



Standardisation Procedure of Infra-red Imaging in Biomechanics

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Abstract. Purpose: The methods of thermal imaging in biomechanics and medicine are still not fully standardised, in contrary to other popular methods of muscle activity examination. This this makes it difficult to compare test results performed in different laboratories or even undermines credibility of some of the results.

Methods: The proposed standardisation procedure is based on the International Association of Certified Thermographers, American Academy of Thermology, European Association of Thermology, scientific publications and authors experience. The most restricted recommendations are chosen, described and discussed.

Results: The standardisation procedure of infra-red imaging in biomechanics is presented and discussed. Volunteer preparation, laboratory conditions, and tips how to make a thermal image are described. The state of the art is presented and chosen aspects of thermal imaging pointed out.

Conclusions: The presented method allows to create repeatable conditions and to minimise the influence of factors that can change the temperature readings. As a result, when using the proposed standardisation, higher repeatability and precision of measurements are obtained.

Keywords: Thermal imaging · Biomechanics · Musculo-skeletal

1 Introduction

Modern thermography is a relatively young science and it can be stated, that it starts in the early 30s of the 20th century, despite the infra-red radiation is a much earlier discovery. During the last 100 years, the thermal imaging technique gains in popularity and is often used for many purposes like security, control of electrical systems, buildings insulations, finding wet/humid areas. Nevertheless, its most prominent use should be identified with medicine and biomechanics. Detecting symptoms of diseases, vascular problems, or even scanning for cancer is one of the most common use. In biomechanics scanning muscle systems for its activity, overloading, faulty posture or musculoskeletal injury is just one of the most common applications [1, 2]. Definitely, this technique is getting more and more popular in the field of biomechanics; one can find plenty of research on this topic. According to Google Scholar, there is about 18,000 answers for the question “thermal imaging muscle system”.

The biggest advantage of infra-red is that it is a non-contact technique. Unfortunately, when speaking about a musculoskeletal system (human or animal), researchers can expect many variables that can influence the experiment results. When analysing State of the Art of thermal imaging regarding humans, one can find some propositions of standardization procedures. International Association of Certified Thermographers, American Academy of Thermology, European Association of Thermology, and papers [3, 4] are just examples of them. Nevertheless, it is worth to notice, that in recently published and analysed papers (see for example [3–5, 11, 12] authors are using different methods of volunteer preparation and providing conditions in laboratories, which sometimes even they are changing during an experiment. This generates a question if the published results are repeatable or even reliable. According to the author's knowledge, the most advanced (and restricted) procedure is presented in [4], nevertheless, it can be improved and supplemented with new findings.

The aim of this paper is to present a method of infra-red experiments standardization in biomechanics. Method of volunteer and laboratory facility preparation along with guidelines for making thermal images are presented and described.

2 Standardisation Procedure of Thermal Imaging

The main points of the standardisation procedure are based on the International Association of Certified Thermographers, American Academy of Thermology, European Association of Thermology, and papers [4–6]. The most restricted advices are chosen and supplemented with recommendations created based on the author own experience.

2.1 Volunteer Preparation

The most important element of the standardization procedure is the correct preparation of the volunteer. The main recommendations are pointed out in Table 1. Listed recommendations should help to minimize the influence of external factors or the behaviour of the volunteer on the skin temperature prior to the experiment. The most important ones are connected with the actions which effects persist for a long time, especially like sunburns or muscle recovery after an extensive workout. Some of the recommendations, like not to use any lotions, creams, detergents, or similar minimum 3 days before the experiment should help to stabilize emissivity for body areas on the same level [7]. If the thermal image is to be done on a hairy area, hair should be removed three days before, preferably by shortening them at skin level, but not shaving, which can cause local inflammation. About one day before the experiment, the volunteer should stop consuming alcohol and should start to avoid greasy meals or other meals, spices, and substances that lead to greater thermogenesis (ex. spices with capsaicin, black pepper, ginger, mixed spices, and drinks like green or black tea and caffeine) [8]. Tight garment parts can restrict blood flow [13] and as a result change body segment temperature, what is the reason why they should be avoided before thermal imaging experiments.

Additionally, volunteer's skin should be free from any inflammations, wounds, cuts, and other types of skin damage. Some tattoos can modify temperature readings, which makes it necessary for screening tattooed areas for unexpected, local differences in

temperature [14]. Core temperature should not exceed 37 °C. It is recommended to have an interview regarding all volunteer injuries. Some of them, even considered as insignificant can have long-lasting (even life-lasting) effect, however, finding volunteer without any injury-history can be a real challenge, thus the researchers should be aware of a possible influence of the injury and faulty posture history on the thermal imaging.

Table 1. Main recommendation of the volunteer preparation.

