

<b>Institution:</b> Swansea University		
<b>Unit of Assessment:</b> 24		
<b>Title of case study:</b> Competition day strategies for enhanced performance in elite and professional athletes.		
<b>Period when the underpinning research was undertaken:</b> 2013 – 2020		
<b>Details of staff conducting the underpinning research from the submitting unit:</b>		
<b>Name(s):</b>	<b>Role(s) (e.g. job title):</b>	<b>Period(s) employed by submitting HEI:</b>
Liam Kilduff	Professor	01/10/2002–present
Neil Bezodis	Associate Professor	18/01/2016–present
<b>Period when the claimed impact occurred:</b> 1 August 2013–31 July 2020		
<b>Is this case study continued from a case study submitted in 2014?</b> No		
<b>1. Summary of the impact</b>  <p>Research led by Professor Kilduff at Swansea University on passive heat maintenance and morning priming exercise has transformed the competition day strategies of practitioners in the elite and professional sports domain. These strategies have led to significant performance improvements for elite power-based athletes and improved movement and performance indicators for international team sport athletes. Within the impact period, this research has been successfully incorporated into competition day preparations for athletes competing at the Commonwealth Games (Glasgow 2014 and Gold Coast 2018), Winter Olympic games (Sochi 2014 and PyeongChang 2018), Summer Olympic games (Rio 2016) and Rugby World cups (England 2015 and Japan 2019). In addition, Team GB are currently implementing these procedures in preparation for the upcoming Olympic Games in Tokyo (2021) and Beijing (2022).</p>		
<b>2. Underpinning research</b>  <p>In the context of elite sport, the smallest margins can often make the difference between winning and losing. Sports have several windows of opportunity for practitioners to implement strategies that positively impact performance on competition day. Research led by Professor Kilduff at Swansea University, in collaboration with UK and International sporting partners, has identified two unique opportunities: 1) the application of <b>morning priming exercise</b> to enhance afternoon/evening performance [R1 and R4], and 2) the application of <b>passive heat maintenance strategies</b> to attenuate the decline in muscle temperature between warm-up and start of competition, as well as during intervals, leading to enhanced subsequent performance [R1, R2, R5 and R6]. In both cases, this important, novel programme of research, conducted in truly elite athletes, has developed and provided an evidence-base for competition day strategies that have been implemented to enhance elite performance on the International stage.</p> <p><b>Morning Priming Exercise [R1, R4]</b></p> <p>The concentration of key hormones, including testosterone, are known to be important for performance in elite power and team-based athletes. However, testosterone exhibits a circadian rhythm with concentrations peaking in the morning and subsequently decreasing throughout the day. This has important implications for elite performance during afternoon and evening events. Research at Swansea University, conducted in elite athletes, demonstrated how different modes of morning exercise can offset this decline in testosterone concentrations, and thereby enhance subsequent power-based performance during the afternoon (countermovement jump by ~4% and repeated sprint performance by ~2% [R4]).</p> <p><b>Passive Heat Maintenance [R1, R2, R5 and R6]</b></p> <p>Muscle and whole-body temperature are also important for elite athletic performance. During team sports, there are periods between the warm-up and competition start, and during intervals, where body temperature can decrease and therefore negatively impact subsequent performance.</p>		

Swansea University research demonstrated the efficacy of a passive strategy (wearing a survival jacket) to offset the decrease in core body temperature observed in elite Rugby Union players during these 'heat loss windows' [R2, R5, R6]. The application of this intervention improved lower body power output (increase of ~3%) and repeated sprint performance (increase of ~2%) compared to control following both a simulated half-time period [R2, R6] and following a simulated period between warm-up and start of competition [R5]. In addition, [R2] showed that combining a passive heat maintenance strategy with a short active 're warm-up' was more effective for preserving lower body power output and repeated sprint performance compared to either strategy in isolation.

