Accepted Manuscript

Evaluation of two different resistance training volumes on the skin surface temperature of the elbow flexors assessed by thermography

Paulo Uchôa, Filipe Matos, Eduardo Borba Neves, Francisco Saavedra, Claudio Rosa, Victor Machado Reis, José Vilaça-Alves

PII: S1350-4495(17)30840-X
DOI: https://doi.org/10.1016/j.infrared.2018.07.038
Reference: INFPHY 2652

To appear in: *Infrared Physics & Technology*

Received Date: 17 December 2017
Revised Date: 27 July 2018
Accepted Date: 30 July 2018

Please cite this article as: P. Uchôa, F. Matos, E.B. Neves, F. Saavedra, C. Rosa, V.M. Reis, J. Vilaça-Alves, Evaluation of two different resistance training volumes on the skin surface temperature of the elbow flexors assessed by thermography, *Infrared Physics & Technology* (2018), doi: https://doi.org/10.1016/j.infrared.2018.07.038

EVALUATION OF TWO DIFFERENT RESISTANCE TRAINING VOLUMES ON THE SKIN SURFACE TEMPERATURE OF THE ELBOW FLEXORS ASSESSED BY THERMOGRAPHY

Paulo Uchôa[a], Filipe Matos[a,d], Eduardo Borba Neves[a,b,c,], Francisco Saavedra[a,d], Claudio Rosa[a], Victor Machado Reis[a,d], José Vilaça-Alves[a,d]

a. Sports Department, Trás-os-Montes e Alto Douro University, Quinta de Prados St, 5001- 801, Vila Real, Portugal

b. Brazilian Army, Quartel General do Exército, Sector Militar Urbano 4º andar, 70.630-901 - Brasília/DF, Brazil 'Permanent address'

c. Graduate Program of Biomedical Engineering, Federal Technological University of Paraná, Sete de Setembro Ave 3165, 80230-901, Curitiba, PR, Brazil

d. Research Center for Sports, Health Sciences and Human Development, CIDESD; University of Trás-os-Montes & Alto Douro, Vila Real, Portugal.

Corresponding Author
Filipe Matos
E-mail Address: filipejosematos@gmail.com

Co-authors: Paulo Uchôa (paulouchoapersonal@gmail.com) Eduardo Borba Neves (borbaneves@hotmail.com), Francisco Saavedra (fjfsaave@utad.pt) Cláudio Rosa (claudiorosa23@yahoo.com), Victor Machado Reis (victormachadoreis@gmail.com), José Vilaça-Alves (josevilaca@utad.pt),

Summary

Resistance Training (RT[1]) variables allow different hypertrophy methodologies such as the drop-sets, however, the physiologic and structural acute effects on the muscle related to the use of this methodology are still unclear. Surface skin temperature (T_{SK}[2]) is considerate a marker of the inflammatory muscle response induced by RT. The aim of the present study was to observe the acute effect of the two resistance training volumes, organized in the drop-sets, on T_{sk} of the Elbow Flexors. 17 Caucasian men performed an elbow flexors exercise (10 repetitions per set, with 80%, 60% and 40% of the 10RM), organized in drop-set, in two different experimental sessions with a 7 days interval. The sessions differed only on the volume of the RT (3 x 6 sets). The T_{sk} was assessed by thermography in the moments before, immediately as well as 24h, 48h and 72h post exercise. When 6 sets were performed there was significantly higher T_{sk} values when compared to 3 sets, either in Control Arm (CA[3]) ($p=0,015$) and Experimental Arm (EA[4]) ($p=0,015$). It seems that a higher training volumes (6 sets) possibly induce more muscle response than a lower training volumes (3 sets) in the follow days post RT.

Keywords: Resistance Training; Training Volume; Thermography; Heat; Drop-set.

---

[1] **RT=**Resistance Training
[2] **T_{sk}=**Surface Skin Temperature
[3] **CA**=Control Arm
[4] **EA**=Experimental Arm

1. INTRODUCTION

Resistance training (RT) variables for strength training prescription such as the intensity, load, number of repetitions and sets, interval between sets, the order of the exercises and the cadence of execution, have to be manipulated in order to enhance muscle hypertrophy (Kraemer & Ratamess, 2012). However, many of RT methods are still poorly studied and have been empirically developed by RT practitioners aiming positive responses to muscle hypertrophy. Most of these methodologies were not scientific tested such as drop-sets (Fleck & Kraemer, 2006). Drop-sets methodology is discussed in the non-scientific literature of RT and proposes to provide a higher volume of muscle work at higher intensities, also with shorter intervals. This system is characterized by sets performed to muscle failure. After each set, exercise load is immediately reduced (e.g., ~20%), allowing individuals to perform additional repetitions to muscle failure on each set (Melibeu Bentes et al., 2012).

RT induces an aggression to muscle-skeletal tissue and promotes an inflammatory response proportional to duration, strength and muscle mass recruited. The inflammatory response to that muscle damage will provide muscle recovery through supercompensation mechanisms, resulting in muscle hypertrophy (Cleak & Eston, 1992; Kraemer & Ratamess, 2012). Indirect muscle injury caused by RT, which usually occurs after eccentric muscle action, can cause muscle swelling, tenderness, prolonged loss of strength, pain and increase localized muscle temperature.

