software selected the five hottest pixels (the software was instructed to select pixels having a minimum distance of 5 pixels from each other). The temperature value was obtained by averaging over an area of 5×5 pixels around them. In this way the results are representative of an overall amount of 125 pixels on each calf. This allowed us to obtain a more representative sample of the warmest areas of the calves (Fig. 2). Finally, we averaged left and right calf temperature values (no significant difference was found between left and right), thus obtaining one representative temperature value in each subject. In this way, for every thermal image, each subject was represented by a temperature value derived from the same number of pixels representative of the most important cutaneous areas for heat dissipation.

Data Analysis

The time course of skin temperature showed a nonlinear profile displaying three phases (Fig. 3 shows a representative subject). The first phase was the 1-min time window prior to the exercise. During this phase, the skin temperature remained approximately constant. The basal temperature in each subject was calculated as the mean of three consecutive skin temperatures prior to the initiation of the exercise. The second phase was the 2-min time window during which the subjects performed standing calf raise exercise. During this phase, the skin temperature showed a mixed behavior: in some subjects it began to rise almost immediately following the initiation of the exercise, while in some other subjects the skin temperature decreased a little, achieving a nadir approximately 60 s after the initiation of the exercise, and then began to rise. The former behavior of skin temperature was typical of trained subjects, while the latter was typical of untrained subjects. The third phase was the 7-min time window following the end of the exercise. In that period, skin temperature continued to rise, achieved a maximum value and then began to slowly decline.

Data analysis of skin temperature values was aimed to quantify key parameters descriptive of the skin temperature time course. The definition of each parameter (together with its abbreviation and units) is reported in Table 1. Calculation of parameters $Time_{50\%}$ and $Time_{delay}$ was accomplished by linearly interpolating the skin temperature data measured at two consecutive time points. Calculation of parameter T_{ir} (i.e., the temperature increase rate immediately following the time delay) was performed by taking the slope of the regression line estimated from the four consecutive temperature data measured after the time delay.

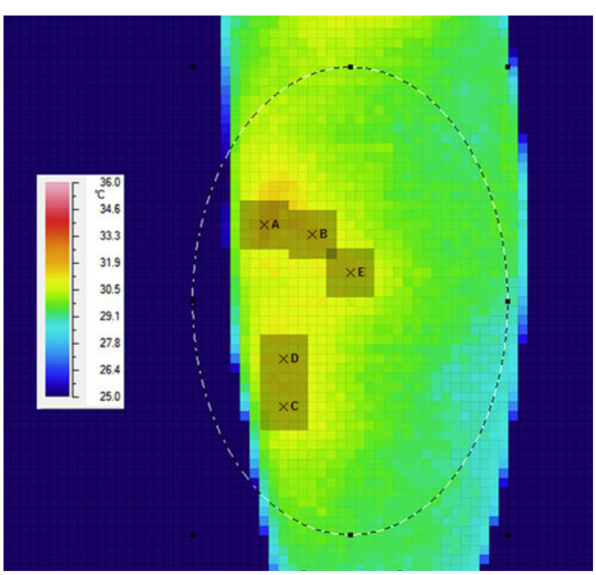

FIGURE 2. Method to detect representative temperature of the calf. Five hottest spots and relatives 24 pixels around them were taken into account inside a wider area selected by the operator and including all the calf.

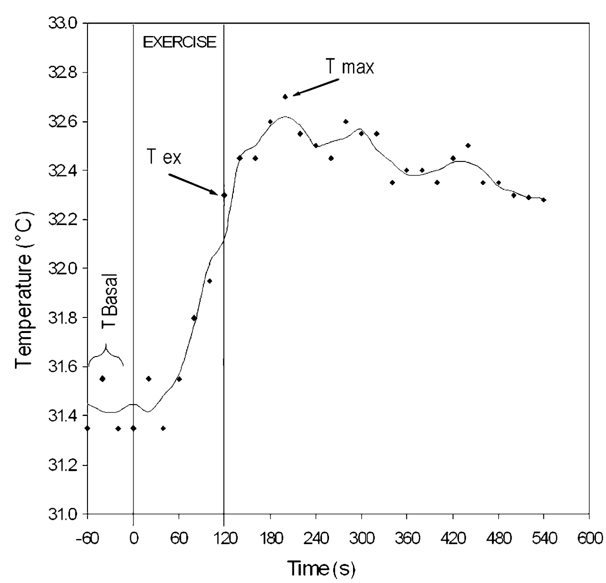

FIGURE 3. Time course of cutaneous temperature during the experiment in a representative subject (athlete). The dots are the experimental data and the continuous line is the smoothed profile provided by a low-pass filter over three points for each homogeneous range (basal, exercise, recover). The figure also illustrates how parameters T_{basal}, T_{ex}, and T_{max} are calculated from the experimental data. The description of such indices is reported in Table 1.

