Does Shifting the Age Category in Masters Athletics Significantly Change the Thermal Response to Exercise?

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Abstract

Due to involutional changes, the ability to perform physical exercise may undergo dynamic alterations. Therefore, the analysis of physiological parameters characterizing the response to competitive effort in the Masters athletes group can provide information about the condition of the athlete and any potential dysfunctions. The aim of the study was to assess the impact of physical effort (warm-up and competition) on changes in skin surface temperature (T_{sk}) of the lower limbs in athletes across different age groups. Considering the abrupt changes in the functioning of various systems, the athletes were divided into three groups: 35–45 years, 50–65 years, and over 70 years of age. Thermographic imaging was applied at rest and immediately after the race.

In the 35–45 age group, a statistically significant decrease in Tsk was observed after exercise, particularly in the area of the rectus femoris muscle of both lower limbs, with the largest reduction recorded for the right rectus femoris muscle (ΔT_{sk} = 0.63°C). Significant changes in Tsk were also found in the left biceps femoris muscle and the right gastrocnemius muscle. In the 50–65 and 70+ age groups, the changes were not statistically significant. The comparison between age groups did not reveal significant differences in the thermal profile either at rest or after exercise ($p > 0.05$). Similarly, the assessment of temperature asymmetry between the right and left lower limbs did not show statistically significant differences.

In Masters athletes, neither the post-50 nor the post-70 age periods cause significant changes in the thermal profile, which suggests long-term adaptation due to athletic training.

Introduction

During human ontogeny, the function of multiple physiological systems undergoes gradual yet significant changes, reflecting the dynamic nature of biological maturation and aging. Between the ages of 25 and 30, people reach their peak functional and adaptive capacity [1]. After this period, a decline in the efficiency of various physiological processes is observed, including the thermoregulatory mechanism [2], as well as an increase in stiffness and a simultaneous decrease in the elasticity of muscle fibers [3, 4] and potential asymmetries [5]. Aging is also associated with deteriorating peripheral circulation, particularly in the distal parts of the body, such as the hands and feet. This impairment in blood flow leads to thermoregulatory disorders in these areas [6]. Furthermore, with age, the sweating threshold increases and the ability to evaporate sweat decreases [7]. These factors directly affect the body's ability to dissipate heat.

With regard to physical activity, studies on the body's heat dissipation capacity during exercise indicate that this mechanism already begins to decline after the age of 40, with significant differences observed in the 45–49 and 50–55 age groups [8]. Performance parameters, including the efficiency of thermoregulation, deteriorate with age. This directly impacts exercise tolerance, recovery ability, and perceived exertion. In older adults, a decrease in maximal oxygen uptake (VO_2max), stroke volume, pulmonary diffusing capacity, and muscle mass and strength is observed. The decline in these parameters reduces the body's ability to generate energy required during intense exercise (Vigorito & Giallauria, 2014). Impaired heat dissipation caused by a disrupted thermoregulatory mechanism contributes to a faster rise in core body temperature [8, 9], which directly affects physical performance and, in the context of recovery, prolongs the return to homeostasis [10].

Research has shown that regular physical activity has a positive effect on slowing down the adverse changes associated with aging [11]. The benefits of regular sports training help maintain (or even improve) muscle mass and strength [12], and counteract the decline in VO_2max [13] - a key indicator of cardiovascular performance. Regular sports activity may also slow down age-related changes in tendon tissues [14] and limit the decline in thermoregulatory control in older adults[2, 15]. Therefore, older athletes represent a group that effectively mitigates the negative changes of biological aging through physical activity [16].

Despite the proven benefits of regular physical activity in delaying the effects of aging, critical periods occur throughout human ontogeny, characterized by significant hormonal changes that affect the functioning of various bodily systems. One such period is around the age of 50, which involves the onset of menopause in women and andropause in men. Both periods are associated with a sharp decline in estrogen and testosterone levels, hormones that affect the thermoregulatory center in the hypothalamus [17]. Another critical period occurs around the age of 70. Physical performance declines linearly until about age 70, after which the rate of decline accelerates [18, 19]. This period is also marked by a significant drop in testosterone levels [20]. As a result, changes occur in energy levels, muscle strength, physical function, and more [21]. In the context of thermoregulatory dysfunction, it is important to note the reduced ability of the body to maintain water-electrolyte balance. This is due to impaired kidney function - by age 70, the kidneys filter approximately 50% less than they did at age 30 [19]. These changes also contribute to decreased athletic performance [22].