The magnitude of these secondary effects it will provide the amount of internal stimulus for the muscle. Diagnostic tools have been developed to evaluate these secondary effects resulted from aggression induced by RT. Diagnostic by image have been increasingly used by health professionals to carry out or complement the diagnosis (Matos et al., 2015). Some authors also propose the combined use of images generated by different technologies (Sanches, Gamba, de Souza, Neves, & Nohama, 2013).

Thermography has been developed in the two last decades and being applied in sports medicine and medical fields, used for diagnosis of sports injuries and muscle injury caused by tension after resistance training (Matos et al., 2015; Eduardo Borba Neves et al., 2015). Recently, researchers have investigated the thermal response during and after exercise (Cholewka, Stanek, Sieroń, & Drzazga, 2012; Merla, Mattei, Di Donato, & Romani, 2010). Thermography has been recognized as a completely safe diagnostic, painless, with no ionizing radiation, contact or contrast. The method involves the detection of infrared radiation emitted by the skin and provides the analysis of physiological functions related to the skin temperature (Matos et al., 2015)

Based on this information and due to the reduced number of studies analyzing the physiological effects of the training volume and the reduced number of studies scientific testing the effects of drop-sets on the magnitude of muscle aggression, the aim of our study was to analyze the effect of two training volumes with a drop-set methodology in the acute and chronic thermal response, assessed by thermography.

2. METHODS

2.1. Ethical Approval. Before providing their written informed consent, all participants were informed of the requirements and potential risks of the studies. The study complied with the Helsinki declaration and was approved by the Institutional Review Board of the University of Trás-os-Montes and Alto Douro, Vila Real, Portugal.

2.2. Subjects. This study was randomized controlled trial in which Seventeen physically active men (n=17) who were familiar with Biceps Curl exercise, and who had been RT 2 to 3 times a week for the previous 6 months, volunteered to participate in a 2 week experimental sessions. Experimental procedures and risks were explained to the participants before they provided their informed consent to take part in the study. The criteria inclusion was: Males, Caucasians and apparently healthy. To define the inclusion criteria the subjects completed the following questionnaires: Par-Q test (ACSM, 2007), an anamnesis specifically designed according the requirements of assessment methods involved in this investigation. The characteristics of the participants in this study are described in Table 1.

Table 1. – Descriptive characteristics of the subjects.

2.3. Study overview. All trials started at 10 a.m. The participants were informed to eat similar food during the experiment trials, and were asked to avoid consuming stimulants, alcohol, tobacco, antioxidants and nutritional supplementation for 24h preceding all trials, and not to do any strength exercise for 48h prior to each trial. At the first and second sessions it was applied a 1RM[5] (Maximum Repetition) Test (W. Kraemer & Fry, 1995) for *Biceps Curl* (with forearm supination) in order to inferred the workload for each subject. 72h after, 1RM re-test was performed to achieve a workload data reliability.

The experiment trial was divided in two weeks, which differ only in the number of sets performed in the RT. On both weeks, the subjects performed the same RT protocol to the Exercised Arm (EA). The other arm doesn't perform any RT protocol so that can be useful as a Control Arm (CA). The difference between the weeks was the number of sets: 1) 3 sets; 2) 6 sets. Surface skin temperature, assessed by thermography, at pre and post RT moments as well as 24h, 48h and 72h post exercise.

A. ***Resistance Training Protocol.*** Subjects were submitted to the same RT protocol in both weeks, differing only in the number of sets: in one week subjects perform 3 sets of Bicep Curl (with forearm supination), organized in drop-set, at 80%, 60% and 40% of 1RM, respectably (E. B. Neves, Vilaça-Alves, Moreira, Lemos, & Reis, 2015). The rest period established was 1min30sec. The movement cadence was 60 bpm[6] (beats per minute), monitored by a metronome (Dolphin® Dp31g). In the other week subjects perform 6 sets of Bicep Curl (with forearm supination), organized in drop-set, at 80%, 60% and 40% of 1RM, respectably, and the last 2 sets to the concentric failure.

2.4. Skin Temperature Assessment. Thermal Images were taken pre and immediately post as well as 24, 48 and 72 hours post exercise. Images were acquired during morning (10:00 am).

The skin surface temperature assessment was performed in a room with a conditioned environment within a range of 22ºC to 24ºC, monitored by a digital thermometer (Elecs HTC-2). Thermal images were captured using a Thermographic Camera Ti32 from Fluke® Technologies (Mumbai, India). The camera was positioned

[5] 1**RM**=1 Maximum Repetition
[6] **bpm**=Beats per minute

on a tripod 1 meter above the ground and 1 meter from the subject. There was a non-reflecting background behind the subject (Ring & Ammer, 2012).