TABLE 1. Parameters used to characterize the skin temperature time profile.

Index abbreviation	Definition	Units
Basal temperature (T_{basal})	Mean temperature value prior to the exercise	°C
End-of-exercise temperature (T_{ex})	Temperature value achieved at the end of exercise	°C
Maximum temperature (T_{max})	Maximum value of temperature recorded	°C
End-of-exercise delta temperature (ΔT_{ex})	$T_{ex} - T_{basal}$	°C
Delta max temperature (ΔT_{max})	$T_{max} - T_{basal}$	°C
Time to 50% ΔT_{max} ($Time_{50\%}$)	Time when temperature is 50% of ΔT_{max}	s
Time to T_{max} ($Time_{T_{max}}$)	Time when T_{max} is recorded	s
Time delay	Time between the initiation of exercise and the rise in temperature above T_{basal}	s
Temperature increase rate (T_{ir})	Initial temperature increase rate after the $Time_{delay}$	°C/s

Statistical Analysis

Data were expressed as mean ± SEM. The normality of the distribution of age, anthropometric variables, as well as the parameters described in Table 1 was checked by graphical methods and by the Shapiro–Wilk's test.

Age and the anthropometric variables had normal distributions, so that the homogeneity of the sample characteristics (trained vs. untrained subjects) was tested using unpaired pooled Student's *t* test.

To test whether the pattern of temperature change during the experiment was influenced by the training level, we used two-factor (i.e., subjects' group and time) analysis of variance (ANOVA) with repeated measures on one factor (time). Three crucial time points during the experiment were selected to provide the three repeated measures of temperature: 0 s (basal), 120 s (end of the exercise), 420 s (time when temperature has attained a quasi-steady state in both groups). We were particularly interested in testing for a significant interaction effect between group (trained vs. untrained subjects) and time. Although no violation of the assumption of sphericicity was revealed by application of the Mauchly's test of sphericity, we nonetheless preferred to be on the conservative side and perform the *F* test for the interaction effect using the Greenhouse–Geisser correction.

As for the parameters describing the skin temperature profiles, it was found that the parameters describing key time points of the skin temperature profile (i.e., $Time_{50\%}$, $Time_{T_{max}}$, $Time_{delay}$) had non-normal distributions. Thus, statistical comparison between the parameters obtained in the two groups (athletes vs. sedentaries) was performed using either the Student's *t* test (for parameters T_{basal}, T_{ex}, T_{max}, ΔT_{ex}, ΔT_{max}, T_{ir}) or the Mann–Whitney nonparametric test (for parameters $Time_{50\%}$, $Time_{T_{max}}$, *Time*-delay).

Statistical analysis was carried out with STATA 10 software (StataCorp., College Station, TX, USA). A *p* value lower than 0.05 was considered statistically significant.

RESULTS

Figure 4 shows the average skin temperature data recorded in athletes and sedentary controls during the experiment. The temperature profile of the athletes group was characterized by a very short latency period (10 s) followed by an almost linear heating-up attaining an average temperature of 31.8 °C at the end of the exercise. During the post-exercise recovery time, skin temperature reached an average maximum value of 32.2 °C at 265.7 s and then began to decline very slowly. Contrary to athletes, sedentary controls showed a prolonged latency period (75 s). After that, temperature began to increase more gradually than in athletes group reaching an average temperature of 30.9 °C at the end of exercise. During the post-exercise recovery time, skin temperature reached an average maximum value of 31.6 °C at 440 s and then exhibited a quasi-steady-state.

Results of the two-way ANOVA with repeated measures provided evidence of a statistically significant interaction between group and time ($p = 0.03$), thus indicating that athletic subjects increased their skin temperature differently with respect to sedentary subjects.