Therefore, the assessment of motor functions, muscle–tendon responses, and thermoregulatory adaptations becomes an essential component of health prevention, personalized training processes, and rehabilitation in older adults. At the same time, technological advancements allow for the use of sophisticated, non-invasive methods to monitor these physiological parameters. Thermography appears to be a useful tool for assessing the body’s response in terms of changes in surface temperature, which reflect, among other things, blood flow, muscle metabolism, and inflammatory processes [23]. Thus, analyzing changes in these parameters, particularly in the lower limbs, in response to competitive high-intensity exercise in Masters athletes provides information about the current physiological state and potential dysfunctions in these mechanisms, offering new possibilities in training monitoring, recovery, and load planning [24, 25].

Given the need for monitoring active older athletes and the lack of clear conclusions regarding the effects of maximal competitive effort on surface temperature distribution, this study aimed identification whether age is a modifying factor in the post-exercise thermal response.

Material and methods

Participants

Masters track and field athletes are defined as 35 years of age and older. Athletes are divided in 5-year age groups starting at age 35 and goes as follow 35–39, 40–44, 50–54, etc. In total 148 male Masters track & field athletes participating in the European Masters Athletics Championships Indoor (Toruń 2024) were enrolled in the study. Due to the intermittent nature of exertion in certain events, athletes competing in throwing and jumping disciplines were excluded from the study, as the specific structure of these competitions involves repeated short bursts of effort with rest intervals of highly variable duration.

All participants were Caucasian. The mean age of the participants was 55.56 years (± 15.07), and their average athletic experience was 18.08 years (± 31.85). During the current season, participants trained an average of 6.6 hours per week (± 7). The athletes represented various track and field running disciplines, including sprint events (60 m, 200 m, 400 m, 60 m hurdles) as well as middle- and long-distance events (800 m, 1500 m, 3000 m, cross-country).

Based on the study hypothesis and the rationale outlined in the introduction, participants were divided into three age groups:

- **M35–45, n = 68** (athletes aged 35 to 49 years) – mean age: 40.23 ± 3.93 years;
- **M50–65, n = 64** (athletes aged 50 to 64 years) – mean age: 58.13 ± 6.29 years;
- **M70+, n = 16** (athletes older than 70 years) – mean age: 74.06 ± 4.91 years.

In order to participate in the study, all subjects had to previously complete and sign an informed consent in which they were explained how the study will be conducted and requirements necessary to participate in it. In addition, they signed the authorization to use their data for academic and research purposes while maintaining their anonymity. The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans was applied. The project was approved by the Bioethics Committee of the National Institute of Public Health, National Institute of Hygiene in Warsaw (protocol number 1/2021).

Data collection

The data collection was carried out indoor, close to the warming up zone of the facilities of the indoor track of Arena Toruń. In the room an ambient temperature of 20.1 ± 0.3°C was recorded. An ambient humidity of 48.0 ± 2.5% was noted.

After arrival and collection of personal data, participants underwent a 10–15-minute thermal adaptation period to acclimate to the ambient temperature. During this adaptation phase, athletes rested passively without wearing tracksuit pants or any other clothing that would cover the surface of the lower limbs, remaining only in shorts. Following acclimatization, two thermal images of each athlete's lower limbs were taken – one from the anterior view and one from the posterior view. This imaging procedure was conducted prior to competition, and this condition will henceforth be referred to as the *REST* state.

Subsequently, athletes completed an individualized warm-up following the RAMP protocol. This protocol consists of four phases [26]: Raise: focused on increasing key physiological parameters, including blood flow, muscle temperature, core temperature, muscle elasticity, and the quality of neuromuscular activation and conduction. This is achieved through intentional use of low-intensity movements and key locomotor patterns; Activate: targeted activation of key muscle groups; Mobilise: mobilization of key joints and range of motion required for the upcoming activity; Potentiate: high-intensity exercises that are highly specific to the demands of the sport. Preparation according to the RAMP protocol is considered one of the most effective warm-up strategies [27].

Immediately after completing the warm-up, the athletes participated in their main event at the Championship race. Given their participation in the European Masters Athletics Championships Indoor, it is reasonable to assume that the race was performed at maximum intensity by each athlete.

Directly after the race (approximately 5 minutes, although this time may have varied slightly depending on the participants due to different procedures for transitioning from the track to the measurement area), the subjects moved to the measurement stand, where thermographic images of the lower limbs were taken again.The study protocol is presented in Fig. 1.