Thermal images were analyzed using Regions of Interest (ROI[7]) (see Figure 1), which include: 1) 60% of the distance between the posterior ridge of the acromion and the olecranon of the arm; 2) the xiphoid process (XP[8]) as reference of the central body temperature. These regions were accessed with a computer software *SmartView® Thermal Imaging Analysis (*Fluke® Technologies, Mumbai, India), which provided us with the average and mean temperatures from each analyzed ROI (Fernández-Cuevas et al., 2015; Maniar, Bach, Stewart, & Costello, 2015).

Figure 1. – Thermal image of Biceps Brachii ROI's immediately post performing 3 and 6 sets, respectably.

2.5. Statistic Treatment. All data will was analyzed using the SPSS software (Statistical Package for the Social Sciences, SPSS Science, Chicago, USA) version 21. An exploratory analysis of all data was performed to characterize the values of the different variables in terms of central tendency and dispersion. A graphical observation was made to detect possible outliers and incorrect data entries of all the variables used. According to the biological nature of the measurements, an analysis of the type of distribution through the *Shapiro-Wilk test* was carried out and the sphericity was ensured and tested through the *Mauchly test.* Verified the assumption for parametric tests, a Univariate ANOVA was used to observe the existence of statistically significant differences between the two training volumes studied.

An ANOVA for repeated measures analysed were utilised with the models: five moments (pre exercise, post exercise, 24h, 48h and 72h post exercise) x two sessions (3 sets x 6 sets) x two arms (exercise and control). A *bonferroni post hoc test* was used to identify differences between the moments, sessions and arms. All data analyzed with the ANOVA were tested for assumptions of normality, homogeneity and sphericity. The level of significance was established at 5%.

[7] **ROI**=Regions of Interest
[8] **XP**=Xiphoid Process

3. RESULTS

In relation to T_{sk} a significant moment effect was observed ($F_{(4,\ 240)}$=25,255, p<0,0001;η_p^2=0,311), an interaction moment x experimental arm ($F_{(4,\ 240)}$=3,295, p=0,012;η_p^2=0,056), and an interaction moment x set ($F_{(4,\ 240)}$=18,624, p<0,0001;η_p^2=0,250).

When were analyzed each arm individually in relation to the number of sets (3 sets versus 6 sets), a significant moment effect was observed in T_{sk} of the control arm ($F_{(4,\ 120)}$=22,656, p<0,0001;η_p^2=0,447) and an interaction moment x set ($F_{(4,\ 120)}$=9,858, p<0,0001;η_p^2=0,260). No set effect was observed on the CA. In the EA a significant moment effect was observed ($F_{(4,\ 120)}$=6,260, p<0,0001;η_p^2=0,183), an interaction moment x set ($F_{(4,\ 120)}$=9,022, p<0,0001;η_p^2=0,244) and was not observed any set effect (see details in Table 2).

Table 2 – Mean ± standard deviations of T_{sk} and $T_{A\text{-}XP}$ in both CA and EA, for each number of sets (3 set or 6 sets). *p<0,05 between perform 3 or 6 sets; ** p<0,05 between CA and EA; $ p<0,05 in relation to the moment immediately post RT; £ p<0,05 in relation to the moment 24h post RT; ¢ p<0,05 in relation to the moment pre RT; ¥ p<0,05

On the other hand, when analysed each set individually in relation to in the T_{sk} of each arm (CA versus EA), it was observed a moment effect when subjects performed 3 sets ($F_{(4,\ 120)}$=11,624, p<0,0001;η_p^2=0,309), although it was not observed interaction moment x arm. When subjects perform 6 sets, a significant moment effect was observed ($F_{(4,\ 120)}$=34,142, p<0,0001;η_p^2=0,532), and an interaction moment x arm ($F_{(4,\ 120)}$=2,860, p=0,047;η_p^2=0,087).

When we individually analysed the T_{sk} in each arm (CA and EA) with the use of each volume training, individually, it was observed that the moment immediately post RT, when were performed 3 sets in the CA, presented T_{sk} values lower than the pre, 24 and 48 hours post RT moments (p = 0.002, p = 0.001 and p = 0.001, respectively). 72h post RT presented values significantly (p = 0.026) lower than the 24h moment post RT. In the EA, it was only observed values significantly (p = 0.034) lower in the moment 72h post RT when compared with the moment 24h post RT (Figure 2).

Figure 2. - Estimated marginal means of T_{sk} per arm between perform of 3 sets versus 6 sets. Means statistical difference between moments (p<0.05) (Exercise Arm); Means statistical difference between moments (p<0.05) (Control Arm).

Regarding the results of who performed 6 sets, it was observed in the CA T_{sk} values significantly higher at the moment pre RT in relation to the moment immediately post RT (P=0,004) and lower values in the moments 48 and 72h post RT (p<0,0001 and p=0,036, respectively). At the moment immediately post RT, T_{sk} values were significantly (p <0.005) lower than the other moments analysed. It was also observed that in the moment 48h post RT, T_{sk} values were significantly (p = 0.021) higher than the moment 24h post RT. In the EA, it was observed that the moment 48h post RT presented values significantly higher than the moments pre, immediately post and 24h post RT (p <0.0001, p <0.0001 and p = 0.003, respectively) and in the moment 72h post RT it was observed values significantly higher than the moments pre and post RT (p = 0.039 and p = 0.003, respectively).