Table 2 reports the mean parameter values together with the results of the statistical comparisons between the athletes and the sedentary group.

DISCUSSION

The main finding of the present study is that, during steady-load localized exercise, the skin temperature of female athletes increases more quickly than that of female sedentary controls. Many lines of evidence point to such a conclusion. First of all, visual inspection of the average time courses of skin temperature during and after the exercise (Fig. 4) suggests that the rise in skin temperature that follows the initiation of exercise occurs more quickly in athletes as compared to sedentary subjects. This visual impression is objectively corroborated by the results of the two-way

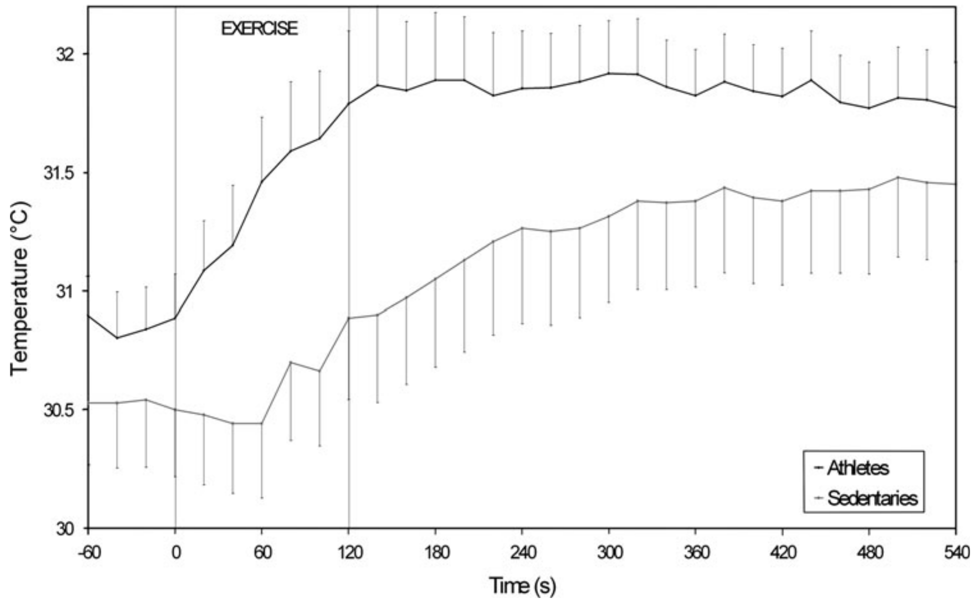

FIGURE 4. Average skin temperature data recorded in athletes ($n = 7$) and sedentaries ($n = 7$) during the experiment (mean ± SEM). To improve the readability of the graphs, discrete experimental data were connected by linear segments, yielding piece-wise linear functions.

TABLE 2. Parameter values in athletes and sedentaries.

Parameter	Athletes ($N = 7$)	Sedentaries ($N = 7$)	*p* value
Basal temperature (T_{basal}, in °C)	30.8 ± 0.2	30.5 ± 0.3	0.37
End-of exercise temperature (T_{ex}, in °C)	31.8 ± 0.3	30.9 ± 0.3	0.07
Maximum temperature (T_{max}, in °C)	32.2 ± 0.3	31 6 ± 0.3	0.20
End-of-exercise delta temp (ΔT_{ex}, in °C)	1.0 ± 0.2	0.4 ± 0.1	0.013
Delta max temperature (ΔT_{max}, in °C)	1.3 ± 0.2	1.0 ± 0.2	0.25
Time to 50% ΔT_{max} ($Time_{50\%}$, in s)	80.2 ± 13.9	205.1 ± 28.0	0.007
Time to T_{max} ($Time_{T_{max}}$, in s)	265.7 ± 51. 6	440.0 ± 39.5	0.018
Time delay (s)	10.0 ± 6.7	75.3 ± 22.1	0.010
Temperature increase rate (T_{ir}, in °C/s)	0.009 ± 0.002	0.004 ± 0.001	0.041

Statistical comparison between the two groups (see the "Statistical Analysis" section for details) was performed using either the Student's *t* test (for parameters T_{basal}, T_{ex}, T_{max}, ΔT_{ex}, ΔT_{max}, T_{ir}) or the Mann–Whitney test (for parameters $Time_{50\%}$, $Time_{T_{max}}$, $Time_{delay}$).

