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Variability of shoulder girdle temperature in the initial phase of the snatch in weightlifting

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Purpose: The identification of activation, synchronization and work of individual muscles in the subsequent stages of lifting weights is interesting for researchers and trainers. Unfortunately, the existing methods of research do not provide such possibilities. Such information could be gathered from infrared measurements as they are non-invasive and can be carried out without the direct involvement of the weightlifter. The purpose of the study was to analyse temperature changes in the shoulder girdle in the first phase of the snatch in weightlifting. *Methods*: The study involved 11 weightlifters who competed in two weight categories, 94 and 105 kg, during the World University Championships in 2018. The performance of the snatch was recorded using a thermographic camera in three consecutive attempts. We analysed the temperature changes in the left and right shoulder girdles in the two initial stages of the snatch. Statistical analysis of empirical data was performed using linear mixed effects models. *Results*: Statistically significant temperature increases were found from the moment of gripping the barbell to the moment it was pulled. These effects were different in individual weightlifters, but did not depend on the attempt or the side of the body. *Conclusions*: Temperature increases in the initial phase of the snatch are most likely the result of activating successive motor units in order to perform the effort needed to pull the barbell and cause it to accelerate. The results obtained confirm that thermography is an effective method of monitoring muscle activity in weightlifting, which may be useful for coaches and athletes.

Key words: *infrared thermography, temperature variability, shoulder girdle, weightlifting, snatch*

1. Introduction

Infrared thermography is being increasingly widely applied in medicine and physiotherapy [4], [16], [28]. It does not require direct contact with the skin or special preparation, it is non-invasive, and the available software makes it possible to perform static and dynamic analyses. The accuracy of measurements made using thermographic cameras depends on the observance and precise description of measurement conditions related to the environment, the individual, and the apparatus [9]. Thermography has been used in sports medicine [17], especially in analyses carried out with the aim of preventing muscle injury. In studies involving athletes, thermographic cameras are used mainly for performing measurements before and after exercise [1], [7], [10], [20], [22], [30]. Changes in skin temperature during intense physical exercise depend on the operation of thermoregulation mechanisms [6], [18], [19], which allow for the performance of long-lasting physical activity and the activation of motor units [26]. A correlation has been found between increased skin temperature and muscle fatigue in long-lasting strength exercise [2]. During exercise, part of the energy of the muscles is expended on work, and a significant part is converted into heat [13].

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Muscle efficiency, which is the ratio of energy expended on work to the total energy produced, is the higher, the better trained and the less fatigued the muscles are. Our previous study [14] demonstrated that during the maintenance of constant torque, an almost linear increase occurs in skin temperature in the region of the quadriceps muscle. This is due, on one hand, to a decrease in muscle efficiency due to fatigue and, on the other hand, to the involvement of a greater number of motor units in maintaining a high torque value. This is confirmed by the analysis of electromyographic signals, whose frequency drops and amplitude increases.

Studies of skin temperature changes in the regions of specific muscle types can be an important source of information about their activity and synchronisation in weightlifting. In previous studies of muscle performance in weighlifters, torque was analysed under static conditions [11], [25]; in dynamic measurements, inverse dynamics models were used [8]. As already mentioned, attempts have also been made to perform controlled measurements of electromyographic signals [12], [29].

Successes in weightlifting result from proper training and the interaction of specific muscles at each stage of barbell lifting. However, the currently used non-invasive methods do not enable to determine, without the involvement of the competitor, which muscles are excited at which stage of lifting. The use of electromyography is difficult and limited not only because of the need for a direct contact between the electrodes and the competitor's skin, but also due to their instability associated with the movement of the barbell.

The research presented in this article aims to check the possibility of using thermal imaging cameras to track the work of individual muscles in the subsequent stages of weightlifting. The use of dynamic thermal imaging for this purpose would create new possibilities for non-invasive tracking of muscle work, which can be of interest to both trainers and researchers.

