Institution: University of Portsmouth		
Unit of Assessment: UoA24: Sport and Exercise Sciences, Leisure and Tourism		
Title of case study: Athletes in extreme environments: changing policy and practice, improving safety and enhancing performance		
Period when the underpinning research was undertaken: 2007 - 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:**
Martin Barwood	Senior Lecturer	01/09/2007 - 31/07/2013
Jo Corbett	Associate Head (Research)	19/09/2005 - date
Joseph Costello	Senior Lecturer	05/01/2015 - date
Jim House	Reader in Environmental Physiology	01/05/2008 - 22/11/2018
Mitch Lomax	Senior Lecturer	01/10/2007 - date
Heather Massey	Senior Lecturer	01/10/2010 - date
Michael Tipton	Professor of Human Applied Physiology	01/04/1998 - date
Period when the claimed impact occurred: 01 August 2013 - 31 December 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Exercise in extreme environments (very cold or hot conditions) impairs performance and can endanger athlete health and safety. Research undertaken by the Extreme Environments Group (EEG) at the University of Portsmouth has:

i) underpinned international water-safety regulations that protect athletes in over 200 countries across two sports;

ii) changed sports event organisation and safety protocols for open water swimming competition;

iii) improved sport science support practices and the preparation of Team GB athletes competing in extreme environments, across ten Olympic and Paralympic sports and over two Olympic cycles.

These impacts have increased the safety of many millions of recreational and elite athletes who compete in extreme environments worldwide, improved British athletes' performances in extreme environments, and contributed to Team GB's Olympic, Paralympic and World Championship successes.

2. Underpinning research

The EEG has an international reputation for fundamental and applied research examining the physiology, pathophysiology, psychology and psychophysiology of extreme terrestrial and aquatic environments, and the selection, preparation and protection of individuals operating in these environments.

(**R1**) and (**R2**) are from a collaboration between the EEG and the International Olympic Committee, International Triathlon Union (ITU), and Fédération Internationale de Natation (FINA) (**G1**, **G2**). This began following the in-competition death of elite open-water swimmer Fran Crippens in 2010, which highlighted the need for evidence-based water-safety regulations to protect athlete-health. Our previous research, examining the thermophysiological responses to cold water, had shown that the 'cold shock' response can cause cardiac arrhythmias and that excessive cooling can result in hypothermia and swim failure. (**R1**) examined the thermophysiological responses of triathletes swimming for 20 minutes in a range of cool and cold-water temperatures with, and without, wetsuits. This enabled identification of a lower safe water temperature limit, in terms of minimising 'cold shock' and preventing excessive neuromuscular and deep-body cooling, with and without a wetsuit. (**R2**) extended this research to 'marathon' swimming of up to 2 hours, in standard swimming costumes across a range of water temperatures. The research demonstrated that 'marathon' swimmers could not maintain their deep-body temperature in water of 18°C or less and did not accurately sense their thermal state, meaning that they could be unaware of becoming hypothermic.

(**R3**), (**R4**), (**R5**) and (**R6**) are representative examples of our research developing evidence-based interventions for optimising athlete performance in hot conditions. This work was undertaken as part of a collaborative relationship between the EEG and UK Sport / English Institute of Sport (EIS) that commenced prior to the 2004 Olympic Games and has continued through the Rio 2016 and Tokyo 2021 Olympic cycles (**G3**, **G4**, **G5**). (**R3**) and (**R4**) examined acute interventions for enhancing performance in the heat. (**R3**) built on our previous research developing cooling interventions for Defence groups, comparing the heat-extraction rates of a range of different cooling interventions, in athletes. This research demonstrated the effectiveness of two, easy to implement, interventions for cooling athletes following exercise in a hot environment (whole body fanning and hand immersion in cool water). (**R4**) investigated a new approach to manipulating thermal perception during exercise in the heat. Menthol is a chemical compound that elicits feelings of coolness when applied to the skin. (**R4**) demonstrated that high concentrations of menthol made the participants feel cooler during exercise in the heat, but also initiated a heat-storage response, which had the negative effect of increasing the athlete's body temperature. However, a lower menthol concentration still provided some cooling sensation, whilst reducing the heat-storage response.