ANOVA for repeated measures which showed a significant interaction between group and time, thus indicating that athletes increase their skin temperature differently with respect to sedentary subjects. Further evidence in this direction is provided by the parameters used to quantify crucial signposts (temperatures as well as time points) of the skin temperature profile (Table 1). The parametric portraits obtained in the two groups (Table 2) confirms that the skin temperature increases more quickly in trained subjects than in sedentary controls.

One initial observation is that the initiation of exercise was not followed by an immediate rise in skin temperature above the baseline. Rather, many subjects, and especially sedentary controls, responded to the initiation of exercise displaying a latency period, during which skin temperature slightly fell below the baseline, achieved a nadir, and finally resumed above the baseline and began to rise. In order to describe this phenomenon in quantitative terms, we introduced the notion of a time delay. We found that the time delay of the athletes was much shorter than that of the sedentaries.

The presence of a latency period at the onset of the exercise has been previously observed by other investigators.[8,10,14,15,18,20] As reviewed by Johnson[8] and Kenney and Johnson,[10] at the beginning of exercise there is an initial decrease in temperature, followed by a subsequent increase. Torii *et al.*[18] found a fall in seven skin temperatures (forehead, arm, hand, foot, leg thigh, and trunk) during the initial stage (9 min) of muscular work on a bicycle ergometer. Zontak *et al.*[20]

measured the hand skin temperature during both graded- and constant-load exercise. They found that hand skin temperature continuously decreased throughout the graded-load exercise, but displayed a biphasic pattern during steady-load exercise, with an initial descending trend (reflecting vasoconstriction) followed by an ascending trend (reflecting vasodilation). Merla *et al.*[15] monitored the entire cutaneous anterior surface of the body in trained runners during graded-load exercise on a treadmill. Skin temperature continuously decreased throughout the exercise period (12 min) and began its resumption to the basal level during the recovery phase. The findings that, during graded-load exercise involving the whole body, the temperature of either the hand[20] or various other surfaces of the body[15,18] decreased throughout the exercise period was probably due to a continuous skin vasoconstrictor response, linked to an increase in catecholamine and other vasoconstrictor hormones as the exercise intensity increased.[17] In the present study, subjects performed standing heels raise exercise for only 2 min, thus producing a little amount of heat confined to a single muscle–tendon unit. In this way, even though the local muscle apparatus was properly loaded, no global phenomena of thermoregulation such as perspiration were activated. Therefore, one possible interpretation of the latency period observed in our study is that the demand of blood flow to working muscles at the beginning of the exercise led to skin vasoconstriction. As the body temperature increased, the skin vessels dilated, increasing heat loss through the skin. Our observation that the latency period was much shorter in athletes than in sedentary controls suggests that the dynamics of initial muscle vasoconstriction and subsequent muscle vasodilation are faster in athletes than in sedentary controls.

After the latency period, skin temperature increased in both groups. Such temperature increase is in accordance with previous work by Bertmaring *et al.*[1] and Ferreira *et al.*[3] In the paper by Bertmaring *et al.*,[1] IRT was used to assess the changes of skin temperature of the anterior deltoid during static exertion until exhaustion in four different conditions: at two shoulder angles (90° and 115°), and at two work loads (15 and 30% maximum voluntary contraction). The time course of thermal readings showed a skin temperature increase for all the four conditions. In particular, the condition (90°/30%), which showed the fastest rate of skin temperature change, exhibited a temperature increase of approximately 0.8 °C at the end of the observation period (189 s, on average). In the paper by Ferreira *et al.*,[3] IRT was used to investigate temperature changes in response to a localized exercise (consisting in a 3-min knee flexion) in young and elderly subjects. The temperatures of the skin over the knee flexors in the exercised limb and in the contralateral limb were assessed. Infrared thermographic images were taken before the beginning of the exercise and in the post-exercise phase (for 10 min, at 2-min intervals). Temperature variation in the exercised limb and in the contralateral limb showed different profiles. When compared with the pre-exercise temperature, the exercised limb showed a positive temperature variation immediately post-exercise, whereas the contralateral limb showed a negative temperature variation immediately post-exercise. In particular, temperature in the exercised limb tended to increase, albeit not significantly, in both young and elderly subjects when compared with the pre-exercise temperature (from 30.4 ± 1.5 to 30.8 ± 1.5 °C in young subjects and from 28.9 ± 1.8 to 29.0 ± 1.8 °C in elderly subjects). The skin temperature changes observed in the present study were larger than those observed by Ferreira *et al.* We speculate that this may related with the fact that the type of exercise and the load used in the present study (2-min repetitions of heel raise exercise without overload) was fairly different from the one adopted by Ferreira and colleagues (3-min isotonic exercise of knee extension and flexion with a 1 kg weight resistance placed above the ankle).

