McCafferty, D. J., Koprowski, R., Herborn, K., Tattersall, G. J., Jerem, P. and Nord, A. (2021) Editorial: Advances in thermal imaging. *Journal of Thermal Biology*, 102, 103109. (doi: 10.1016/j.jtherbio.2021.103109)

Editorial: Advances in Thermal Imaging

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https://www.sciencedirect.com/journal/journal-of-thermal-biology/special-issue/10X97TFPQBJ

Thermal imaging, or more correctly infrared thermography, has been widely applied to studies of animal and human biology (see Burnay, Williams, and Jones 1988; McCafferty 2007; Soerensen and Pedersen 2015; Fernández-Cuevas et al. 2015; Tattersall 2016). This technique provides non-contact measurement of surface temperature, allowing real-time recording of the spatial temperature distribution of a body region, physical structure or habitat of interest. Thermal imaging technology has advanced rapidly in the last decade and is now becoming a key tool in thermal biology. Technological advances include greater spatial and temporal resolution, increased capacity to record and store high resolution radiometric video, as well as reduced device size and portability. In addition, high-quality thermal imaging devices are quickly becoming more affordable, meaning thermal imaging is an increasingly common item of the research tool-kit in many pure and applied fields. The aim of this Special Issue was to highlight how advances in thermal imaging can be used to answer important questions in biology, and to demonstrate how the combination of this technology with novel analytical methods can further advance our conceptual understanding of thermal biology.

Papers in this Special Issue showcase how thermal imaging provides opportunities of examining anatomical, physiological and behavioural adaptations to hot and cold environments in captive and wild animals (Schneider, Ziegler, and Kolter 2020; Barroso et al. 2020; Ferretti et al. 2020; Stone et al. 2021; Rogalla et al. 2021; Szafrańska et al. 2020). One of the challenges of thermal imaging is determining exactly what surface temperature represents and which regions of interest to select. Barroso et al. (2020) demonstrate that eye temperature in ectotherms is strongly correlated with core temperature, so non-contact thermal imaging may avoid some of the difficulties of measurement of core temperature. Rogalla et al. (2021) show well that analysis of surface temperature patterns may be aided by including micro-computed tomography (μ-CT) to reveal underlying vasculature. Moreover, in such comparisons Szafrańska et al. (2020) clearly demonstrate the value of simultaneous internal temperature measurement and time series data collection for understanding thermoregulatory costs and processes of acclimation. Thermal imaging can also reveal how well insulated some endotherms are, including how behaviour alters insulation (Ferretti et al. 2020) and how insulation develops with age (Stone et al. 2021). Even so, careful interpretation of surface temperature patterns across a range of environmental temperatures may allow estimation of an organism's thermoneutral zone (Schneider, Ziegler, and Kolter 2020). When combined with biophysical modelling, thermal imaging also provides a powerful method of estimating metabolic heat exchange that would otherwise require more invasive approaches. Thermal imaging is therefore a valuable tool for wildlife biologists to define thermal characteristics of habitats (Fuller et al. 2021), and to answer important questions related to how well animals will cope with climate change or conditions in captivity (Schneider, Ziegler, and Kolter 2020).

Thermography has long been a diagnostic tool in veterinary medicine and animal husbandry. In this Special Issue, Casas-Alvarado et al. (2020) review how thermography can be used to detect haemodynamic changes in vascular tissues for the assessment of pain and in response to drug administration in non-human animals. Other important diagnostic applications are in the use of surface temperature measurement for the detection of estrus (Vicentini et al. 2020), for monitoring differences in body temperature in cattle as a function of pelage colouration (Isola et al. 2020) and to predict the growth performance of pigs (Cook et al. 2020).