Infrared thermographic images of the anterior and posterior surfaces of the lower limbs were taken for each participant while in an upright standing position. The analysis focused on cutaneous temperature (T_{sk} °C) within predefined regions of interest (ROIs) corresponding to the following muscle groups: tibialis anterior, gastrocnemius, biceps femoris, and rectus femoris (Fig. 2). To ensure consistency in thermographic assessment pre- and post-exertion, ROIs were delineated using physical markers, thereby standardizing the anatomical sites evaluated across all imaging sessions. Throughout both the thermal adaptation phase and the period between physical exertion (race) and subsequent image acquisition, the target skin areas remained exposed to facilitate accurate thermal pattern. For subsequent analysis, the mean skin temperature values of the marked ROIs were computed separately for the anterior and posterior aspects of both the right and left lower limbs (Fig. 3).

Thermal imaging was conducted using a FLIR E8 thermal camera (FLIR Systems, Sweden), following the 'Thermographic Imaging in Sports and Exercise Medicine (TISEM)' protocol outlined by Moreira [28]. The device operates within a temperature range of -20 to + 250°C, offering an accuracy of ± 2°C or ± 2%, a thermal sensitivity of less than 0.05°C, a 9 Hz refresh rate, and a 320 × 240 pixel Focal Plane Array resolution. The camera was positioned 2.5 meters from the subject during image capture. Data analysis was carried out using FLIR Tools software.

Statistical analysis

Statistical analysis of the obtained results was conducted using the STATISTICA 13 software (TIBCO Software Inc., 2017, USA). Descriptive statistical analysis was used to determine the mean values, standard deviations, and 95% confidence intervals of the mean for the studied indicators. The Shapiro-Wilk test was used to check the assumption of normal distribution of the variable distributions. Additionally, the homogeneity of variance was assessed using Levene's test.

Comparison between groups of skin temperature mean values before and after the race was examined using the Student's t-test for dependent variables. If at least one variable did not have a normal distribution, the Wilcoxon test was applied. Mean values of analyzed parameters for three groups in the same measurement, was examined using the single factor ANOVA. In case of non-compliance with the normal distribution, when at least one group did not have a normal distribution or did not meet the criteria for homogeneity of variance, of the Kruskal-Walli**s** test was used. The effect size for the parametric T-test (both dependent and independent variables) were assessed using dCohen indicator with: small effect – 0.2; medium effect – 0.5; and large effect – 0.8. Meanwhile, for the Wilcoxon test, the coefficient of two-way serial correlation for matched pairs (r_c) was applied, and for single factor ANOVA eta2, Glass's rank biserial (r_g) correlation coefficient was used. For both of these indicators, the following magnitudes were adopted: weak effect – 0.1; moderate effect – 0.3; and strong effect – 0.5.

To determine the required sample size, an a priori sample size calculation was performed using G*Power (v. 3.1.9.7; Düsseldorf, Germany). Based on previous studies about effort effect on skin temperature, estimation for a difference between tow dependen6t means, using a large effect size of dz = 0.7, α error of 0.05, 1–β = 0.8, with one group and two testing times a minimum sample size of n = 15 was determined. Also due to the applied research design, F tests (ANOVA: one-way) were used to test differences between three groups in the same measurement, assuming a large effect size of f = 0.25 and a minimum sample size of n = 84.

Results

The warm-up and competition in the 35–45 age group caused drop in skin temperature (T_{sk}) and significant changes were noted in T_{sk} in the area of the Rectus femoris muscle in both the left and right lower limbs (Table 1). A significant decrease in skin temperature was also observed in the left Biceps femoris, accompanied by a similar contralateral reaction in the area of the right Gastrocnemius. Interestingly, the magnitude of the statistically significant changes observed for the left Rectus femoris and the right Gastrocnemius was identical (ΔTsk = 0.54°C and 0.55°C, respectively), and very similar for the Biceps femoris (ΔT_{sk}=0.51°C). The greatest decrease in T_{sk} was recorded for the right Rectus femoris (ΔT_{sk}=0.63°C) – Fig. 3.

In the 50–65 age group after exercise, lower skin surface temperature values were observed and (as in 35–45 age group) the most reactive area to physical effort related to the warm-up and competition was the right Biceps femoris, although the temperature change (ΔT_{sk}=0.32°C) – Fig. 3, was not statistically significant. In both the 50–65 and 70 + age groups, none of the post-exercise temperature changes were statistically significant (Tables 2–3). However, symptomatically, the oldest athletes showed higher surface temperatures in five out of eight regions of interest (ROIs) after the competition compared to resting conditions. Exceptions included the rectus femoris, biceps femoris, and gastrocnemius areas – but only on the right lower limb (Table 3).

