OCCUPATIONAL HEAT STRESS

Historic developments and future challenges in applied thermal physiology

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Introduction

Research in applied thermal physiology has changed over the years in methodology, topics under investigation, customers and locations where research took place. It is the purpose of this paper to examine historic developments and future challenges to maintain relevance and leadership in the area of thermal physiology.

History

While temperature has been a primary driving force throughout human evolution, thermal physiology as a distinct scientific discipline was largely initiated during WWII. Famous researchers in this initial period include Yas Kuno in Japan and Edward Adolph in the U.S.A. (see http://www.feverlab.net/pages/people/History.html for more information). Also, the JB Pierce lab of NASA played an important role, in particular in thermal modelling.

Thermal physiology had four major application areas at the end of the last century: 1) military performance, in particular related to clothing and equipment research, 2) sports and occupational physiology, 3) indoor climate and 4) clinical applications. USARIEM was a leader in the first application area (e.g. Ralph Goldman), Scandinavia in the second one, Povl Ole Fanger for the third and Daniel Sessler was an example for the latter area.

At the end of the last century, thermal research labs were often linked to military research, e.g. USARIEM (U.S.A.), DRDC Toronto (Canada), TNO (Netherlands), DSTO (Australia), Qinetiq and INM (UK). The recent changes in operation, budget cuts in military funding and the switching focus towards mental (e.g. post-traumatic stress disorder) instead of physical performance reduced the budgets and staffing for thermal physiology research. Most military institutes are allowed to perform research for external customers, bringing the challenge to identify new potential markets. It seems that university-based thermal research is increasing, but funding through national scientific agencies and industrial contracts remains a consistent challenge. Therefore, re-analysing the market is important to maintain high-quality thermal physiology research.

The movement away from military-relevant research to other markets is also visible when analysing publication statistics. Figure 1 shows the number of scientific papers, derived from Scopus, over the period 1960 -1980, 1981 - 2000 and 2001 - 2012 for keywords 'human', 'temperature' and 'physiology' with the additional subcategory keywords of 'military', 'sport', or 'clinical'. Importantly, research in the ‘military’ subcategory has remained largely stable in absolute number throughout the years, despite the general, large proliferation of publication drive in all fields. In contrast, both ‘sport’ and especially ‘clinical’ research in human thermal physiology have shown tremendous growth through the years. Sport applications may have shown an increase as a compensation for the drop in occupational applications as work conditions improved

in the industry.

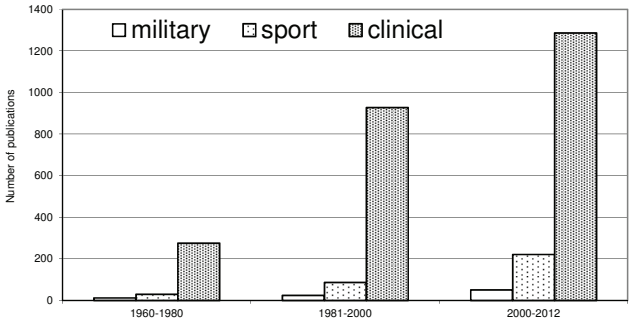

Figure 1. Number of publications with keywords 'human', 'temperature' and 'physiology' with added keyword subcategories 'military', 'sport', and 'clinical'. Total publications for military, sport and clinical subcategories are 87, 337 and 2490, respectively.

Conferences

The shift in focus can also be deduced from the organisational and content changes of conferences where thermal physiologists meet.

One of the first conferences on thermal physiology was the Thermal Physiology Symposium, with the inaugural meeting organised by James Hardy in New Haven (U.S.A.) in 1968. This was the legendary meeting known for the famous book, “Physiological and Behavioral Temperature Regulation”. Since then, the Thermal Physiology Symposium was held as a satellite meeting of the IUPS main congress.

Another conference series was the Symposium on the Pharmacology of Thermoregulation, first organised by Ed Schönbaum and Peter Lomax in San Francisco (U.S.A.) in 1972. This series of meetings arose from the increasing recognition of the strong relationship between pharmacology and thermoregulation. This symposium continued every three years, independently of the Thermal Physiology Symposium, with the last conference from this series being held in 1999 (Seville, Spain). It was decided to merge the two conferences at the Pharmacology meeting in 1999. The integrated conference would use the name: Physiology and Pharmacology of Temperature Regulation (PPTR).