(**R5**) and (**R6**) examined chronic interventions for enhancing performance in the heat and the variability between individuals in the response to this type of intervention. (**R5**) is from a series of heat acclimation studies examining the adaptation profile, time-course of acquisition and decay, and performance effects of a number of novel approaches to heat acclimation, in well-trained individuals. This included combined (heat and hypoxia) and augmented (heat and dehydration) stressor approaches. (**R5**) demonstrated that the normal thermophysiological adaptations occurring with heat acclimation were not adversely affected by sleeping in a hypoxic tent. This was important because elite athletes often use hypoxic stress (e.g. altitude training or hypoxic tents) to increase the blood's oxygen-carrying capacity and enhance their performance and it had been hypothesised that this could impair the adaptive responses to heat. (**R6**) examined the individual responses to heat acclimation among a group of trained males undergoing a standardised 10-day heat acclimation programme. The study demonstrated substantial inter-individual variability in the adaptive profile, which was independent of fitness-level, as well as the independence between different indices of heat acclimation. Based upon these findings, it was concluded that, in contrast to the traditional view, highly trained endurance athletes should not be considered partially heat-adapted and that each athlete has their own, distinct, heat acclimated 'profile' which could be characterised and used to benchmark their 'heat readiness'.

3. References to the research

3.1 Research outputs

R1. Saycell, J., **Lomax, M.**, **Massey, H.**, & **Tipton, M.** (2018). Scientific rationale for changing lower water temperature limits for triathlon racing to 12°C with wetsuits and 16°C without wetsuits. *British Journal of Sports Medicine*, *52*(11), 702-708. https://doi.org/10.1136/bjsports-2017-098914

R2. Saycell, J., **Lomax, M., Massey, H.**, & **Tipton, M.** (2019). How cold is too cold? Establishing the minimum water temperature limits for marathon swim racing. *British Journal of Sports Medicine*, *53*(17), 1078-1084. https://doi.org/10.1136/bjsports-2018-099978

R3. **Barwood, M. J.**, Davey, S., **House, J. R.**, & **Tipton, M. J.** (2009). Post-exercise cooling techniques in hot, humid conditions. *European Journal of Applied Physiology*, *107*(4), 385-396. https://doi.org/10.1007/s00421-009-1135-1

R4. Gillis, D. J., **House, J. R.**, & **Tipton, M. J.** (2010). The influence of menthol on thermoregulation and perception during exercise in warm, humid conditions. *European Journal of Applied Physiology*, *110*(3), 609-618. https://doi.org/10.1007/s00421-010-1533-4

R5. Rendell, R. A., Prout, J., **Costello, J. T.**, **Massey, H. C.**, **Tipton, M. J.**, Young, J. S., & **Corbett, J.** (2017). Effects of 10 days of separate heat and hypoxic exposure on heat acclimation and temperate exercise performance. *American Journal of Physiology Regulatory Integrative and Comparative Physiology, 313*(3), R191-R201. https://doi.org/10.1152/ajpregu.00103.2017

R6. **Corbett, J.**, Rendell, R. A., **Massey, H. C.**, **Costello, J. T.**, **& Tipton M. J.** (2018). Inter-individual variation in the adaptive response to heat acclimation. *Journal Thermal Biology, 74,* 29-36. https://doi.org/10.1016/j.jtherbio.2018.03.002

3.2 Evidence of the quality of the research

All outputs are original research studies employing appropriate design, techniques, analysis, and interpretation and are published in peer-reviewed journals relevant to the discipline. R1, R2 and R5 are returned in REF2 with Output IDs 10340508, 24892099 and 8963823, respectively.

3.3 Related grants

G1. **Tipton, M.,** et al. *Scientific support for lower water temperature limits for open water swimming events: parameters for participant safety*. Funded by the International Triathlon Union, 01/09/14 → 01/07/15 (GBP31,667)

G2. **Tipton, M.,** et al. *Scientific support for lower water temperature limits for open water swimming events: parameters for participant safety.* Funded by the Fédération Internationale de Natation, 01/09/14 → 30/09/15, (GBP31,667)

G3. **Tipton, M.** *Maintaining athletic performance in the heat*. Funded by UK Sport, 01/10/07 → 30/09/11 (GBP118,293)

G4. **Corbett, J.,** et al. *Physiological responses to environmental stressors*. Funded by UK Sport, 01/10/13 → 30/09/16 (GBP40,000)

G5. **Corbett, J.,** et al. *Physiological responses to environmental stressors*. Funded by UK Sport, 01/10/13 → 30/09/16 (GBP12,500)