Time before experiment (minimum)	Action
5 days	Do not sunbath, do not use sauna or cryochamber Stop using detergents when taking shower Avoid hot or cold baths
3 days (72 h)	Do not use: Creams, lotions, powders, perfumes, deodorants, antiperspirants and other similar substances Avoid: Physical exercise, intensive physical activity, massage, electrical muscles/nerves stimulation, ultrasound examination, acupuncture, use of warm or cold compresses etc Remove hair from the study area
1 day (24 h)	Do not consume alcohol, Avoid greasy, spicy meals and or other substances that can improve thermogenesis Do not use tight clothing items
12 h	Last bath: a short shower in lukewarm water without detergents
4 h	Avoid physical exertion (quick gait, run, stairs climbing to higher floors, exercises) Do not consume drinks with caffeine (including strong tea), hot or cold drinks Last meal, avoid high caloric one
2 h	Do not eat, but avoid experiment on empty stomach

2.2 Laboratory Conditions

Not only the volunteer has to be prepared for the experiment. Very important is to correctly prepare the laboratory facility. The key actions are presented in Table 2. At first, the temperature and real humidity should be stabilised. It is advised to keep the room temperature in the range 21 °C–24 °C [9] and to allow the volunteer to choose his/her preferred temperature during the experiment in this range to ensure a proper thermal comfort level. The temperature should not change during the experiment. Temperature below 18 °C can cause shivering, above 24 °C – extensive sweating. Highly efficient heat sources, ACs, fans, humidifiers, or air dryers may be used, but they should be removed or

turned off during the experiment. Especially IR radiators, like heaters should be removed or covered. On the day of the experiment, the advection and convection in the laboratory should be minimised to avoid cooling air movement. It is also advised to use window blinds, the best is with IR-mirrors. If it is possible, the best placement for the laboratory, where this type of experiment is performed is a northern site of the building or room without windows.

Table 2. Main recommendations for the laboratory preparation.

Time before experiment (minimum)	Action
2 days (48 h)	Stabilise: Temperature in range 21 °C–24 °C Real humidity in range 40–55%
1 day (24 h)	Remove all IR raditors (if their temperature is higher than 10 °C than temperature in the laboratory) Cover unmovable IR radiators, especially working heaters
In a day of experiment	Reduce to the possible minimum: Convection Advection Use window blinds in the lab to reduce the external IR radiation Do not use ventilators, AC or similar equipment which can change the temperature or RH rapidly or causes an intensive air movement

2.3 Making the Thermal Image

Last but not least is to make a proper thermal image. Main recommendations are presented in Table 3. After the volunteer arrives at the laboratory an adaptation period should be performed. Volunteers stay in a garment in which thermal image will be done. No additional covers of the skin or body parts are allowed. The volunteer should not touch or leaning anything that can change his/her skin/body temperature. The position should be natural and symmetrical. No muscle part should be overload ex. by standing or sitting in an inconvenient or asymmetrical position. A slow gait is allowed.

The minimal time of adaptation is 15 min and it can be calculated according to the equation:

$$\tau_{min}[\text{min}] = 15 + (|T_{ext} - T_{int}|)$$

where: τ_{min} is minimal time of adaptation in minutes, T_{ext} and T_{int} – external (outside laboratory) and internal (in the laboratory) temperature in Celsius/Kelvin degree respectively. For the Fahrenheit scale, this rule should be adequately modified. The camera should be placed on stable support at a constant and repeatable distance from the volunteer. Its optical axis should be placed with respect to the normal of the object surface

(ex. torso) due to the Lambertian nature of IR radiation [9]. The emissivity should be chosen for proper skin pigmentation. The average and accepted values in the literature are in range 0.97–0.98 [10].

It is also advised to choose a neutral background, for example, a wall with uniform temperature. Moreover, a gold standard should be to check and store all necessary data like temperature and humidity in the laboratory, date, and time of the experiment. A good practice should be to check the body fat of the volunteer (amount and distribution) and to make basic anthropometric measurements. Taking photos in S and F plane should facilitate the analysis. A questionnaire about performed sports/activities should also help to analyse and understand results.

Table 3. Main recommendations for making thermal image.

Action	Advise
Thermal camera placement	Use a tripod Make thermal image with use of a uniform background
Volunteer placement in a front of camera	Keep constant distance from the volunteer for all captured thermal images Place camera optical axis with respect to the normal of the object surface Choose a proper duration of thermal adaptation
Setting the emissivity	Constant for all recordings at the level of 0.97–0.98

2.4 Control List

It is advised to create a control list. It should help to understand all problems found during the analysis of thermal images and to distinguish between technical problems/errors in procedure and natural phenomena. An example of this type of control list, created on the basis of control list (translated and rearranged) used in the laboratory of Biomechanics Lodz University of Technology is presented in Supplementary Materials. It includes the most important questions about volunteer activity, faulty posture, photography in anatomical position (Table S1) and checklist (Table S2).

3 Conclusions

Standardisation of examination procedures is crucial for obtaining reliable and repeatable results. For some of the techniques, conditions are restricted. For example, when sEMG is made not according to the SENIAM regulations this makes results unpublishable. The variety of methods, equipment, conditions in the laboratory, and procedures in different research centres makes published results of thermal analysis often incomparable and even questionable. Such a standard procedure in this field is mandatory. Presented procedure should help to obtain a repeatable conditions of thermal imaging experiments and to obtain more reliable results. Main recommendations are presented in Tables 1–3.