Table 1

Thermal response to warm-up and competition in the 35–45 group, statistically significant ($p < 0.05$) values are bolded

Muscle group	Mean T_{sk} [°C]	SD	P
Tibialis anterior left rest	31.03	1.07	0.274
Tibialis anterior left after race	30.78	1.84	
Rectus femoris left rest	31.22	1.08	**0.013**
Rectus femoris left after race	30.68	1.69	
Rectus femoris right rest	31.63	1.38	**0.007**
Rectus femoris right after race	31.00	1.72	
Gastrocnemius left rest	31.11	1.20	0.268
Gastrocnemius left after race	30.63	1.76	
Gastrocnemius right rest	31.03	1.31	**0.020**
Gastrocnemius right after race	30.48	1.92	
Biceps femoris left rest	31.06	1.17	**0.014**
Biceps femoris left after race	30.55	1.66	
Tibialis anterior right rest	31.08	1.21	0.096
Tibialis anterior right after race	30.59	1.97	
Biceps femoris right rest	31.03	1.64	0.851
Biceps femoris right after race	30.98	1.61	

Table 2
Thermal response to warm-up and competition in the 50–65 group

Muscle group	Mean T_{sk} [°C]	SD	P
Tibialis anterior left rest	31.22	1.16	0.086
Tibialis anterior left after race	30.97	1.38	
Rectus femoris left rest	31.15	1.23	0.214
Rectus femoris left after race	30.97	1.48	
Rectus femoris right rest	31.32	1.05	0.055
Rectus femoris right after race	31.05	1.34	
Gastrocnemius left rest	31.12	1.23	0.307
Gastrocnemius left after race	30.97	1.36	
Gastrocnemius right rest	31.02	1.30	0.285
Gastrocnemius right after race	30.90	1.46	
Biceps femoris left rest	31.08	1.19	0.509
Biceps femoris left after race	30.95	1.33	
Tibialis anterior right rest	31.38	1.43	0.513
Tibialis anterior right after race	31.17	1.95	
Biceps femoris right rest	31.65	1.40	0.122
Biceps femoris right after race	31.33	1.89	

Table 3

Thermal response to warm-up and competition in the 70 + group

Muscle group	Mean T_{sk} [°C]	SD	P
Tibialis anterior left rest	31.21	1.28	0.836
Tibialis anterior left after race	31.46	1.75	
Rectus femoris left rest	31.24	1.55	0.979
Rectus femoris left after race	31.36	2.14	
Rectus femoris right rest	31.22	1.18	0.552
Rectus femoris right after race	31.19	2.11	
Gastrocnemius left rest	31.24	1.04	0.313
Gastrocnemius left after race	31.58	1.57	
Gastrocnemius right rest	31.14	1.36	0.679
Gastrocnemius right after race	31.06	1.96	
Biceps femoris left rest	31.16	1.39	0.918
Biceps femoris left after race	31.29	2.11	
Tibialis anterior right rest	31.19	1.23	0.938
Tibialis anterior right after race	31.24	1.67	
Biceps femoris right rest	31.28	1.05	0.670
Biceps femoris right after race	31.08	1.74	

The comparison of potential differences in the thermal profile between age groups reveals certain trends, particularly between the youngest group of athletes and the others. However, these trends appear only after the completion of physical exertion. Statistical analysis did not indicate that these differences were significant ($p > 0.05$), either in the resting condition measurements or immediately after the run (Table 4).

The assessment of asymmetry by comparing the mean temperatures in the analyzed locations showed no significant differences ($p > 0.05$) between the right and left lower limbs, regardless of the group or the measurement time point. As symptomatic, by far the smallest result dispersion (SD) occurs in the 70 + group, although an exception may be the right tibialis anterior, especially in the post-race measurement.