When compared the results of who performed 3 sets x 6 set in each arm (Figure 1), it was observed that performing 6 sets showed T_{sk} values significantly higher in contrast with performing 3 sets, in the CA at moments 48h (p = 0.037). The T_{sk} values of the EA were higher at 48h (p = 0.024) and 72h post RT (p <0.001)

When was compared the CA and EA, it was observed that the EA in the moment immediately post RT presents values significantly higher than the CA, when was performed 3 sets (p <0,0001). Regarding to 6 sets, it was observed that, as well as when performed 3 sets, only in the moment immediately post RT, EA had higher T_{sk} values (p <0.0001) in relation to CA (see details in Table 2).

Regarding to the body's central temperature measurements, through the T_{sk} in Xiphoid Process ROI, a moment effect and a significant moment x set interaction were observed ($F_{(4, 120)}$=44,046, p<0,0001;η_p^2=0,611 and $F_{(4, 120)}$=9,400, p<0,0001;ηp2=0,251, respectively).

When was performed 3 sets the T_{sk} of the XP is significantly (p <0.0001) lower at the moment post RT in relation to the remaining moments, except at the moment 72h post RT. In the other hand, when performed 6 sets, the pre RT moment presents T_{sk} XP values significantly (p = 0.001) higher than the immediately post RT moment and significantly lower than the moment 48h and 72 h post RT (p<0,0001 e p=0,009, respectively), the immediately post RT moment presented T_{sk} values significantly lower than the remaining moments (p <0.002) and the moment 48h post RT presented values significantly (p = 0.029) higher than the moment 24h post RT (Figure 3).

Figure 3. - Estimated marginal means of T_{sk} in the XP between perform 3 or 6 sets. *Means statistical difference (p<0.05) between performs 3 or 6 sets. Means statistical difference between moments (p<0.05) (6 Sets); Means statistical difference between moments (p<0.05) (3 Sets).

When we compared the T_{sk} values of the XP between who performed 3 or 6 sets at each moment, it was observed that at the moment pre RT the T_{sk} XP was significantly (p = 0.032) lower, when performed 3 sets and, when was performed 6 sets, the T_{sk} values were significantly (p = 0.020 and p <0.0001, respectively) higher at moments 48h and 72h post RT (see details in Table 2).

Regarding the difference between the T_{sk} XP, CA and EA ROI's, a significant moment effect ($F_{(4, 240)}$=67,547, p<0,0001;η_p^2=0,547), an interaction moment x set ($F_{(4, 240)}$=12,338, p<0,0001; η_p^2=0,181) and an arm effect ($F_{(1, 60)}$=11,270, p=0,001; η_p^2=0,168). It was not observed a set effect neither an interaction moment x group x set to this variable (table 2). When was analysed each arm individually in relation to the number of sets performed (3 sets versus 6 sets), in the difference between local T_{sk} of both arms and T_{sk} of XP, a significant moment effect was observed in the CA ($F_{(4, 120)}$=14,377, p<0,0001; η_p^2=0,334). It was not observed a significant set effect neither an interaction moment x set, in the CA. Regarding to the EA, it was observed a significant moment effect $F(_{4, 120)}$=57,411, p<0,0001; η_p^2=0,672), an interaction moment x set ($F_{(4, 120)=}$3,840, p=0,016;η_p^2=0,121) and it there was no set effect (see details in Table 2).

On the other hand, when was analysed each number of sets, individually in relation to each arm (CA versus EA), in the difference between T_{sk} of the arms and T_{sk} of the XP ($T_{A\text{-}XP}$ [9]) it was observed a significant moment effect $F_{(4, 120)}$=22,347,

[9] **$T_{A\text{-}XP}$ =** T_{sk} difference between arms and xiphoid process

$p<0,0001$; $\eta_p^2=0,462$), when were performed 3 sets, also, an effect x arm ($F_{(4, 120)}=3,641$, $p=0,022$; $\eta_p^2=0,123$) and an effect arm ($F_{(1, 60)}=4,261$, $p=0,049$; $\eta_p^2=0,141$) were observed.

Regarding to the results of who performed 6 sets, a significant moment effect ($F_{(4, 120)}=52,193$, $p<0,0001$; $\eta_p^2=0,635$), an interaction moment x set ($F_{(4, 120)}=10,042$, $p<0,0001$; $\eta_p^2=0,251$) and an arm effect ($F_{(1, 60)}=7,334$, $p=0,011$; $\eta_p^2=0,196$) were also observed. When was analysed T_{A-XP} individually, in each arm (CA and EA), with the use of each number of sets individually. With 3 sets in the CA, it was observed that at the moment immediately post RT the T_{A-XP} was lower than the remaining moments (p <0.048), except for the moment 24h post RT. In the EA, the immediately post RT moment presented a lower T_{A-XP} in relation to the moments 24h, 48h and 72h post RT (p=0,003, p=0,001 e p=0,006, respectively), and presents an inverse variation in relation to the moment pre RT with significant difference (p=0,002), in the moment pre RT the T_{A-XP} was -0,79, in the other and in the moment immediately post RT the T_{A-XP} was 0,77.

