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Changes in Skin Surface Temperature during Muscular Endurance indicated Strain – An Explorative Study

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Abstract

Introduction: Non-contact thermography enables the diagnosis of the distribution of skin surface temperature during athletic movement. Resistance exercise results in stress of required musculature, which is supposed to be measurable thermographically in terms of skin surface temperature change. Objective: This study aims to evaluate the application of thermography to analyze changes in skin temperature, representing specific muscle groups, during and after resistance exercise. Method: Thirteen male participants (age: 27.1 ± 4.9 years, height: 181.5 ± 5.7 cm, mass: 74.8 ± 7.4 kg) completed the study. On 5 separate visits to the laboratory, participants performed one of 5 resistance exercise to target specific muscles (M. pectoralis major, M. rectus abdominis, M. trapezius, M. erector spinae, M. quadriceps femoris). The exercise protocol consisted of 3 sets of 20 repetitions, with 1 minute rest between exercise sets. The average skin surface temperature above the muscle groups used was thermographically determined using standard methods at 7 time points; pre-exercise, immediately following each exercise set, and post exercise (2, 3, and 6 minutes after the finale exercise set). The measurement areas were standardized using anatomic reference points. Results: From an inferential statistical point of view, no significant change in the average temperature caused by the applied resistance training was found for the individual muscle groups over time at the individual measurement times (all $P>0.08$). However, thermography showed a characteristic chronological temperature curve for the five body areas between measurement times, as well as a distinctive spatial temperature distribution over the measurement areas. Discussion: Based on the thermographic image data and the characteristic temperature curve, it is possible to identify the primarily used functional musculature after device-controlled resistance training. Therefore, thermography seems to be suited for visually imaging functional musculature.

Keywords: Thermography, strength training, skin surface temperature, visual imaging, resistance exercise

1. Introduction

The human body has the special ability of regulating and adapting its body core temperature (BCT) to internal and external conditions. The average internal body temperature is approx. 36.8 ± 1.5°C and subject to variation throughout the day. Due to this characteristic, humans belong to the group of homoiotherm beings, who are able to maintain a constant BCT throughout their lifetime. In contrast to the BCT, the skin surface temperature (SST) is defined as being poikilotherm (De Marées, 2003).

A temperature gradient is registered from the proximal body core going toward the extremities. During intense and constant physical strain, the BCT increases. Blood circulation of the skin is already reduced at sub-maximal strain (vasoconstriction). This results in an increased BCT and reduced skin temperature and thus in the reduction of heat loss via the skin (Brück, 1986; Wenger, 1986). This is how the body regulates the intramuscular tissue temperature required for optimal strength and endurance performance, for example, in order to ensure favorable effective temperatures for enzymatic processes (Weineck, 2010). After the BCT has reached a specific target value, the peripheral vessels are dilated (vasodilation) and the skin's blood circulation increases. The primary contribution of the skin to temperature regulation is cooling by heat dissipation (a total of four mechanisms for heat dissipation exist: heat loss through conduction, convection, heat radiation, and evaporation). With an increased blood supply to the skin, the skin's temperature increases accordingly, which can be measured with a delay of 5 to 15 minutes depending on the type and intensity of physical strain. Since the increase in skin temperature is a result of the metabolic processes described above, the skin temperature can be operationalized as an indicator for athletic strain (Weineck, 2010; Wenger, 1986; Zontak, Sideman, Verbitsky, & Beyar, 1998).

Being the largest organ, the skin is thus of major significance when it comes to temperature regulation. It supports thermoregulation in terms of maintaining a constant temperature of the body core, and, initially, it also supports muscular activity by increasing the intramuscular temperature level. The metabolically generated energy or heat is always dissipated via complex regulation processes. The dissipation of excess BCT is performed via several physiological thermoregulatory mechanisms, with the transport of the heat produced within the body core toward the skin being implemented via the blood circulation. The degree of blood circulation in the skin is therefore the primary determinant of the increase in skin temperature. This leads to the conclusion that the skin's blood circulation throughput majorly influences heat dissipation or skin temperature, which explains why blood or blood circulation is often assigned the characteristic of being a "coolant" or "cooling system".

In scientific praxis, various methods (such as, oral application of pills, ear thermometers, etc.) are available for determining the BCT. In literature, however, only the usage of contact thermometers to record the temperature is discussed. In contrast, the thermographic analysis of the skin temperature would provide a non-contact procedure that can examine skin areas regarding temperature distribution (Gaussorgues, 1994). Merla, Mattei, Di Donato, and Romani (2010) already employed thermal imaging cameras for their study to measure the skin temperature before, during, and after athletic activity. The use of thermographic systems thus enables analyses and visual imaging interpretation of skin temperature, which could lead to both didactic and diagnostic sports-related valences.