Table 4
Variation of thermal portrait between groups, p values

Age group	Time point	Tibialis ant. left	Tibialis ant. right	Rectus femoris left	Rectus femoris right	Gastro. left	Gastro. right	Biceps femoris left	Biceps femoris right
35–45 vs 50–65	Before	0.165	0.166	0.284	0.478	0.160	0.161	0.469	0.101
	After	0.247	0.105	0.082	0.148	0.111	0.083	0.066	0.271
35–45 vs 70+	Before	0.298	0.172	0.496	0.107	0.162	0.368	0.353	0.229
	After	0.089	0.101	0.188	0.103	0.217	0.089	0.075	0.415
50–65 vs 70+	Before	0.495	0.412	0.376	0.102	0.480	0.169	0.371	0.379
	After	0.155	0.251	0.403	0.298	0.433	0.247	0.262	0.430

Discussion

The aim of this study was to analyze the thermal response to competitive effort in Masters athletes of different age groups, with particular emphasis on potential differences between them. In light of the available literature, it is known that the aging process is associated with a progressive deterioration of physiological functions, including thermoregulatory mechanisms, which begin to deteriorate after the age of 40 [8, 9]. At the same time, much evidence suggests that regular physical activity can effectively counteract age-related changes [11.16]. In this context, Masters athletes are increasingly seen as models of so-called successful aging [29, 30]. Recent study has shown that in trained Masters athletes, maximal exercise does not cause significant disturbances in thermoregulation or increased muscle stiffness, suggesting the preservation of adaptive properties of the musculoskeletal system despite advanced age [25].

The study results showed that the most noticeable changes in skin surface temperature (T_{sk}) after exercise occurred in the 35–45 age group. Statistically significant decreases in T_{sk} were recorded over the Rectus femoris muscle in both the left (ΔT_{sk} = 0.54°C) and right lower limb (ΔT_{sk} = 0.63°C). Additionally, changes were observed in the area of the left biceps femoris muscle (ΔT_{sk} = 0.51°C) and the contralateral (right) gastrocnemius muscle (ΔT_{sk} = 0.55°C), indicating the presence of cross-reactions in the thermal response. Such results may stem from the specifics of indoor track running, where the presence of banked turns leads to asymmetrical loading of the lower limbs [25]. Pietraszewski et al. [31] concluded that sprinting on curves places greater demands on the inner lower limb than the outer one, although it should be noted that the degree of these demands depends on the curve radius. In those studies, in contrast to the results of the present study, the most heavily utilized muscle group was the gastrocnemius of the left leg - the inner leg.

In the 50–65 and 70 + age groups, no statistically significant changes in temperature after exercise were recorded. Nevertheless, in the oldest participants, a tendency toward increased surface temperature was observed in five of the eight analyzed regions. This may indicate reduced efficiency of heat dissipation mechanisms and a slower return to thermal equilibrium. Such indications are consistent with scientific reports pointing to the deterioration of thermoregulatory capacity with age. This is caused, among other factors, by a reduced thermal response such as the sweating mechanism or prolonged heat dissipation time [15, 32]. Older individuals also show impaired skin blood flow, which means a slower skin response to heat stress [33]. This points to reduced thermal capacity and reactivity and weaker ability to cope with excess heat in older individuals.

Comparative analysis between age groups did not reveal statistically significant differences, although it should be noted that the temperature decreases were greater in the 35–45 age group. This may be related to the greater thermal capacity of this age group of athletes. Supporting this thesis are the findings of Adamczyk et al. [34], where athletes of higher athletic level showed a similar response (greater temperature drops). It should be added that physically active individuals generally display better heat dissipation mechanisms than non-athletes [35]. Another study supporting this relationship demonstrated that a higher level of aerobic endurance correlated with greater heat loss [36]. Thus, an effective ability to dissipate excess heat is associated with an efficient response to thermal stress[34]. In summary, athletes in the 35–45 age group exhibit a stronger thermal response, which may indicate a properly functioning thermoregulatory mechanism and greater physical fitness. On the other hand, reduced thermal reactivity in older athletes provides evidence of progressive limitations of this mechanism due to the aging process. Based on these findings, in trained athletes, temperature decreases more rapidly, which may be interpreted as a sign of greater thermal capacity - that is, the body’s ability to effectively cope with excess heat during and after exercise [37].

The results of the study provide evidence that long-term sports training effectively mitigates the negative effects of aging on thermoregulatory functions. The most important phenomenon observed was a relatively small number of statistically significant differences in thermal response between age groups (35–45, 50–65, and 70 + years), which is in contrast to population data and suggests a protective effect of regular training [38]. Statistical analysis showed no significant differences in skin temperature between groups both at rest and after exercise, which indicates preserved thermal homeostasis regardless of age. This phenomenon can be interpreted as the effect of physiological adaptation induced by systematic physical activity, including, among others, maintaining cardiovascular fitness [13, 39], maintaining efficient peripheral circulation and elasticity of blood vessels [40], increasing the activity and density of sweat glands and improving their response to an increase in body temperature, which allows faster and more effective heat dissipation through sweat evaporation [41], increased blood flow through the skin, which allows for more efficient heat dissipation [42] and the level of hydration as regular physical activity promotes better hydration [43]. It is also worth emphasizing the importance of metabolic and hormonal adaptations. Regular exercise can influence the regulation of heat stress hormones (e.g. aldosterone, vasopressin), which control water and electrolyte balance, and thus the efficiency of sweating and the maintenance of circulating blood volume [44].