Regarding to the results of who performed 6 sets in the CA, a lower T_{A-XP} was observed at the moment immediately post RT in relation to the moment 24h, 48h and 72h post RT (p=0,001, p=0,004 e p=0,027). In the EA it was observed that the moment pre RT presented a difference significantly lower to the moments immediately and 24h post RT (p<0,0001 e p=0,001, respectively), the moment 24h post RT present a difference significantly higher than the moment 48 post RT, also, the moment immediately post RT shows values significantly lower than the moment 24h post RT (p<0,0001), and significantly higher than the moments pre, 48h and 72h post RT (p<0,0001).

When compared at each moment the use of 3 or 6 sets in each arm in the T_{A-XP}, we observed that it is superior in the when were performed of 6 sets in the moment 24h post RT, either the CA or EA (p=0,015 e p=0,006, respectively). When was analysed T_{A-XP} between the CA and EA in each number of sets, it was observed that with 3 sets, the EA had a superior T_{A-XP} at the moment immediately and 24h post RT (p<0,0001). In the other hand, with 6 sets T_{A-XP} is superior at the moment immediately post RT for the EA in relation to the CA (p <0.0001) (see details in Table 2).

4. DISCUSSION

The Thermal images analysis presents a complex physiological response, dependent of the imposed training load, the muscles and joints involved in the exercise, and also the cardiovascular, neural and adrenergic systems (Charkoudian, 2010). The normal metabolism and organs functioning is possible thanks to optimal temperature conditions called thermal homeostasis. However, the temperature can changes due to stress and physical effort. During and after, the thermoregulation is activated due to energy loss, what simultaneously leads to temperature increase (Kasprzyk, Stanek, Sieroń-Stołtny, & Cholewka, 2017). In this study, the results demonstrated that when were performed both 3 or 6 sets, organized in a drop-set methodology, both T_{sk} of the CA and XP decrease from the moment pre to immediately post RT and, when compared both arms, the Tsk of the EA was significantly higher than the CA in the moment immediately post. This behavior seems to be related to the redirection of blood flow to the active muscles, causing a peripheral vasoconstriction in the musculature that are not intervening directly in the exercise executed (Charkoudian, 2010; Ihsan, Watson, Lipski, & Abbiss, 2013; Stephenson, Vernieuw, Leammukda, & Kolka, 2007),

For example, Neves (2015) studied the behavior of the thermal response in brachial biceps to high intensity exercise in two adult subjects. It was found that the T_{sk} of the CA decreases from the moment pre to immediately post RT. Also, Neves (2014) verified in a pilot study a reduction in T_{sk} of the brachial biceps (CA) during the 1st minute (between the end and the beginning of the new set). The study of Fernandes et al., (2014) evaluated the thermal behavior during aerobic exercise in treadmill (60% VO2max) and showed a decrease in temperature in the initial five minutes of the test.

Other interesting result of this study was that when 3 sets were performed, the T_{sk} in the CA increase from the moment immediately post to 72h post RT, although the T_{sk} values remain lower than the moment pre RT. On the contrary, in the EA, T_{sk} was significantly higher at the moment immediately post RT compared to the CA for both training volumes studied (3 and 6 sets). Also, when 6 sets were performed, the T_{sk} showed significantly higher values in the moments 24h, 48h and 72h post RT, when compared to the pre RT moment. In another similar study, Hani et al (2012) with 41 untrained males who performed 4 sets of 25 repetitions at 35% of 1RM strength exercise for biceps also found T_{sk} variation 24h and 48h post intervention when compared to the moment pre intervention. Also Neves et al., (2015) found evidence that reinforces the results of our study, in the group that performed 5 sets of RT Bi-set protocol, higher T_{sk} values were observed at moments 48h, 72h and 96h post RT compared to the group that only performed 3 sets. Our believe is that this behavior is a result of the heat generation during the muscle recovery process (Al-Nakhli, Petrofsky, Laymon, & Berk, 2012; Fernandes et al., 2014).

RT induces primarily metabolic stress in active skeletal muscles, involving a high rate of aerobic and anaerobic energy transformation (Clanton, 2007), which contribute to an increase in reactive oxygen species (ROS) generation. ROS are highly reactive and can denature proteins, nucleic acids and lipids, which destabilize muscle cell structures including the sarcolemma and structures of the excitation–contraction-coupling system (Tidball, 2005) The sustained high transformation of energy to support repeated contractions and increased intramuscular pressure imposed by hyperemia can also impose mild hypoxic stress on the muscle fiber promoting the accumulation of metabolites (Clanton, 2007). In response to this, the blood flow is restituted to the injured muscle in order to provide immunologic cells, needed to the muscle regeneration and also to remove this metabolites accumulation. This physiologic responses are responsible for heat generation (Armstrong, 1990; Cleak & Eston, 1992). So, the muscle recovery process is also characterized by a heat increase in that specific muscle due to the high metabolism rate and blood flow. The results seem to be in accordance with this physiologic response.