In cancer research, particularly breast cancer diagnosis, thermographic examinations have already been well received (Buzug, 2011). However, besides in medical areas, such as rheumatology, orthopedics, and occupational health, thermography is well established as a diagnostic procedure in few other sectors, for example, building technology, materials science, or non-destructive test procedures, etc. (Jiang et al., 2005; Knobel, Guenther, & Rice, 2011; Lahiri, Bagavathiappan, Jayakumar, & Philip, 2012). Studies as those by Ferreira et al. (2008), Merla et al. (2010), Vainer (2005), or Zontak et al. (1998) were able to show that modern thermographic diagnostics in sports can describe performance-determining physiological regulation mechanisms, which has, however, been hardly exploited. Therefore, the present piece is an explorative study that aims to evaluate the application of thermography to analyze changes in skin temperature, representing specific muscle groups, during and after resistance exercise. The thermographic image data serves the visual and thus didactic creation of an image atlas for selected exercises and point to the direction that further thoughts on how to use thermography in sports may take (Hildebrandt, Raschner, & Ammer, 2010). Furthermore, the paper bridges the gap between scientific research and practical application in this context of thermographic diagnostics.

2. Materials and methods

2.1 Sample

13 male students participated in the explorative study. The average age was 27.1 ± 4.9 years, the average height was 181.5 ± 5.7 cm, and the average weight was 74.8 ± 7.4 kg. Body fat was controlled during the study duration and does not change over time. Before the study, the participants were informed of the procedure and potential risks of this study and provided their written consent. The students were familiar with all testing procedures. Participation was voluntary and did not involve any financial compensation. The study complied with ethical guidelines as outlined in the Declaration of Helsinki as well as with the ethical standards (Harriss & Atkinson, 2011).

2.2 Study procedure

At five subsequent test dates with a delay of 2-3 days, a standardized strength endurance exercise session (3 sets, 20 exhaustive repetitions, 60-65% 1-RM, 1 minute rest in between sets; see ACSM (2011)) was performed for the abdominal muscles (M. rectus abdominis), the lower back musculature (M. erector spinae pars lumbalis), the upper back musculature (M. trapezius), the chest musculature (M. pectoralis major), and the knee-extending musculature (M. quadriceps femoris). The repetition duration was controlled by a metronome and standardized as two seconds for concentric and two seconds for eccentric movement phase (time under tension). Throughout each exercise session, intensity of effort was regressed so that 20 repetitions were performed every time. Exercises were sit-ups, back extension using the device, lat-pull toward the back, bench pressing, and squats with barbells (Astro Sport, Heubach, Germany). Proper execution of the exercises was monitored as well as supervised to qualified persons.

2.3 Measurement methodology

The thermographic determination of the SST was performed using the infrared thermography system TVS 200 EX (NEC Avio Infrared Technologies Co., Ltd., Tokyo, Japan). The evaluation and processing of thermographic data was performed using the software InfReC Analyzer NS9500 Lite 2.5 (NEC Avio Infrared Technologies Co., Ltd., Tokyo, Japan). The customary used software is a standard tool to calculate mean skin surface temperature in a defined area by averaging the detected temperature values. Furthermore, the procedure in the used software was always a standard routine. In order to obtain representative measurements of the skin areas, the camera objective was aligned orthogonally to the measured skin areas and calibrated in a uniform way (Lahiri et al., 2012). Spatial resolution was 76,800 pixels using an infrared spectrum of 8-14 µm (Buzug, 2011). The skin measurement areas were standardized via anatomic reference points that were identified in the thermography image via thermally inactive markers. They were specified individually using the test persons' anthropometrics (Figure 1).

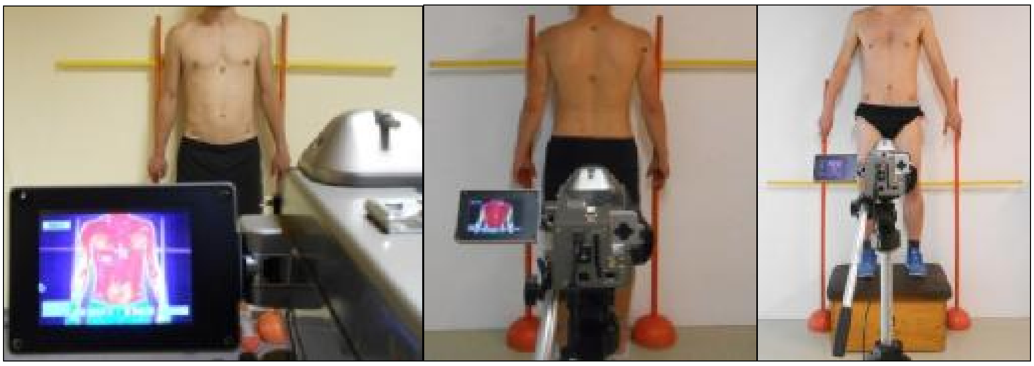

Figure 1. Standardized recording position of the exercise-specific skin areas (left: resistance exercise sit-up and bench press, middle: resistance exercises back extension and lat pull, right: strength exercise squat).