It is worth noting that only the youngest group of subjects showed a significant decrease in skin temperature after exercise, especially in the rectus femoris, biceps femoris and gastrocnemius muscles, which can be interpreted as a model thermoregulatory response resulting from active redistribution of blood flow [45]. The lack of such changes in the older groups does not necessarily indicate dysfunction, but reflects the economical work of the circulatory system and the stability of thermoregulatory mechanisms. This may also be evidenced by the lack of differences in resting temperature between groups, as well as the lack of extreme fluctuations in skin temperature after exercise [38].

Literature indicates that with age, increasing thermal asymmetries are observed in the average population, especially in the lower limbs, which is associated with deterioration of microcirculation [46]. These disorders lead to local differences in tissue perfusion and thus - discrepancies in skin surface temperature.

In this study, no statistically significant differences in skin temperature between the limbs were found, regardless of group affiliation, measurement location or time of measurement. This result by showing thermal symmetry in each group of Masters studied might indicate the preventive effect of sports training .

The preserved thermoregulatory parameters observed in older athletes strongly support and extend the findings of previous research, which consistently highlight that Masters athletes maintain a notably higher level of physical fitness, superior overall health, and enhanced social engagement compared to their age-matched peers who lead more sedentary lifestyles. This elevated physical condition contributes significantly to the efficient functioning of physiological systems responsible for temperature regulation, including cardiovascular stability, sweat gland responsiveness, and skin blood flow adaptations. These mechanisms collectively enable older athletes to better cope with thermal stress [30].

From a comparative perspective, the results of this study contrast with numerous reports from the general population, in which, with age, we observe, among others, increased sweat threshold [7], decreased heat dissipation efficiency and decreased skin circulation [6]. The presence of these adverse phenomena was not confirmed in the group of Masters athletes, which suggests that physical activity plays a compensatory role in the natural aging processes. The average sports experience of the subjects of over 18 years is an additional argument for the long-term nature of this adaptation, which may include, among others, the preservation of capillary density, the efficiency of thermoregulatory receptors or the efficiency of sweat mechanisms [29].

Limitations

Some limitations should be noted. We analyzed the thermograms manually, in future studies it is worth considering automation using software (e.g. TermoHuman) which should speed up the analysis and minimize the risk of ROI reading error. Masters athletes constitute a specific, highly motivated population with high training commitment, which may limit the generalizability of the results, and rather apply them only to a well-trained population. Future studies should therefore include comparisons with recreationally active groups, take into account different environmental conditions (e.g. heat stress) and analyze other aspects of aging, such as cognitive and psychological functions.

Summary and conclusions

In summary, the results of this study support the hypothesis that regular and long-term sports training effectively mitigates the negative effects of aging on thermoregulatory functions. The lack of significant differences between age groups of Masters athletes in response to maximal competitive effort provides evidence that physical activity may be one of the most effective tools supporting successful aging. These observations fit into the broader concept of multidimensional aging, according to which maintaining physical and social functionality is possible also in advanced age, as long as it is accompanied by long-term involvement in sports and exercise.

Our study is one of the first comprehensive analyses of the thermal response to physical exertion in Masters athletes in track and field, taking age categories into account. The only significant changes in thermal response were observed in the 35–45 age group, which, in light of previous findings, can be explained by the fact that younger individuals have a greater thermal capacity and are able to react more quickly and effectively to the demands of competitive exertion. Despite a general, though statistically insignificant, increase in temperature in the oldest group - alongside an overall thermal response that is more often associated with a decrease in temperature (due to vasoconstriction of subcutaneous vessels and redistribution of blood flow toward working muscles and convection) — the observed lack of significant differences in the thermal profile between age groups may indicate effective maintenance of thermoregulation capacity. It may also result from the maintenance of physical fitness at a level sufficient to cope with metabolic and thermal stress. In this context, for Masters athletes, neither the post-50 nor the post-70 age period causes significant changes in thermal profile, which suggests that long-term training adaptation due to athletic training supports active aging and delays the negative consequences of aging.