4. Details of the impact

Immersion in cold water can cause 'cold-shock' (a precursor to drowning and cardiac arrhythmias), neuromuscular incapacitation, hypothermia, and, *in extremis*, death. However, athletes are frequently exposed to cold water during open water swimming and triathlon competition, with a 2012 USA Triathlon Fatality Incidents Study reporting that 79% of triathlon deaths occurred during the swimming leg of triathlon competition. (**R1**) directly underpinned **new water-safety regulations introduced by the ITU in November 2015**, mandating the use of protective clothing (wetsuits) and limiting the water temperature in which athletes can compete. These new regulations specify a minimum safe water temperature of 16°C without a wetsuit, 12°C with a wetsuit, and competition cancellation if water temperature is below 12°C (ITU Competition Rules 4.2 and 4.3; **S1**). They apply to **all ITU sanctioned triathlon competitions including Olympic, Paralympic, World Championship, World Series, and recreational competitions under ITU regulations in 119 ITU affiliated countries**; in the UK and USA alone there are ~4,200,000 triathlon competitors each year. The impact of these regulations in reducing the risk of harm to athletes is evidenced by ITU Medical Committee Chair, Dr Sergio Migliorini, who states '…*after the introduction of the new rules we have had* ***less cases of swim failure and of mild/severe hypothermia****, and we have improved the safety of the swim leg*…' (**S2**).

(**R2**) demonstrated that FINA's extant open water swimming rules, in which athletes were not permitted to wear a wetsuit, could result in 'cold shock' and hypothermia during competition. As a direct result of this research, from February 2016, **FINA introduced a range of new polices to increase athlete safety** at open water swimming events. These FINA policy changes included: i) mandatory athlete cold water exposure preceding the start of the event to mitigate 'cold shock'; ii) a minimum of 60-minutes post-event athlete surveillance; iii) hot baths and hot fluid ingestion for athlete rewarming; iv) increased numbers of event lifeguards; v) additional training for coaches, FINA delegates and local organisation committee safety officers on cold-water swimming risks (**S3**).

(**R2**) also directly underpinned **new water temperature-limits and safety equipment rules introduced by FINA from 1 January 2017.** These regulations permitted wetsuit use for the first time, being compulsory in water temperatures less than 18°C and optional in water temperatures less than 20°C, and mandated that open water swimming competitions could not take place in water temperatures less than 16°C (FINA by-laws 8.4 and 8.5; **S4**). These regulations apply to **all competitions held under FINA rules, including the Olympic Games, Word Championships, World Series and Grand Prix circuit events, as well as competitions under FINA regulations**

in 209 member countries. The importance of this work is evidenced by FINA Bureau member Dr Margo Mountjoy who states that (**R2**) has '*helped to safeguard the health and safety of open water swimmers around the world, and has been a successful risk mitigation strategy for FINA*' (**S5**).

In addition to improving athlete safety and protection, our research has also positively impacted on the performance of athletes competing in cold water. (**R2**) underpinned our applied work supporting Team GB open water swimmers for the Rio 2016 Olympic Games, resulting in the **addition of cold-water acclimatisation sessions within athletes' training and providing the athletes with the confidence that they would not become hypothermic during competition.** According to Bernie Dietzig (Marathon lead; British Swimming), this '…*made a significant impact to our performance at the 2016 Olympic Games in Rio*' (**S6**). (R2) also underpinned our work supporting UN Patron of the Oceans, Lewis Pugh, in his preparations for 'The Long Swim' along the length of the English Channel, **demonstrating that he was unlikely to become hypothermic and that, from a 'thermophysiological perspective', the challenge was achievable** (**S7**). The awareness raised by this record-breaking 49-day swim, culminated in UK Government's commitment to advocate for the protection of at least 30% of the world's oceans by 2030.

At the other end of the temperature spectrum, our research has also improved the safety and performance of Olympic and Paralympic athletes competing in hot conditions, through impacts on practitioner decision-making, sport-science support, and athlete training and preparation. This has been achieved through applied work with Team GB athletes, and through strategic advisory roles with key stakeholder groups, including the EIS, where our evidence-based heat mitigation advice in the areas of heat acclimation, athlete cooling and perceptual manipulation is underpinned by (**R3**) to (**R6**), as well as our wider body of related research. The reach of this research within elite sport in the UK is evidenced by Dr Victoria Downie (Performance Innovation Team; EIS), who has supported multiple sports across the Rio 2016 and Tokyo 2020 Olympic cycles: '…*we look to their research group to provide expert opinion and feed into our applied work from the information coming out of their lab...* ***the Extreme Environments group have been directly involved in informing the heat preparation strategies for hockey, triathlon, athletics, para archery and para equestrian****… the Extreme Environments lab has made considerable impact on our practice and underpinned the advice we give on preparing for performance in the heat…'* (**S8**).