The aim of the current study was to perform a continuous analysis of temperature changes in the shoulder girdle muscles with the use of a thermographic camera in the initial phase of the snatch, which starts from the moment the barbell is gripped until the moment it is pulled. Pulling the barbell requires a large amount of force in order to overcome its weight and cause it to accelerate. For this purpose, weighlifters engage the extensors of the trunk and lower extremities as well as the muscles of the shoulder girdle. In the initial phase of the pull, the shoulder girdle muscles stabilise and control the movement of the barbell and in the second phase, they are responsible for increasing its velocity. The warm-up and operation of these muscles in the initial phase consists of activating as many motor units as possible, which is connected with an increase in muscle temperature.

2. Materials and methods

2.1. Measurements

The research material was collected during the World University Championships in weightlifting, which took place in Biała Podlaska on 19–23 September 2018 and featured competitors from 27 countries. The competition was held in a large sports hall without air circulation. The competitors were not exposed to sunlight when performing the lifts. Three successive snatch attempts were recorded using a thermographic camera. Spatial and temporal changes in ambient temperature recorded in all series of attempts for all competitors did not exceed 0.3 °C. Air humidity was 60%. Video recordings were made with a Flir E60 thermal imaging camera (Flir, Wilsonwille, Oregon, USA). The camera was placed in front of the competitor at a height of 1 m. on a tripod at a distance of 4 m. from the competitor (Fig. 1). The camera was directly connected to the computer. The camera had an infrared resolution of 320×240 pixels and a thermal sensitivity of 0.05 °C. Data were collected continuously at a rate of 30 frames per second and were directly transferred to a computer. The accuracy of temperature changes over time in the camera was 2%. The recordings from the thermographic camera were analysed using FLIR ResearchIR software v. 4.40.7.26.

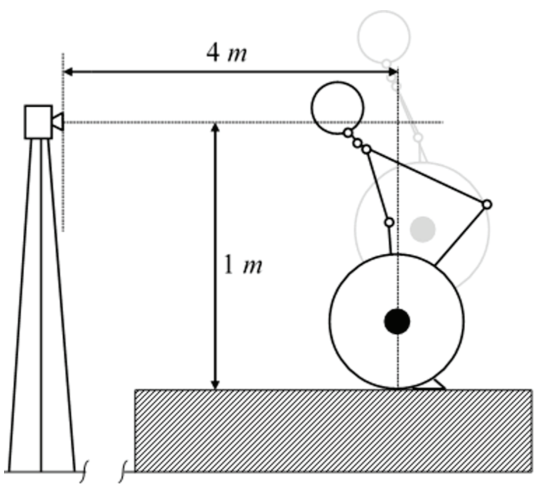

Fig. 1. Measurement of the temperature of the shoulder girdle muscles

The recordings in which the competitors had their shoulders exposed were selected for analysis. Based on this criterion, from among 24 competitors, five weightlifters were selected in the category up to 105 kg, and six were selected from the one up to 94 kg. The only criterion for the selection of the participants was the fact whether the shoulders of the weightlifter were bare or not as for the purpose of the research they could not be covered with any clothing. In the group of weightlifters up to 105 kg were: an Australian, a Dane, a Spaniard, a Pole, a Slovak, and a Taiwanese, while the group of up to 94 kg included an American, an Austrian, a Czech, a Pole, and a Slovak.

The recording of films with the use of thermal imaging camera was carried out with the consent of the International Weightlifting Federation and the International University Sports Federation. The thermograms were saved in the computer's memory, with each record bearing the competitor's symbol and the weight of the barbell being lifted. These records are protected in the Academy of Physical Education research computer database.