Regarding to the results of Neves et al., (2015) and the results observed in our study, the T_{sk} changes at the moments 24h, 48h and 72h post exercise may allow to understand the magnitude of the muscle response to a certain workload, and seems to be a good variable to compare different training volumes. In our study, significantly higher values of T_{sk} were observed immediately post RT as well as 24h, 48h and 72h post RT, when were performed 6 sets comparing to 3 sets of the RT drop-set methodology. In addition, it is known that, during recovery, the internal temperature measured through the esophagus remains high, indicating an increase in metabolic activity (Journeay, Carter, & Kenny, 2006). We assess the T_{sk} trough AP ROI and it was observed that when performed 6 sets, the T_{sk} is higher at the moments 48h and 72h post RT compared to when 3 sets were performed. It seems that, probably, 6 sets of RT drop-set methodology induced more stimulus/response to the body and muscles than when performed 3 sets.

Thermography is a non-invasive and non-contact method and that characteristic becomes a very important advantage over contact methods due to the dynamic nature of T_{sk}. Has been shown that T_{sk} have a high correlation with intramuscular temperature (Hardaker et al., 2007). According to the recent studies and the results of our study, the T_{sk} reveals to be a important variable to be considered in exercise and sport monitoring (Cholewka, Kasprzyk, Stanek, Sieroń-Stołtny, & Drzazga, 2016). In fact, the T_{sk} analysis through thermography seems to show positive and promising results in evaluate and establish the relationship between the internal and external workloads and between different workloads (Al-Nakhli et al., 2012; Korman et al., 2016; E. B. Neves, Moreira, et al., 2015).

5. CONCLUSION

Based on the results of this study, it appears that using a higher training volume (6 Sets) provides surface skin temperature values significantly higher than a lower training volume (3 sets) on the recovery period (24 to 72 hours post exercise, respectively) on the exercised muscle. Seventy-two hours appear not to be enough to return all the T_{sk} values to the basal levels, becoming more evident when performing higher training volumes. The skin temperature seems to be an important variable to be considered in exercise and sports monitoring.

Acknowledgements

Macro-to-Nano Human Sensing: Towards Integrated Multimodal Health Monitoring and Analytics, operation no. NORTE-01-0145-FEDER-000016, co-financed by the European Regional Development Fund (FEDER) through NORTE 2020.

Conflict of Interest

Nothing to declare.

6. REFERENCES

Al-Nakhli, H. H., Petrofsky, J. S., Laymon, M. S., & Berk, L. S. (2012). The Use of Thermal Infra-Red Imaging to Detect Delayed Onset Muscle Soreness. *Journal of Visualized Experiments*, (59). https://doi.org/10.3791/3551

Armstrong, R. B. (1990). Initial events in exercise-induced muscular injury. *Medicine and Science in Sports and Exercise*, *22*(4), 429–435.

Charkoudian, N. (2010). Mechanisms and modifiers of reflex induced cutaneous vasodilation and vasoconstriction in humans. *Journal of Applied Physiology*, *109*(4), 1221–1228. https://doi.org/10.1152/japplphysiol.00298.2010

Cholewka, A., Kasprzyk, T., Stanek, A., Sieroń-Stołtny, K., & Drzazga, Z. (2016). May thermal imaging be useful in cyclist endurance tests? *Journal of Thermal Analysis and Calorimetry*, *123*(3), 1973–1979. https://doi.org/10.1007/s10973-015-4662-5

Cholewka, A., Stanek, A., Sieroń, A., & Drzazga, Z. (2012). Thermography study of skin response due to whole-body cryotherapy: Thermography study of skin response due to whole-body cryotherapy. *Skin Research and Technology*, *18*(2), 180–187. https://doi.org/10.1111/j.1600-0846.2011.00550.x

Clanton, T. L. (2007). Hypoxia-induced reactive oxygen species formation in skeletal muscle. *Journal of Applied Physiology*, *102*(6), 2379–2388. https://doi.org/10.1152/japplphysiol.01298.2006

Cleak, M. J., & Eston, R. G. (1992). Delayed onset muscle soreness: Mechanisms and management. *Journal of Sports Sciences*, *10*(4), 325–341. https://doi.org/10.1080/02640419208729932

Fernandes, A. de A., Amorim, P. R. dos S., Brito, C. J., Moura, A. G. de, Moreira, D. G., Costa, C. M. A., … Marins, J. C. B. (2014). Measuring skin temperature before, during and after exercise: a comparison of thermocouples and infrared thermography. *Physiological Measurement*, *35*(2), 189. https://doi.org/10.1088/0967-3334/35/2/189

Fernández-Cuevas, I., Bouzas Marins, J. C., Arnáiz Lastras, J., Gómez Carmona, P. M., Piñonosa Cano, S., García-Concepción, M. Á., & Sillero-Quintana, M. (2015). Classification of factors influencing the use of infrared thermography in humans: A review. *Infrared Physics & Technology*, *71*, 28–55. https://doi.org/10.1016/j.infrared.2015.02.007

Fleck, J. S., & Kraemer, W., J. (2006). Fundamentos do treinamento de força muscular. 3a ed. Porto Alegre. Artmed.