By means of the standardized measurement area, minima, maxima, and average temperature changes in the skin surface temperature were recorded. Before the actual examination, the undressed test persons were acclimated for 10 minutes to the standardized room temperature and humidity. Immediately thereafter and before the first strength training series, the SST was measured for the first time. One minute after each series, and two, three, and six minutes after the training was finished, further thermographic measurements were performed in the undressed state of the participants for each of the various muscle groups.

2.4 Statistical analysis

The measurement data was calculated using the statistics software IBM SPSS 20 (IBM, New York, USA). In addition to the descriptive values, such as average values, standard deviation, minima, and maxima, 95% confidence intervals were calculated. Temperature changes over time were calculated using single factor variance analysis. The Levene test was employed to check sphericity, and normal distribution was verified using the Kolmogorov-Smirnov adaptation test. The significance level was set to $P<0.05$.

3. Results

As shown in Table 1, a strength training-induced temperature reduction from resting state to the end of the 1st series was measured. When analyzing the temperature curve of the skin surface from the point in time just before strain up to the point in time 6 minutes after strain, no significant temperature difference was found for any of the exercises (all $P \geq 0.08$).

Table 1. Skin surface temperature curve [°C] from before strain until 6 minutes after strength training-induced strain

	Sit-ups		**Back extension**		**Lat pull**		**Bench press**		**Squats**	
	MW SD	**95% Interval**	**MW SD**	**95% Interval**	**MW SD**	**95% Interval**	**MW SD**	**95% Interval**	**MW SD**	**95% Interval**
Before strain	31.66	31.17	32.54	32.10	32.14	31.61	31.77	31.17	30.12	29.49
	0.81	32.15	0.73	32.98	0.88	32.67	0.99	32.37	1.05	30.75
1st series	31.18	30.60	32.03	31.56	31.81	31.33	31.64	31.22	29.94	29.32
	0.96	31.76	0.77	32.49	0.80	32.30	0.69	32.05	1.03	30.56
2nd series	30.94	30.34	31.69	31.06	31.71	31.17	31.92	31.46	30.07	29.46
	0.99	31.54	1.05	32.32	0.90	32.26	0.76	32.37	1.01	30.68
3rd series	30.70	29.99	31.41	30.73	31.78	31.19	31.92	31.38	30.00	29.33
	1.16	31.40	1.13	32.09	0.97	32.37	0.89	32.45	1.12	30.68
2´ after strain	30.91	30.22	31.44	30.70	31.96	31.39	31.97	31.49	30.09	29.41
	1.13	31.59	1.23	32.19	0.94	32.53	0.79	32.45	1.13	30.77
3´ after strain	31.06	30.36	31.54	30.84	31.94	31.29	31.88	31.37	30.12	29.42
	1.16	31.76	1.15	32.23	1.07	32.59	0.83	32.38	1.15	30.82
6´ after strain	31.31	30.63	31.76	31.12	31.94	31.43	31.85	31.36	30.27	29.63
	1.12	31.99	1.07	32.41	0.85	32.46	0.80	32.33	1.06	30.91

At a visual level, however, the thermography image for the individual test persons identified an increased skin temperature of the muscle group measured and a chronological temperature curve between the exercise series.