Thermal imaging is also becoming increasingly important in the field of exercise physiology (see recent outside review by Hillen et al. 2020). Papers in this Special Issue highlight this emerging interest, for example, how running may influence foot and limb temperature (Gil-Calvo et al. 2020; Machado et al. 2021; Jimenez-Perez et al. 2020; Requena-Bueno et al. 2020), ways in which pre-exercise skin temperature may influence swimming performance (Jimenez-Perez et al. 2021) and how thermography can be used for monitoring strength asymmetry with the potential to prevent muscle injuries (Rodrigues Júnior et al. 2021) . For such applications, a key development in thermal imaging technology has been the manufacture of relatively low cost, small, hand-held portable devices. These are now being increasingly used in a range of settings but typically require evaluation and proper calibration. Machado et al. (2021) were able to compare several of these devices with higher specification models and importantly showed there were differences in both recorded temperatures and effort required to process data. This demonstrates the importance of cross validation and caution when using multiple types of devices, as well as proper calibration when accurate absolute temperature measurement is required. Similar evaluation of image analysis software is required. For example, Requena-Bueno et al. (2020) highlight the need to evaluate thermographic software packages, in terms of accuracy, time saving and ease of use for analysis.

Although analysis of thermal images can be undertaken using a range of proprietary software, advances in thermal imaging technology also require new methods of image processing that are tailored to specific applications. Many such methods are seen in the field of human medicine. Jędzierowska et al. (2021) show how more rapid processing of thermograms may be successfully undertaken using MATLAB® with the Image Processing Toolbox. Likewise, thermal camera software use pseudocoloring algorithms to provide superficial contrast between radiation emitted from various sources. However, these may not be sufficient for detecting and differentiating high radiated regions from surrounding areas - necessary for recognising abnormalities such as tumors. Here, Alpar (2020) report new methods to tackle this situation using Nakagami imaging with related distributions for advanced thermogram pseudocolorization. Tattersall et al. (2020) developed a Difference Imaging Thermography (DIT) tool using a frame subtraction algorithm to extract the pixel-by-pixel relative change in thermal video signal and were therefore able to assign activity scores to thermal imaging data for comparison with measurement of metabolic rates. Finally, Pham Xuan et al. (2021) show how pre-processing techniques can magnify features and subsequently improve the tracking in thermal imagery of human faces. This potential to detect and automate measurement of regions of interest illustrates how advances in thermal imaging, from conceptual understanding of physiology to diagnostic application, will be increasingly cross-disciplinary.

What is the future of thermal imaging? It is likely that we will continue to see increased development of thermal imaging hardware, allowing enhanced measurement resolution and further reduction in size and perhaps at a relatively lower cost. The use of thermal imaging from aircraft or by unmanned aerial vehicles (UAVs) combined with machine learning and computer vision methods is now developing rapidly, mainly for animal detection and population census (see: Corcoran, Denman, and Hamilton 2021;Gonzalez et al. 2016; Santangeli et al. 2020) but these approaches could be extended for real-time recording of physiological changes in free-ranging animals. Software development, particularly automation of measurement and image processing are likely to be the greatest challenges for thermal biologists across all fields. However, both hold great promise for multi-disciplinary research in thermal biology and therefore should be a focus for future research and development.

Acknowledgements

This Special Issue was inspired by the SEB2019 Symposium: Heat exchange with the environment: mechanisms and insights into animal energetics www.sebiology.org/events/event/seb-seville-2019/programme/animal-biology#heat

We thank the Society for Experimental Biology, Journal of Thermal Biology, Institute of Biodiversity, Animal Health and Comparative Medicine (University of Glasgow) for generously funding the Symposium. We are indebted to the Editorial Board of the Journal of Thermal Biology and to the many individuals who provided peer-review for this issue. Authors acknowledge funding: KH: Royal Society Research Grant (RGS\R1\191239); AN: The Birgit and Hellmuth Hertz Foundation / The Royal Physiographic Society of Lund (2017-39034) and Swedish Research Council (VR) (2020-04686); GJT Natural Sciences and Engineering Council of Canada Discovery Grant (RGPIN-2020-05089).

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