Institution: Coventry University		
Unit of Assessment: 24		
Title of case study: Using Occupational Physiological Research for Commercial Innovation, Protection and Sustainability in Extreme and Changeable Environments		
Period when the underpinning research was undertaken: 2006 to 2019		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Charles Douglas Thake	Associate Professor	1998-Present
Period when the claimed impact occurred: August 2013 – December 2020		
Is this case study continued from a case study submitted in 2014? Y/N No		

1. Summary of the impact (indicative maximum 100 words)

From those working in explosives ordnance disposal (EOD) suits, to those simply driving their cars, thermal and physical comfort influence the performance of the operator, as well as their health and safety. To minimise discomfort and enable optimal performance in severe and changeable environments, Thake developed rigorous testing protocols based on thermoregulation work in sport and exercise science, concerning occupational physiology. These have enabled manufacturers to put usability at the heart of product development.

Research has informed twin impact areas:

- Improved development and usability of personal protective equipment (PPE) at specialist body armour companies for EOD technicians working in challenging environments.

- Better design and testing of automotive products at Jaguar Land Rover to optimise comfort, usability, and energy efficiency.

2. Underpinning research (indicative maximum 500 words)

Since 2006, Dr. Doug Thake at Coventry University has investigated human function, tolerance and performance in extreme and changeable environments, using techniques from thermoregulatory exercise physiology. This has delivered world-leading applied knowledge of physiological and perceptual strain including thermal sensation and comfort.

Explosives Ordnance Disposal (EOD) Suits

NP Aerospace approached Thake in 2006 to measure carbon dioxide build-up in EOD suit helmets during physical activity against occupational exposure limits. Different helmet airflow rates were assessed against representative task-specific workloads (R1). In response to the client's need to understand the thermal burden experienced by technicians wearing EOD suits (primarily due to suit mass >35kg and encapsulating impermeable nature), Thake conducted a series of investigations between 2006 and 2013 to characterise and mitigate heat exposure (R2, 3, 4) and reviewed this work for NP Aerospace in 2014.

Prior to Thake's work, equipment development focused on increased protection, rather than operative well-being and performance. Thake's research drew on industry partner knowledge and British Army EOD technician feedback, to develop a rigorous laboratory-based protocol

representative of the physical tasks performed during operational activity (2006-7, R2). This protocol formed the basis for subsequent EOD studies, conducted at both 20◦C (temperate) and 40◦C (hot) to reflect prevailing temperatures where EOD personnel were deployed to operate (e.g. Afghanistan). The research informed operational scenario's through characterising the time course of thermal physiological, perceptual, cognitive responses and manual dexterity when wearing EOD suits, examining the impact of suit type, heat acclimation and different cooling systems (convective and conductive) and strategies (R2, 3, 4). Since 2019, Thake has collaborated with United Shield International (R4) to investigate the cooling capacity of a liquid cooling suit with and without head circulation worn when under the Olympia EOD suit.

Automotive - Car Cabin Environments

Thake's applied research expertise in protocol design and experience of measuring thermal sensation and comfort, led to work with JLR. The approach was to develop understanding of the capability of engineered products and systems to impact user comfort (physical and mental) and influence subsequent product design. Thake (2013-2015) designed and led road-based and laboratory studies to examine seated posture and physical and thermal comfort as part of the JLR PLACES project. Data included real-time seat pressure distribution maps, body part discomfort and seat comfort survey data alongside participant anthropometrics together for the first time (n=24), repeated over an extended mixed environmental drive providing a novel temporal-based data set. Thake captured seat thermal outputs and associated perceptions at the occupant-seat interface in associated thermal evaluation chamber-based studies (R5).

Thake designed and led the concurrent STRIVE project (2013-2015), which used a purpose-built driving simulator to characterise and evaluate the capacity of a specific high-end seat type to affect thermal perception in participants. In STRIVE 2 (2014-2015), Thake explored the potential of infrared radiant heating as an adjunct to deliver thermal comfort to car occupants (R5). From 2017 to 2019, Thake worked with a senior JLR engineer researching motion sickness in autonomous vehicles to advance the testing methodology and study design (R6).