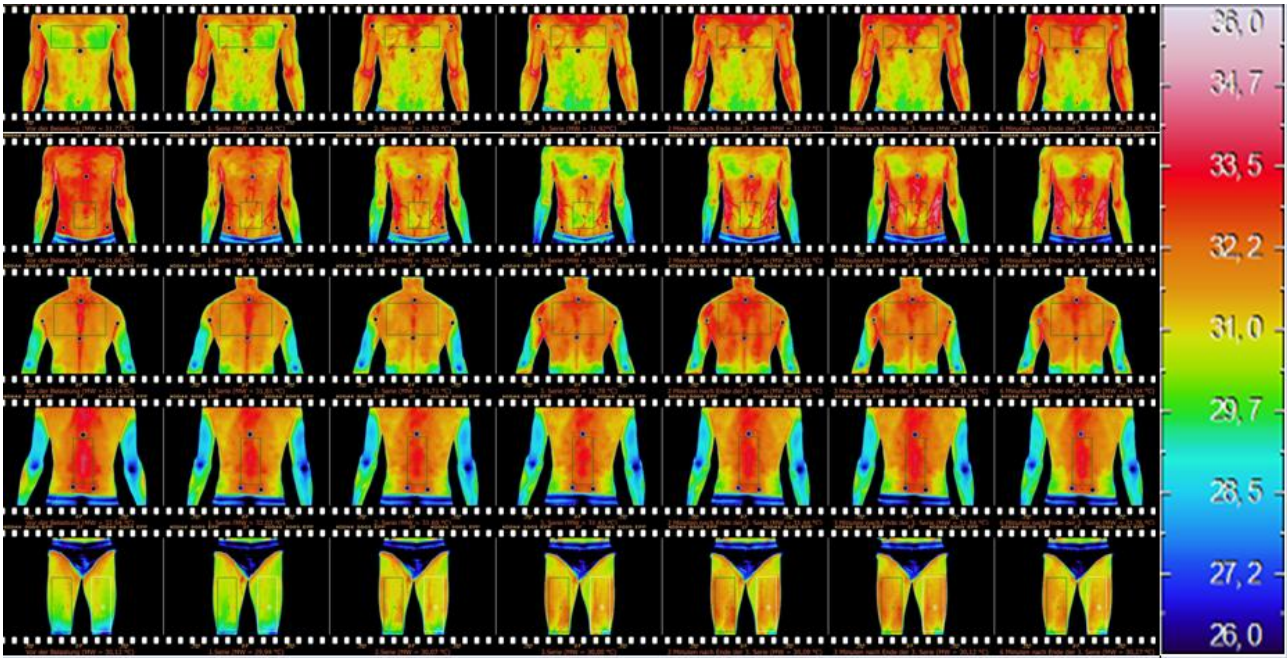

Figure 2. Thermographic skin surface temperature distribution of chest, abdominal, upper and lower back muscular system, as well as knee-extending muscles resting (1st image), after strength endurance training (2nd, 3rd, and 4th image), and after strength training-induced strain (5th, 6th, and 7th image)

4. Discussion

The temperature gradients diagnosed for the five skin areas during seven measurements exhibit similar tendencies as the thermographically measured gradients in the studies by Torii, Yamasaki, Sasaki, and Nakayama (1992), Wenger (1986), and Zontak et al. (1998). This means that after an initially dropping skin surface temperature due to the athletic activities, the temperature increases again over time, which is explained by the blood circulation throughput. The measurement results indicate that after the first series, all strength exercise-induced measurement areas show a temperature drop. This is due to concurrent vasoconstriction of the superficial blood vessels and increased blood circulation in the (deeper) muscle groups (De Marées, 2003). After a minimum temperature is reached, an almost continual increase of the skin temperature takes place, which can be interpreted as a thermoregulatory cooling effect of the now dilated superficial blood vessels (Wenger, 1986). As Table 1 illustrates, not all temperature curves have the same gradient characteristics. The skin areas close to the body core show an earlier increase in skin temperature and a higher average temperature than the skin areas further away from the body core. These findings corroborate the results by Clark and Stothers (1980).

In this study, thermographic data recording was based on a predefined chronological sequence. The upper back and chest musculature measurement areas close to the body core suggest a constant temperature plateau already two minutes after finishing the third series. The other three skin areas show an almost consistent increase after a temperature minimum. The maxima of the specific skin surface temperatures are reached six minutes after finishing the third series at the latest. Authors Xu, Castellani, Santee, and Kolka (2007) registered a maximum skin surface temperature only 20 minutes after the end of strain caused by athletic activity. In view of that fact and the temperature curves identified in the course of this study, it can be assumed that a temperature maximum of the skin areas analyzed is not reached six minutes after the last strain. Therefore, it might be advisable to extend the time of data recording in further examinations in order to document the maximum temperature values within the evaluated measurement areas by means of thermographic software.

The extent to which modified strength training, such as a full-load hypertrophy training may prove characteristic skin temperature changes remains speculative and should be examined in further studies. Furthermore, it may be interesting to determine the extent to which thermography can be employed to evaluate different warm-up procedures in terms of regional and global blood circulation effects. In conclusion, thermography provides a non-contact and non-invasive procedure to represent muscle groups used in sports, whose visual imaging capabilities can be applied in sports didactics, as well. While the use of thermography is increasing in medical research (Jiang et al., 2005; Knobel et al., 2011; Lahiri et al., 2012; Ring & Ammer, 2012), the research situation in a sports-specific context is still rudimentary (Ferreira et al., 2008; Merla et al., 2010).

3. Conclusion

Based on the thermographic image data and the characteristic temperature curve, it is possible to identify the primarily used functional musculature after device-controlled resistance training. Therefore, thermography seems to be suited for visually imaging functional musculature.

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Conflict of interest

No conflicts of interest exist.

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