In the present study, skin temperature increased approximately to the same extent in the two groups, but the speed of rise of skin temperature resulted higher in athletes than sedentary controls. In fact, the temperature rate of change, T_{ir}, in athletes resulted twice as high as that of sedentary controls. Another evidence that athletes responded to the exercise stimulus more promptly than untrained controls is given by comparing parameters ΔT_{ex} and $Time_{50\%}$ in the two groups. ΔT_{ex} was higher in athletes than in sedentary controls, indicating that, when exercise was stopped, athletes had already increased their skin temperature more than sedentary controls. $Time_{50\%}$ was lower in athletes than in sedentary controls, indicating that athletes were faster than sedentary controls in achieving 50% of the respective skin temperature excursion. It is worth noticing, however, that $Time_{50\%}$ comprises the duration of the latency period. Thus, one may wonder whether the reduced $Time_{50\%}$ observed in athletes simply reflects a shorter time delay or is indeed an evidence of a more rapid increase in skin temperature. To address this issue, we calculated the difference $Time_{50\%} - Time_{delay}$ in the two groups. In this way, we were able to rule out the influence of the different length of the latency period and arrived at a more fair comparison between the two groups. We found that $Time_{50\%} - Time_{delay}$ was significantly lower in athletes than in sedentary controls (70.2 ± 12.8 vs. 129.9 ± 16.2,

$p = 0.018$), thus confirming that the speed of rise of skin temperature was higher in athletes than in sedentary controls.

The evidence that trained and untrained subjects exhibit different dynamics of skin-temperature variation is in keeping with the results of a preliminary report by Merla *et al*.[14] Our data are not sufficient to establish whether such different time courses in skin temperature are also reflective of different time courses of heat dissipation in the two groups. In fact, heat dissipation not only depends on skin temperature change, but also on local blood flow, which was not evaluated in our study. Fritzsche and Coyle[5] reported that during exercise, trained subjects have an higher CBF and have a better efficiency in dissipating heat than untrained ones. It is of interest to notice that the different patterns of skin temperature increase observed in the present study in trained and untrained female subjects are reminiscent of the patterns of CBF increase reported by Fritzsche and Coyle in their study (see Fig. 3 in Fritzsche and Coyle[5]). On the other hand, the type of exercise that the subjects of the study by Fritzsche and Coyle underwent was rather different from calf rise exercise of our study. In that study, ten trained men and ten untrained men underwent three 20-min cycling exercise bouts at 50, 70, and 90% peak oxygen uptake in this order with 30 min rest in between. In addition, whole-body sweating took place over the entire experiment, especially in trained subjects. In contrast, in our study the trial consisted of a localized muscle work, lasted only 2 min, and sweating did not occur. Thus, the evidence derived by Fritzsche and Coyle that trained subjects are more efficient than untrained one in dissipating heat cannot be safely extrapolated to our study *tout court*.

Finally, we put in evidence that our conclusions cannot be surely extended also to male subjects. Heat dissipation is influenced by many variables. Among them, variables such as body surface, presence of body hair, fat distribution are different in male and female subjects. Thus, further studies will be addressed to compare exercise-associated skin temperature changes in male and female subjects.

In conclusion, we found evidence that the level of physical training influences how fast skin temperature increases in response to localized exercise in female subjects. This work contributes to improve the knowledge about the potential of IRT to provide a detailed description of the changes of skin temperature in response to localized exercise. This methodology may be useful for investigating the physiopathology of cutaneous temperature changes and may also present implications to studies aimed to investigate athletic performance.

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