Hardaker, N., Moss, A. D., Richards, J., Jarvis, S., McEwan, I., & Selfe, J. (2007). Relationship Between Intramuscular Temperature and Skin Surface Temperature as Measured by Thermal Imaging Camera. *Thermology International*, *17*(1), 45–50.

Ihsan, M., Watson, G., Lipski, M., & Abbiss, C. R. (2013). Influence of Postexercise Cooling on Muscle Oxygenation and Blood Volume Changes: *Medicine & Science in Sports & Exercise*, *45*(5), 876–882. https://doi.org/10.1249/MSS.0b013e31827e13a2

Journeay, W. S., Carter, R., & Kenny, G. P. (2006). Thermoregulatory Control Following Dynamic Exercise. *Aviation, Space, and Environmental Medicine*, *77*(11), 1174–1182.

Kasprzyk, T., Stanek, A., Sieroń-Stołtny, K., & Cholewka, A. (2017). Thermal Imaging in Evaluation of the Physical Fitness Level. *Innovative Research in Thermal Imaging for Biology and Medicine*, 141–164. https://doi.org/10.4018/978-1-5225-2072-6.ch007

Korman, P., Straburzyńska-Lupa, A., Kusy, K., Kantanista, A., & Zieliński, J. (2016). Changes in body surface temperature during speed endurance work-out in highly-trained male sprinters. *Infrared Physics & Technology*, *78*, 209–213. https://doi.org/10.1016/j.infrared.2016.08.003

Kraemer, P. W. J., & Ratamess, N. A. (2012). Hormonal Responses and Adaptations to Resistance Exercise and Training. *Sports Medicine*, *35*(4), 339–361. https://doi.org/10.2165/00007256-200535040-00004

Kraemer, W., & Fry, A. (1995). Development and evaluation of methology. Phyological Assessment of Human Fitness. *Human Kinetics*, 115–138.

Maniar, N., Bach, A. J. E., Stewart, I. B., & Costello, J. T. (2015). The effect of using different regions of interest on local and mean skin temperature. *Journal of Thermal Biology*, *49–50*, 33–38. https://doi.org/10.1016/j.jtherbio.2015.01.008

Matos, F., Neves, E. B., Norte, M., Rosa, C., Reis, V. M., & Vilaça-Alves, J. (2015). The use of thermal imaging to monitoring skin temperature during cryotherapy:

A systematic review. *Infrared Physics & Technology*, *73*, 194–203. https://doi.org/10.1016/j.infrared.2015.09.013

Melibeu Bentes, C., Simão, R., Bunker, T., Rhea, M. R., Miranda, H., Matassoli Gomes, T., & Da Silva Novaes, J. (2012). Acute effects of dropsets among different resistance training methods in upper body performance. *Journal of Human Kinetics*, *34*(1). https://doi.org/10.2478/v10078-012-0069-6

Merla, A., Mattei, P. A., Di Donato, L., & Romani, G. L. (2010). Thermal Imaging of Cutaneous Temperature Modifications in Runners During Graded Exercise. *Annals of Biomedical Engineering*, *38*(1), 158–163. https://doi.org/10.1007/s10439-009-9809-8

Neves EB, Moreira TR, Lemos RJ, Vilaça-Alves J, Rosa C, Reis VM (2015). The influence of subcutaneous fat in the skin temperature variation rate during exercise. Research on Biomedical Engineering;31(4):307-12. https://doi.org/10.1590/2446-4740.0805

Neves, E. B., Vilaça-Alves, J., Krueger, E., & Reis, V. M. (2014). Changes in skin temperature during muscular work: a pilot study. *Pan American Journal of Medical Thermology*, *1*(1), 11–15.

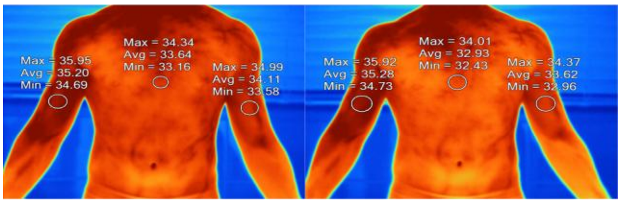
Neves EB, Vilaça-Alves J, Moreira TR, Reis VM (2016). The thermal response of biceps brachii to strength training. Gazzetta Medica Italiana - Archivio per le Scienze Mediche.;175(10):391-9.

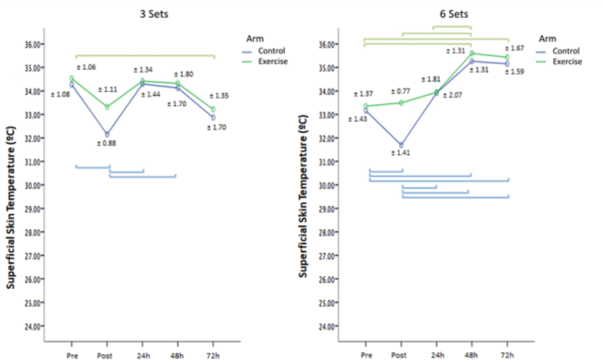
Ring, E. F. J., & Ammer, K. (2012). Infrared thermal imaging in medicine. *Physiological Measurement*, *33*(3), R33–R46. https://doi.org/10.1088/0967-3334/33/3/R33

Sanches, I. J., Gamba, H. R., de Souza, M. A., Neves, E. B., & Nohama, P. (2013). Fusão 3D de imagens de MRI/CT e termografia. *Rev. Bras. Eng. Bioméd*, *29*(3), 298–308.