Supplementary Materials

Example of the checklist and questionnaire

Date: _____

№ of volunteer (code): _____

Name/surname: (if the code system is not used)
: _____

Hour: arrival of the volunteer: _____ /departure: _____

Temperatures:

in the lab.: beginning of experiment _____, end of experiment _____

external: _____

Humidity in the lab.:
beginning of experiment _____, end of experiment _____

Time of adaptation: _____ min.

Camera model used during experiment: _____

Emissivity: _____

Anthropometry:

Sex: _____, Age: _____, Height: _____ cm, Mass: _____ kg,

Body fat: _____ %

Other notes: _____

Table S1. Photography in anatomical position.

F plane, front of the body	F plane, back of the body	S plane, left site of the body	S plane, right site of the body

Sports and activities performed by volunteer:

Is any of the activity asymmetrical? YES / NO

Faulty postures:

Is leg length equal? YES / NO if no, then the L / R leg is longer by
 _____ cm.

Table S2: Preparation.

Time before experiment (minimum)	Action	Fulfilled Yes / No	Notes: Ex. antiperspirant was used
5 days	Do not sunbath, do not use sauna or cryochamber Stop using detergents when taking shower Avoid hot or cold baths	Yes / No Yes / No Yes / No	
3 days (72h)	Do not use: creams, lotions, powders, perfumes, deodorants, antiperspirants and other similar substances Avoid: physical exercise, intensive physical activity, massage, electrical muscles / nerves stimulation, ultrasound examination, acupuncture, use of warm or cold compresses, etc. Remove hair from the study area	Yes / No Yes / No Yes / No	
1 day (24h)	Do not consume alcohol, Avoid greasy, spicy meals and or other substances that can improve thermogenesis Do not use tight clothing items	Yes / No Yes / No Yes / No	
12h	Last bath: a short shower in lukewarm water without detergents	Yes / No	
4h	Avoid physical exertion (quick gait, run, stairs climbing to higher floors, exercises) Do not consume drinks with caffeine (including strong tea), hot or cold drinks Last meal, avoid high caloric one	Yes / No Yes / No Yes / No	
2h	Do not eat, but avoid experiment on empty stomach	Yes / No	

Other notes: _____

Examiner: _____

References

1. Somboonkaew, A., et al.: Mobile-platform for automatic fever screening system based on infrared forehead temperature. In: Proc. Opto-Electron. Commun. Conf. (OECC) Photon. Global Conf. (PGC), pp. 1–4 (2017)
2. Vollmer, M., Möllmann, K.-P.: *Infrared Thermal Imaging: Fundamentals, Research and Applications*, 2nd edn. Wiley, USA (2017)
3. Bauer, J., Dereń, E.: Standardization of thermographic studies in medicine and physical therapy. *Acta Bio-Optica Inform. Med. Biomed. Eng.* **20**(1), 10–12 (2014). in Polish
4. Moreira, D.G., et al.: Thermographic imaging in sports and exercise medicine: a Delphi study and consensus statement on the measurement of human skin temperature. *J. Thermal Biol.* **69**, 155–162 (2017)
5. Coletta, N.A., et al.: Core and skin temperature influences on the surface electromyographic responses to an isometric force and position task. *PLoS ONE* **13**(3), e0195219 (2018)
6. Chudecka, M., Lubkowska, A.: Temperature changes of selected body's surfaces of handball players in the course of training estimated by thermovision, and the study of the impact of physiological and morphological factors on the skin temperature. *J. Thermal Biol.* **35**(8), 379–385 (2010)
7. Steketee, J.: The influence of cosmetics and ointments on the spectral emissivity of skin (skin temperature measurement). *Phys. Med. Biol.* **21**, 9–20 (1976)
8. Westerterp-Plantenga, M., et al.: Metabolic effects of spices, teas, and caffeine. *Physiol. Behav.* **89**(1), 85–91 (2006)
9. Priego Quesada, J.I., et al.: Effects of graduated compression stockings on skin temperature after running. *J. Thermal Biol.* **52**, 130–136 (2015)
10. Jones, B.F., Plassmann, P.: Digital infrared thermal imaging of human skin. *IEEE Eng. Med. Biol. Mag.* **21**, 41–48 (2002)
11. Zagrodny, B., et al.: Could thermal imaging supplement surface electromyography measurements for skeletal muscles? *IEEE Trans. Instrum. Meas.* **70**, 1–10 (2021)
12. Kuniszyk-Józkowiak, W., Jaszczuk, J., Czaplicki, A.: Changes in electromyographic signals and skin temperature during standardised effort in volleyball players. *Acta Bioeng. Biomech.* **20**(4), 115–122 (2018)
13. Xiong, Y., Tao, X.: Compression garments for medical therapy and sports. *Polymers* **10**, 663–668 (2018)
14. Zagrodny, B., Kaczorowski, Łukasz, Awrejcewicz, J.: Influence of Body Tattoo on Thermal Image—A Case Report. In: Gzik, M., Paszenda, Z., Pietka, E., Tkacz, E., Milewski, K. (eds.) *AAB 2020. AISC*, vol. 1223, pp. 209–214. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-52180-6_23