A third conference series is the International Conference of Environmental Ergonomics (ICEE). After a small interest group meeting in the UK, the first conference was organised by Igor Mekjavic and colleagues in 1986 in Whistler (Canada). The 15th meeting is currently in Queenstown (New Zealand). This conference focuses on applied thermal physiology.

After the 2001 Thermal Physiology Symposium, and due also to the overlapping interests with scientists attending ICEE, it was decided to more closely align these independent conferences. Accordingly, the PPTR and ICEE conferences are generally held on alternating years: 2011 (ICEE:

Greece), 2012 (PPTR: Brazil), 2013 (ICEE: New Zealand), 2014 (PPTR: South Africa), 2015 (ICEE: UK), 2016 (PPTR: Slovenia).

Thermal physiology also is becoming an increasingly important topic in the sports conferences: American College of Sports Medicine (ACSM) and European Conference of Sports Science (ECSS).

In summary, the first conferences started in the seventies and eighties of the last century with integration and coordination of the conferences in the decades thereafter. In the current field thermal physiology is becoming increasingly important in sports applications (ACSM and ECSS), while it is relatively constant for military, clinical, pharmacological applications (PPTR and ICEE).

The market for Thermal Physiology

For the military, important topics are the optimal garments for operational performance in thermal extremes: how can protection be matched with comfort and performance? Although protective clothing and equipment has improved, the issue is still there, and thermal management techniques still have much room for improvement.

Thermal physiology should integrate better with thermal psychology. Thermal behaviour is essential to survive in thermal extremes considering the limited human physiological capabilities. Yet, thermal behaviour is hardly investigated. There is a market for knowledge on thermal behaviour in the military domain, with expeditionary missions, but particularly in health research.

Thermal modelling has a long tradition, and the work of Jan Stolwijk and Eugene Wissler was setting new standards. However, thermal modelling has hardly been applied outside areas of military clothing and has a high potential in sports research, forensics (e.g. to estimate post-mortal times) and in particular as a partial model for operational performance. Thermal models should be linked to models on human behaviour to make the next step. Typically, modelling dismounted soldier operations involves thermal submodels (e.g., IWars, SCOPE, CAEN).

Global warming and urban heat island effects have changed and will change our environments drastically with concomitant changes in productivity, morbidity and mortality. These effects need to be estimated and cost/benefit analysis should be performed for potential safety measures in order to support the decision makers.

Elderly over 80 years old are the most vulnerable subjects in extreme heat and cold. Yet, their ability to regulate their thermal state is hardly investigated. Generally, they live in a homogeneous climate in elderly homes, but a question may be if a more challenging environment will improve their resilience.

The costs of energy are rapidly increasing and we have to think how we as thermal physiologists can contribute to energy savings. Can we achieve the same level of thermal comfort when only the subject is heated in an office and not the entire environment? Does it help when we heat the keyboard to have sufficient manual dexterity in typing? Those kind or questions are important to address and can only be addressed with the involvement of thermal physiologists.

Research methods

Miniaturisation of sensor technology and wireless communication systems have improved the possibility for measuring humans and other mammals in natural environments. Field labs offer the opportunity to investigate soldiers, first responders and employees during their actual work, with high ecological validity. For example, clothing can be the future platform of integrated sensors, measuring large amounts of physiological data. With these advances in the quality and quantity of information, data mining techniques become increasingly important to process the datasets to get answers to questions.

Some topics that were difficult to address in previous times due to methodological limitations may be clarified in the near future using better techniques. New imaging techniques are promising so that real-time 3D thermal imaging may take place and this may improve our knowledge on body thermal status during rest and exercise and the presence of selective brain cooling (SBC) in humans.

Imaging techniques like PET scans and near infrared spectroscopy may elucidate the close connections between the thermoregulation centre and other centres in our brain and thus learn us more about the interaction between thermal regulation and sleep, behaviour and pain.

Traditional methods in thermal research are not taking molecular and genetic aspects into account. More research should be dedicated to heat and cold shock proteins in order to assess their impact on function in the heat and cold.

Conclusions

Applied thermal physiologists face a number of major changes in our quest to both maintain scientific relevance and innovate our research capacity. The collapse of heavy reliance on military funding requires a diverse approach to obtaining research support. While a daunting challenge, we should embrace this opportunity to create new fields of research, through applying and integrating our thermal expertise with other human factors fields, applying new methodologies. The predicted climatic changes will affect the lives of our descendants and thermal physiologists can contribute to the understanding of optimal adaptation to the challenges that we will have to face.