Fig. 2. Three stages of initial phase of the snatch: barbell grip, barbell pull, and holding barbell at knee level. Ellipses denote the measurement areas. Arrows inside ellipses (red) indicate maximum temperatures and those outside ellipses (blue) indicate minimum temperatures

Digital recordings of the snatch were analysed frame by frame with automatic recording of the maximum temperature in the shoulder region (Fig. 2) within the marked areas. The area of interest was determined manually in the form of an ellipse covering the shoulder girdle. Due to the fact that the manual selection of the area of interest may not coincide very closely with the shoulder muscle, maximum temperatures were determined instead of average ones. After each frame, the location of the marked area was verified. We decided to measure the changes in maximal temperature in order to eliminate the potential effects of discrepancies in the selection of measurement points on the results of the analysis. Bearing in mind that the heat transferred to the external layers of the skin can also cause increases in temperature in other regions of the skin, during all of the measurements, the maximal temperature index was measured within the ellipse surrounding the electrodes (Fig. 2). Measurements were taken frame by frame from the moment the barbell was gripped by the competitor until it was lifted to knee level. In these positions, the angle of incidence of the infrared rays was comparable. This is important because this angle can affect the accuracy of measurements. A frame by frame analysis of the recordings made it possible to capture the moment when the barbell was pulled with high time accuracy.

2.2. Statistical analysis

A linear mixed model ($Model_1$) was used in the statistical analysis [21], [24], because three consecutive attempts performed by the same subject cannot be regarded as independent from each other. The random part of the model was formed by the subjects, who were an 11-element random sample of 24 competitors participating in both weight categories. The dependence of body temperature on the weightlifter's manner of warming up and the time interval between successive attempts (sometimes the weightlifter had to correct the failed attempt within 2 minutes) additionally justified the treatment of the subjects as a random component of the model. The fixed part of the model was composed of three categorical variables: *attempt* {1, 2, 3}, *side* {L, R}, and *position* {G, P} (grip, pull).

The empirical data were coded in a long format. According to the commonly accepted practice in linear mixed effects analysis, we also built an unconditional random intercept model ($Model_0$) to estimate the intraclass correlation coefficient (ICC) [3], [5], [23].

We performed the statistical analysis in the R environment (R Foundation for Statistical Computing, Austria) using the *lmer* function from the *lmerTest* [15] package. The models were coded in R as follows:

$$Model_0 = lmer(snatch \sim 1 + (1|subject),\ data,\ REML = FALSE), \tag{1}$$

$$Model_1 = lmer(temperature \sim attempt + side + position + (1|subject),\ data,\ REML = FALSE). \tag{2}$$

The terms in inner brackets denote the random parts of the models, *data* is the file in a long format, and *REML = FALSE* means that maximum likelihood estimation (*ML*) was used for computations instead of default restricted maximum likelihood (*REML*). Applying the *ML* method allows for a direct comparison between the two models nested in each other using the *anova* method [3].

3. Results

In all of the weightlifters, we observed an increase in temperature from the moment the barbell was gripped to the moment it was pulled, followed by a rapid drop, for both the left and right shoulders. A sample curve representing these changes in one of the subjects is shown in Fig. 3. It is visible that at the moment when the barbell was pulled (dashed line), the temperature of the skin in the shoulder girdle region dropped sharply.

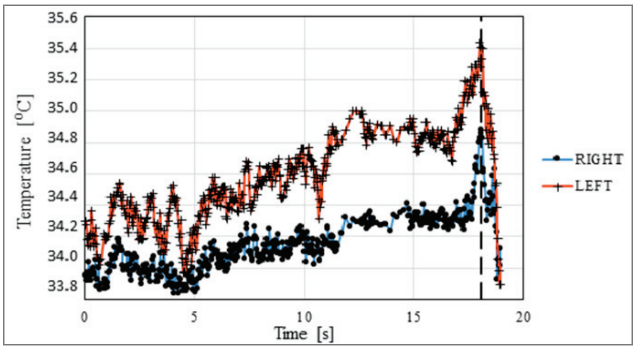

Fig. 3. Changes in temperature of skin in shoulder girdle region in one of the subjects. Dashed line indicates moment of pulling the barbell