The significance of our impact on elite sport performance in the heat is exemplified by our work supporting British Triathlon's preparations for the Rio 2016 Olympic Games. Despite taking place in the Brazilian winter, the anticipated air temperature (around 25°C) was assessed as having the potential to impair performance. The EEG worked with practitioners from British Triathlon and the EIS to develop an evidence-based strategy to mitigate the effects of heat on performance and support athlete health. (**R3**) to (**R5**), as well as our wider body of related research, guided practitioner decision-making in the areas of heat acclimation/acclimatisation, hydration, cooling, and perceptual manipulation, evidencing appropriate interventions and highlighting ineffective, or potentially dangerous, practices. The resultant strategy contributed to Team GB's triathletes having their most successful Olympics to date, despite hotter-than-anticipated temperatures (up to 29°C). This is supported by testimony from Andrew Shaw (Physiologist; British Triathlon), who states that the EEG '…*have been a fantastic asset to British Triathlon when formulating our extreme environment strategy.* ***Their expertise and guidance contributed towards a heat strategy that aided our athletes to deliver 3 medals at the Rio Olympic games****, in addition to multiple medals at a world level…* ' (**S9**).

Our research has continued to change practice and enhance performance within British Triathlon into the Tokyo Olympiad, which is predicted to be the hottest Olympic and Paralympic Games to date. (**R6**) directly underpinned **a new 'heat-readiness' test that was introduced by British Triathlon in 2018.** According to Laura Needham (Co-Head of Physiology; EIS and Senior Physiologist; British Triathlon): '*This is a novel approach and one that enables us to assess the acclimation state or 'heat readiness' of triathletes at a given time and was* ***used in the preparation for our triathletes this summer for the Tokyo test event and will be implemented next year for the Olympic Games****. The input of the Extreme Environments Laboratory, drawing upon their research on assessment of heat acclimation state, was invaluable in developing this test'* (**S10**). This heat preparation strategy supported the British Triathlon Team to win 9 medals at the 'Tokyo Test Event' in August 2019, for which British Triathlon received the award for 'Support staff from

any specialism who have made a special impact on high-performance' at the 2020 UK Sport PLx awards.

'Heat-readiness' testing also enabled British Triathlon to make evidence-based comparisons of the effectiveness of a traditional warm weather training-camp with laboratory-based heat acclimation amongst their elite triathletes. This process demonstrated the superiority of laboratory heat acclimation and resulted in the **decision by British Triathlon to include a laboratory heat acclimation programme as part of the Olympic Preparation Camp; this is a mandatory element of the athlete preparation process for the Tokyo Olympic Games**. Importantly, this new approach has been well received by the athletes and has increased their confidence in the heat preparation strategy. Moreover, the efficacy of this novel approach within British Triathlon has led to **'heat-readiness' testing now also being used by Team GB cycling, para-triathlon, sailing, hockey, athletics, and equestrian** to support the Olympic and Paralympic preparations of their athletes and para-athletes (**S10**).

In summary, original research from the EEG has increased the safety and improved the performance of athletes competing in extreme conditions, at both ends of the temperature spectrum, and in terrestrial and aquatic environments. Our research has had worldwide impact, in able-bodied and para-sport, and from recreational to elite level. It has changed the policies of National and International sports organisations, underpinned regulations applying to athletes in over 200 countries, and improved sports event safety. Our research has positively impacted on elite athletes and their professional support staff across ten Olympic sports, over two Olympiads. It has guided practitioner decision making, changed sport science support, improved athlete training, underpinned Olympic preparation policy, and enhanced performance. Together, these impacts have increased the protection and duty of care for athletes competing in extreme environments and contributed to British medal successes at Olympic, Paralympic and World Championship level.

5. Sources to corroborate the impact

S1. International Triathlon Union Competition Rules, 06/12/2015.

S2. Letter of support from Sergio Migliorini MD, International Triathlon Union Medical Committee chair, 07/03/2020.

S3. Email from [text removed for publication] to Professor Mike Tipton (University of Portsmouth) detailing the introduction of new FINA by-laws at FINA open water swimming events, 01/02/2016.

S4. Fédération Internationale de Natation wetsuit suit by-laws memorandum, 11/01/2017 and Fédération Internationale de Natation by-laws 2017-2021.

S5. Letter of support from Dr Margo Mountjoy, Bureau Member (portfolio of Sport Medicine), Fédération Internationale de Natation, 05/03/2020.

S6. Letter of support from Bernie Dietzig, Marathon Swimming Lead, British Swimming, 05/03/2020.

S7. Is Lewis Pugh physically ready to take on The Long Swim? Sky News, 24/08/18. https://news.sky.com/story/is-lewis-pugh-physically-ready-to-take-on-the-long-swim-11432873

S8. Letter of support from Dr Victoria Downie, Performance Innovation Team, English Institute of Sport, 07/06/2019.

S9. Letter of support from Dr Andrew Shaw, Physiologist, British Triathlon, 07/08/2017.

S10. Letter of support from Laura Needham, Co-Head of Physiology, English Institute of Sport and Senior Physiologist, British Triathlon, 22/10/2020.