Declarations

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

J.G.A. conceptualized and supervised the study. B.M., J.G.A, A.K., J.B., Ł.G., K.G. and D.B. performed the experiments and data analysis. J.G.A., B.M., Ł.G. and J.B. wrote and edited the manuscript. J.G.A, B.M. and M.S-Q. discussed the data and corrected the manuscript. All authors revieved final version of manuscript.

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Data Availability

The datasets (generated during and/or analysed during the current study) are available from the corresponding author on reasonable request.

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Figures

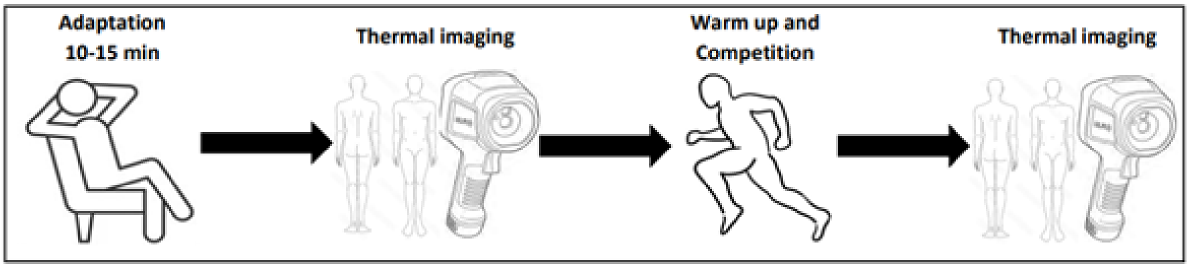

Figure 1

Study timeline with subsequent activities.

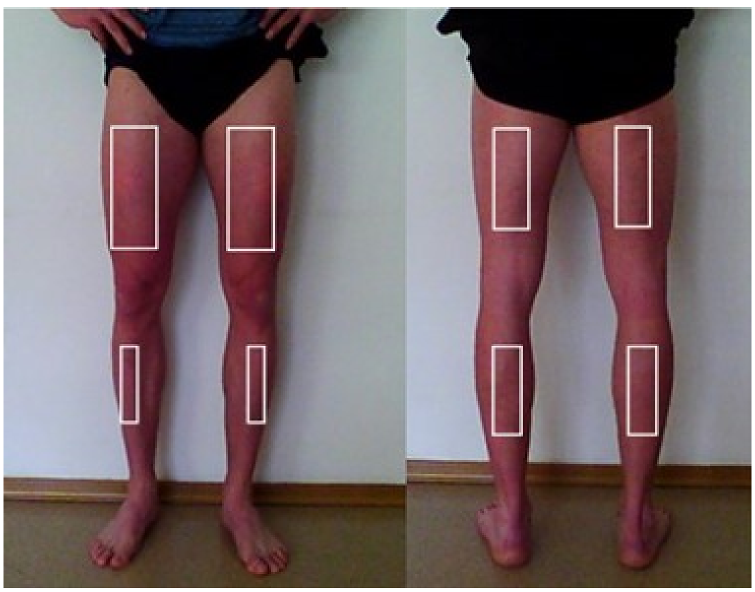

Figure 2

The anterior and posterior view with marked regions of interest (ROI's) taken for analysis.

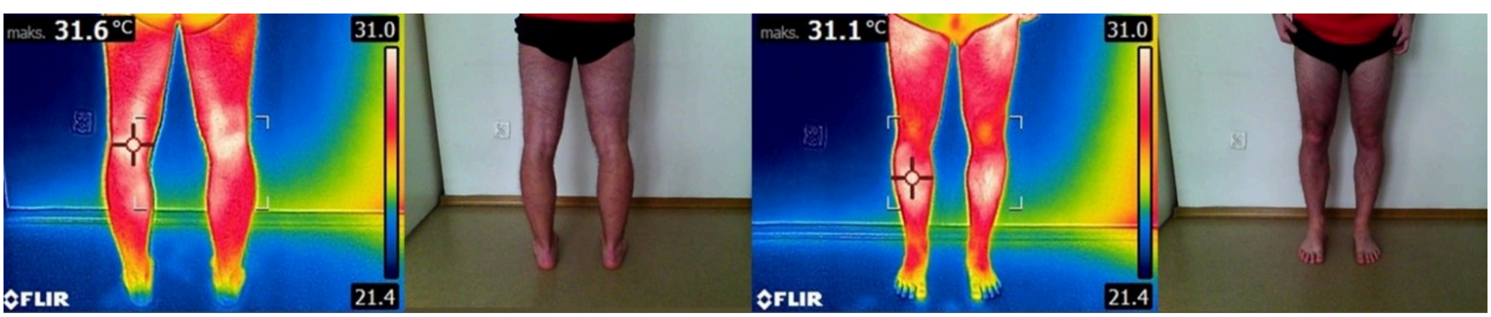

Figure 3

Example thermal images taken in anterior view.