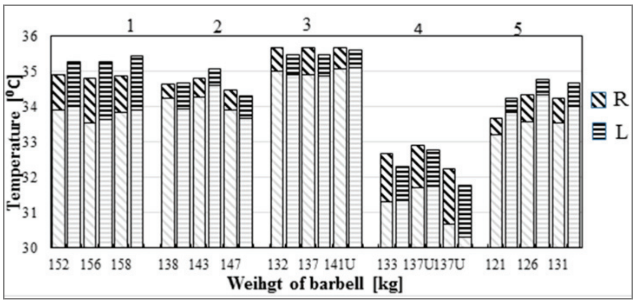

Fig. 4. Temperature of skin in shoulder girdle region (R – right, L – left) during barbell grip (light-coloured bars) and pull (dark-coloured bars, indicating increase in temperature) in individual competitors weighing up to 105 kg in successive attempts. Horizontal axis shows barbell weight; U indicates an unsuccessful attempt

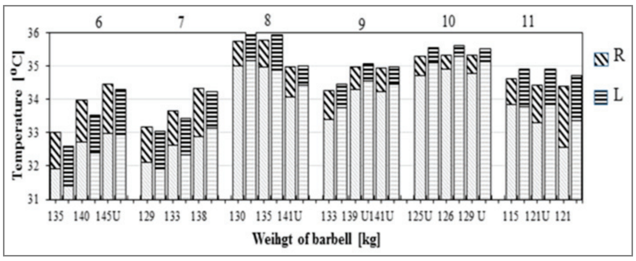

Fig. 5. Temperature of skin in shoulder girdle region (R – right, L – left) during barbell grip (light-coloured bars) and pull (dark-coloured bars, indicating increase in temperature) in individual competitors weighing up to 94 kg in successive attempts. Horizontal axis shows barbell weight; U indicates an unsuccessful attempt

In Figs. 4 and 5, the temperatures recorded for all subjects in the shoulder girdle at the moment of gripping (light-coloured bars) and pulling the barbell are shown. Temperature increases are indicated with darker lines. The horizontal axes show the barbel weights in consecutive attempts. Both temperature increases and initial temperature values were different for each athlete, as confirmed by statistical analysis.

The results of statistical analysis are presented in Table 1. Before interpreting them, it should be emphasised that the *lmer* function took variables that come first in the alphabet to be the reference level. This means that the reference level was defined by the first attempt, left side, and grip position.

Table 1. Estimation of model parameters

Parameter	*Model*$_0$	*Model*$_1$
Coefficient (SE)		
Fixed effects		
Intercept	34.08^{***} (0.31)	33.67^{***} (0.32)
Attempt		0.02 (0.04)
SideR		−0.10 (0.07)
PositionP		0.89^{***} (0.07)
Variance (SD)		
Random effects		
Intercept	1.02 (1.01)	1.03 (1.02)
Residual	0.40 (0.63)	0.18 (0.42)
−2*LL*	290.6	192.2

*** $p < 0.001$, *LL* – log likelihood.

The intercept value for *Model*$_0$ represents the average temperature for all 132 recorded cases. The ICC for *Model*$_0$ was 1.02/(1.02 + 0.4) = 0.72, suggesting that about 72% of the total variation in the snatch scores was due to between-subject differences.

The intercept value for *Model*$_1$ is the average temperature in the first attempt (1) for the left side (L) and the barbell grip position (G). The SideR and PositionP values indicate that the average temperature of the right side of the body (R) differed by −0.10 °C from the left side (L), and the average temperature during the barbell pull (P) was by 0.89 °C higher than that during the barbell grip (G). The latter difference was found to be statistically significant. The *anova* method applied to models 0 and 1 ($\chi^2(3) = 98.39$, $p \approx 0.0$) showed that *Model*$_1$ fits the data considerably better.