3. References to the research (indicative maximum of six references)

R1. Kemp J, Gaura E, Brusey J, Thake C.D. (2011) 'Embedded sensing and actuation for helmets CO2 levels control', International Journal on Smart Sensing and Intelligent Systems 4(1):160–185. http://dx.doi.org/10.21307/ijssis-2017-432

R2. Thake C. D., Price M. (2007). 'Reducing uncompensable heat stress in a bomb disposal suit: A laboratory based assessment'. In Environmental Ergonomics XII: Proceedings of the 12th International Conference on Environmental Ergonomics, ICEE 2007, Piran, Slovenia [August 19-24, 2007],pp. 229 – 232. Edited by Mekjavic I., Kounalakis S., Taylor N., 2007. ISBN 978-961-90545-1-2.

R3. Thake C. D., Zurawlew M., Price M., Oldroyd M. (2009). 'A thermal physiological comparison between two Explosives Ordnance Disposal suits during work related activities in moderate and hot conditions'. In Environmental Ergonomics XIII: Proceedings of the 13th International Conference on Environmental Ergonomics, Boston, Massachusetts, USA [August 2nd – 7th, 2009], pp. 516 – 520. Edited by Castellani J., Endrusick, T. ISBN: 978-1-74128-178-1 (CD ROM), ISBN: 978-1-741-179-1 (on-line).

R4. Davey, S. L, Lee, B.J., Smith, M., Oldroyd, M. and Thake, C. D. (2020). 'Optimizing the use of phase change material vests worn during explosives ordnance disposal operations in hot conditions'. Frontiers in Physiology 11:573521. https://doi.org/10.3389/fphys.2020.573521

R5. STRIVE Technical Report (2015). i. Air vs. surface heating project: The influence of seat heating and cooling level on thermal perception and thermal physiological response in preconditioned hypothermic and hyperthermic car seat occupants (Thake D, Owen, R and Collins D). ii. Infrared heating project: Evaluation of infrared heating as an adjunct to achieve car

seat occupant thermal comfort (Thake D and Collins D). Approved Jaguar Land Rover Technical Report.

R6. Salter, S., Diels, C., Herriotts, P., Kanarachos, S. & Thake, D. (2020). 'Model to predict motion sickness within autonomous vehicles'. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 234: 5, pp. 1330-345. https://doi.org/10.1177/0954407019879785

4. Details of the impact (indicative maximum 750 words)

Thake's research in occupational and exercise physiology has examined thermal and physical comfort, providing data and rigorous human factor testing protocols that continue to inform product design and testing across two industries (S1-S5). The research has resulted in a fundamental paradigm shift in the way problems are approached in the development of products, with an evidence based approach to human testing now embedded (S1, S2, S4, S5).

Since 2014 this work has driven commercial innovation, protection and sustainability in extreme and changeable environments, based on a legacy of collaborative research with commercial application focused on improving EOD suit design, and car cabin environments for JLR.

Improving EOD Suit Design

Body armour specialists NP Aerospace and United Shield International have used Thake's research extensively. The Technical Engineering Manager of NP Aerospace (previously employed by United Shield) has noted that the innovative legacy of the work is of 'huge importance, given the burden that the EOD suits place on the user and the fact that those wearing them in hot conditions can only use them for 45mins to 1hr at a time' (S1). The application of the research has resulted in 'a practical methodology that can be applied in the laboratory in a scientific way to these [use of different EOD suits and systems in varied environments] comparisons and evaluations' (S1). Thake's methods 'save significant cost and time and has generated an understanding that would probably not otherwise exist' (S1).

Detailed knowledge of physiological effects on wearers of protective suits has enabled 'NP Aerospace [and United Shield International] to design and develop their products with a far better understanding of the effect the garment had on the thermal stress of the user' (S1). Thake's work has 'provided independently verifiable real world research data to show the effectiveness of the suits cooling performance' (S1) across a variety of models, cooling systems and environmental conditions with 'each new design and upgrade incorporating this understanding' (S1). This knowledge has proved valuable, as it has enabled the business to provide clients with usability recommendations including wear tolerance times for their specific products, and options to mitigate thermal strain and limit its potential impact on the user. This technical insight has offered a user-led approach, giving NP Aerospace and United Shield the edge over competitors who cannot provide this research-informed, bespoke evidence-based development (S1, S2).