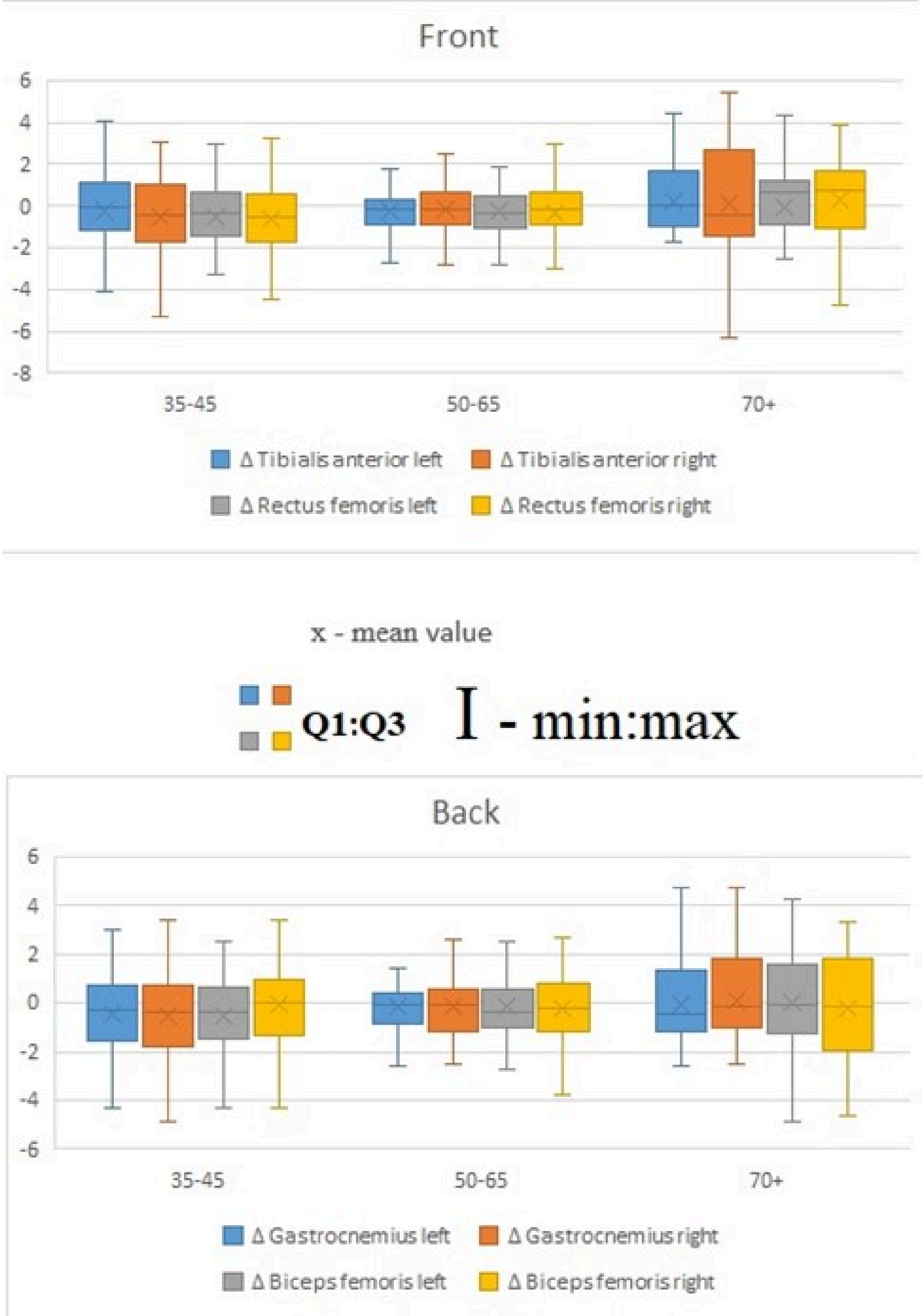

Figure 4

Changes in thermal portrait (ΔT_{sk} [°C]) in response to exercise in the 35–45, 50–65, and 70+ age groups in the analyzed regions of interest in front and back view.