4. Discussion

Investigating the role of particular muscles and the interactions between them in different phases of a lift not only has cognitive value but can also be of practical value for coaches and athletes in the training process. Most of the studies conducted so far have been based on inverse dynamics models [6]. Attempts to apply the analysis of electromyographic signals in research conducted on weightlifters have encountered a number of difficulties related to electrode fixing, proper preparation of the subjects' skin, and the instability of electrodes and wires due to the movement of the barbell [12], [29]. For these reasons, the use of thermographic cameras to record temperature during weightlifting may significantly contribute to broadening our knowledge about the role of individual muscles in the subsequent stages of a lift. The current study focused on the activity of the shoulder girdle muscles in the initial phase of the snatch, from the moment the barbell is gripped to the moment it is pulled. The role of the shoulder muscles is appreciated by coaches and taken into account during the warm-up [27]. However, quantitative evaluations of the activity of the shoulder girdle muscles in the initial phase of the snatch have not been conducted so far.

The current study has examined the activity of the shoulder muscles in randomly selected athletes from different countries, who were trained by different coaches and used different warm-up methods. The analysis was carried out with the use of professional software with a high time accuracy, which made it possible to capture the moment when the barbell was pulled. As can be seen from the results of the measurements and statistical analyses, the temperature of the shoulder girdle muscles increased significantly from the moment the barbell was gripped to the moment it was pulled from the floor. The reason for such growth in temperature might be the increase in the recruitment of motor units, which occurs intuitively in weightlifters as a result of the training used to prepare the shoulder muscles for the considerable effort needed to overcome the weight of the barbell and give it acceleration. Once the barbell has been pulled, the temperature of these muscles decreases. It is likely that other muscles become active at a later stage. Both the initial temperature and the temperature increase varied from athlete to athlete, which is understandable bearing in mind the different warm-up and training methods used by the weightlifters who participated in the study.

When discussing the results obtained, it is necessary to mention the assumptions of the model applied in the calculations. These assumptions were checked by analysing a residual plot, a histogram of the residuals, and the output of the *lmer* function, which are not reported on in their entirety in this paper. There was no evident pattern in the residual plot indicating a violation of the linearity assumption of the model. The residuals had a similar amount of deviation from the predicted values. This means that the homoscedasticity assumption was not violated either. The histogram confirmed the normality of the residuals assumption, whereas the output of the *lmer* function showed no significant correlations among fixed effects predictors. The largest coefficient of correlation between the intercept and attempt was at the level of –0.141.

When summing up the discussion, it is important to mention the limitations that may have affected the results obtained. As mentioned above, the same conditions were maintained for all subjects with regard to the environment and the apparatus; the measurements did not require skin contact and were non-invasive. Other conditions that needed to be fulfilled were assuring constant ambient temperature as well as constant size and thermal insulation of the measurement room, positioning the camera adequately, adapting emissivity settings to the skin, and considering the competitor's physique. Such measurements also require that the skin be exposed and that an adequate angle of incidence of the infrared rays be maintained. These measurements do not make it possible to estimate the strength of the muscles, but only their activity and possibly synchronisation. Similarly as with electromyographic signal measurements, thermography does not capture the activity of deep muscles. Despite all these limitations, measurements performed in weightlifting using dynamic thermography can provide important information for coaches and athletes.

5. Conclusions

The results of the current study showed that the increase in the temperature of the shoulder girdle muscles in weightlifters did not depend on the side of the body or on the attempt. It was found to be directly related to the energy expended by the muscles during contraction in the initial phase of the snatch, which stems from the basic laws of thermodynamics governing the relationships between thermal energy, the efficiency of the system, and temperature changes.

The measurements whose results were discussed revealed both the role of the shoulder girdle muscles and the way they are activated during the snatch. The results of the current study justify conducting thermographic research in weightlifters in order to determine which muscles are activated in a specific barbell position.

The conclusion from the presented research that in the initial stage of lifting weights trained athletes experience a significant increase in the temperature of the shoulder area can be an important indication for proper training preparation. For the researcher, this result has serious cognitive significance, because it points out that the determinant of increased muscle activation may be due to temperature increase. It, therefore, can be expected, that the use of thermal imaging cameras will allow to track the activation of individual muscles at subsequent weight lifting stages based on temperature changes.

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