The 2014 review Thake conducted of his legacy EOD work 'has had ongoing use since that time, testament to the continued relevance of the data' (S1). His work has 'significantly changed the knowledge and understanding of many managers, sales directors and developers on thermal strain'; this knowledge has driven a culture of product development focussed on the 'human factor' and usability within both NP Aerospace and since 2017 United Shield International (S1). Across these businesses, it continues to influence 'the design of the suits, the way they are marketed and user education and training' (S1, S2). This research on usability has international significance: a 2015 technical report on thermal and metabolic strain within EOD suits produced for the US Army Research Institute of Environmental Medicine is framed by six publications, two of which (including R3) were authored by Thake (S3).

Improving Car Cabin Environment

Thake's research 'has been used by JLR to provide key knowledge on thermal physiology, postural comfort, and thermal trials for product development' (S4). Broadly, it has changed 'how the company's approach to the 'human factor' could be improved', using 'far more rigorous and scientific testing methodologies and protocols' than were previously utilised (S5).

His work on the PLACES project (2013-2015) helped JLR to 'identify user needs with regards to short-term vehicle comfort', giving the company 'a new awareness of what the acceptable postures were for seating, as well as acceptable limitations on movement'. This 'changed the way… [JLR] approach thermal mass in design' (S4). Protocols for testing which Thake helped to develop 'have been embedded into JLR's processes' (S5), and associated data and methodologies are consistently utilised in both research and core engineering environments (S4, S5, S6), impacting on the development of new products. These include a Land Rover seat variant seat (S4); JLR Vector Pod (S7) autonomous vehicle (S4, S6); and a 'ground breaking new Morphable seat' (S8) aimed at tackling the discomfort or back pain associated with prolonged sitting (S4).

Thake's work on STRIVE (2013-2015) identified that thermal flux between seat and occupant is as important as the postural aspect to user comfort. This 'informed the use of heat flux in testing at JLR for the first time' (S5). This knowledge directed seat design, its control and integration with the HVAC (Heating, Ventilation and Air-Conditioning) systems at JLR (S4, S5, S6). His work on STRIVE 2 (2014-2015) provided JLR with an evidence base to support the incorporation of an infrared heat source within a vehicle's HVAC system. This was revisited in 2020 when it was presented to 'research development designers and senior managers', and further in-house investigations were subsequently conducted using Thake's methodologies, 'to show how the panels could be effectively integrated into vehicles' (S5, S6)

From 2017-2019 Thake added 'value to the study design and human factors aspects of [motion sickness] investigations' at JLR, which delivered a novel and validated assessment of motion sickness performance. This is now being integrated within driverless vehicles, with the ultimate objective of improving acceptance of future driverless vehicles (e.g. Vector Pod, S6, S7). Thake's research has 'fundamentally changed the way JLR research engineers evaluate the physical effects of vehicles on humans' (S6).

5. Sources to corroborate the impact (indicative maximum of 10 references)

S1: Testimonial, Technical Engineering Manager, United Shield International (formerly NP Aerospace).

S2: Testimonial, Lead Engineer EOD systems, NP Aerospace.

S3: Explosive Ordnance Disposal (EOD) Ensembles: Biophysical characteristics and predicted work times with and without chemical protection and active cooling systems. US Army Research Institute of Environmental Medicine technical report (no. T15-5; April 2015).

S4: Testimonial, Senior Engineer, Jaguar Land Rover.

S5: Testimonial, Senior Engineer, Jaguar Land Rover.

S6: Testimonial, Senior Manager/Technical Leader, Jaguar Land Rover.

S7: Press Release. Jaguar Land Rover Vector Pod. Hyperlink, JLR Vector Pod: https://www.youtube.com/watch?v=GDfAC_nqiiY [Accessed 31.12.20].

S8: Press Release. Jaguar Land Rover Morphable Seat. Hyperlink, Morphable seat: https://media.jaguarlandrover.com/news/2020/01/jaguar-land-rovers-new-shape-shifting-seat-future-makes-you-think-youre-walking [Accessed 31.12.20].