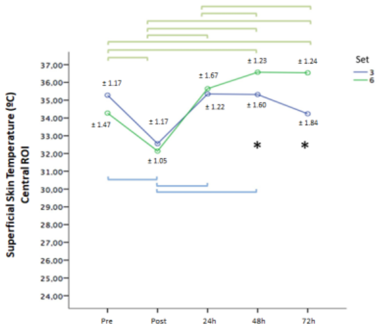
Stephenson, L. A., Vernieuw, C. R., Leammukda, W., & Kolka, M. A. (2007). Skin temperature feedback optimizes microclimate cooling. *Aviation, Space, and Environmental Medicine*, *78*(4), 377–382.

Tidball, J. G. (2005). Inflammatory processes in muscle injury and repair. *American Journal of Physiology - Regulatory, Integrative and Comparative Physiology*, *288*(2), R345–R353. https://doi.org/10.1152/ajpregu.00454.2004


Max = 34.34
Avg = 33.64
Min = 33.16
Max = 35.95
Avg = 35.20
Min = 34.69
Max = 34.99
Avg = 34.11
Min = 33.58
Max = 34.01
Avg = 32.93
Min = 32.43
Max = 35.92
Avg = 35.28
Min = 34.73
Max = 34.37
Avg = 33.62
Min = 32.96



3 Sets
6 Sets
Superficial Skin Temperature (ºC)
Arm
Control
Exercise
36.00
35.00
34.00
33.00
32.00
31.00
30.00
29.00
28.00
27.00
26.00
25.00
24.00
Pre
Post
24h
48h
72h
± 1.08
± 1.06
± 1.11
± 0.88
± 1.34
± 1.44
± 1.80
± 1.70
± 1.35
± 1.70
± 1.37
± 1.43
± 0.77
± 1.41
± 1.81
± 2.07
± 1.31
± 1.31
± 1.67
± 1.59



Superficial Skin Temperature (ºC)
Central ROI
37,00
36,00
35,00
34,00
33,00
32,00
31,00
30,00
29,00
28,00
27,00
26,00
25,00
24,00
Pre
Post
24h
48h
72h
Set
3
6
± 1.17
± 1.47
± 1.17
± 1.05
± 1.67
± 1.22
± 1.23
± 1.60
± 1.24
± 1.84
*
*

Variable	Mean ± Standard Deviation
n	17
Age (years)	21,35 ± 0,70
Body Mass (kg)	74,85 ± 12,77
Height (cm)	175,82 ± 5,48
10 RM (kg)	11,29 ± 2,23
Biceps Skinfold (mm)	6,26 ± 4,03

Table 1. – Descriptive characteristics of the subjects.

	Sets	Pre	Immediatly Post	24h post	48h post	72h post
CA	**3**	34,27±1,08$	32,15±0,88	34,30±1,44$	34,13±1,70$	34,13±1,70$£
	6	33,16±1,43*$	31,67±0,77¢	33,92±2,07¢$	35,26±1,31*¢$£	35,15±1,59*¢$
EA	**3**	34,53±1,06	33,32±1,11**	34,42±1,34	34,32±1,80	33,22±1,35£
	6	33,35±1,37*	33,43±1,41**	33,94±1,81	35,60±1,31*¢$£	35,43±1,67*¢$
XP	**3**	35,31±1,17$	32,59±1,17	35,44±1,22$	35,35±1,60$	34,24±1,84
	6	34,27±1,47$*	32,14±1,05¢	35,65±1,67$	36,58±1,23¢$£*	36,59±1,24¢$*
T_{A-XP}CA	**3**	- 1,01±0,06$	-0,40±0,87	-1,05±0,68	-1,19±0,61$	-1,37±0,68$
	6	-1,12±0,93	-0,44±0,74	-1,73±0,82$*	-1,31±0,50$	-1,38±0,84$
T_{A-XP}EA	**3**	-0,79±0,70$	0,77±1,08**	-0,93±0,17$**	-1,19±0,61$	-1,02±0,86$
	6	-0,92±0,75$	1,36±0,88**	-1,71±0,90¢$*	-0,98±0,51£$	1,11±0,92$

Table 2 – Mean ± standard deviations of T_{sk} and T_{A-XP} in both CA and EA, for each number of sets (3 set or 6 sets). *p<0,05 between perform 3 or 6 sets; ** p<0,05 between CA and EA; $ p<0,05 in relation to the moment immediately post RT; £ p<0,05 in relation to the moment 24h post RT; ¢ p<0,05 in relation to the moment pre RT; ¥ p<0,05

Highlights

- Information about the skin temperature behavior during and after a resistance training protocol.
- Analysis of the skin temperature behavior during and after performing two different drop-set volumes.
- Evidence supporting the thermal image as a method for sports monitoring.