More recently, significant funding awarded to Professor Kilduff and Dr Bezodis from the English Institute of Sport and the Welsh Government [G5, G6 & G8] has facilitated unique research to enhance the underpinning technology used in these passive heat maintenance strategies. This research has developed advanced functional nano and micro-materials (e.g., graphene) into printable, flexible coatings that offer a uniform heat distribution and can be embedded into the bespoke clothing garments required by elite athletes [R3].

### Combined Competition Day Strategies [R1]

[R1] demonstrated the positive impact of combined pre-competition strategies (passive heat maintenance and morning "priming") on skeleton bobsleigh performance time (increase of 3.5% on their key sprint performance indicator) in elite British skeleton athletes preparing for the Olympics.

### 3. References to the research

The reference list below includes six journal articles and eight grants. All published outputs are in peer reviewed journals (5xQ1, 1xQ2, JCR). Five have national or international rugby team collaborations. Competitive grant funding from sports clubs, sports professional organisations, and Welsh Government totalling £2,601,664 has supported the body of work. This research has made important contributions to the discipline internationally and contributes important knowledge to the field likely to have a lasting influence.

[R1] Cook, C.J., Holdcroft, D. Drawer, S., & Kilduff, L.P. (2013). Designing a warm-up protocol for elite bob-skeleton athletes. *International Journal of Sports Physiology and Performance*, 8 (2), 213-215. doi.org/10.1123/ijsp.8.2.213

[R2] Russell, M., Tucker, R., Cook, C.J., Giroud, T., & Kilduff, L.P. (2018). A comparison of different heat maintenance methods implemented during a simulated half-time period in professional Rugby Union players. *Journal of Science and Medicine in Sport*, 21 (3), 327-332. doi.org/10.1016/j.jsams.2017.06.005

[R3] Claypole, A., Claypole, J., Holder, A., Claypole, T.C., & Kilduff, L.P. (2020). Rheology of high-aspect-ratio nanocarbons dispersed in a low-viscosity fluid. *Journal of Coatings Technology and Research*, 17, 1003-1012. doi.org/10.1007/s11998-020-00319-2

[R4] Russell, M., King, A., Bracken, R.M., Cook, C.J., & Kilduff, L.P. (2016). A Comparison of Different Modes of Morning Priming Exercise on Afternoon Performance. *International Journal of Sports Physiology and Performance*, 11 (6), 763-767. doi.org/10.1123/ijsp.2015-0508.

[R5] West, D.J., Russell, M., Bracken, R.M., Cook, C.J., Giroud, T., & Kilduff, L.P. (2016). Post-warm up strategies to maintain body temperature and physical performance in professional rugby union players. *Journal of Sports Sciences*, 34 (2), 110-115. doi.org/10.1080/02640414.2015.1040825

[R6] Russell, M., West, D.J., Briggs, M.A., Bracken, R.M., Cook, C.J., Giroud, T., Gill, N., & Kilduff, L.P. (2015). A passive heat maintenance strategy implemented during a simulated half-time improves lower body power output and repeated sprint ability in professional Rugby Union players. *PLoS One*, 10 (3), e0119374. doi.org/10.1371/journal.pone.0119374

### Grants underpinning the research

- [G1] Kilduff, L.P. [Principal Investigator]. (2013-2014). Morning Priming and afternoon performance in professional athletes. Swansea City AFC. GBP7,000.
- [G2] Kilduff, L.P. [Principal Investigator]. (2015-2018). Preparation and recovery for training and competition in elite sport performance. Sport Wales. GBP52,000.
- [G3] Kilduff, L.P. [Principal Investigator]. (2016-2019). Concurrent Training in Team Sports. Swansea City AFC. GBP75,000.
- [G4] Kilduff, L.P. [Principal Investigator], (2016-2021). & Bezodis, N. [Co-Principal Investigator] (2020-2021). Welsh Institute of Performance Science. Sport Wales. GBP428,000.
- [G5] Kilduff, L.P. [Principal Investigator], & Bezodis, N. [Co-Principal Investigator]. (2017-2018). Development of heated garments for athletes Phase 1. English Institute of Sport. GBP75,842.
- [G6] Kilduff, L.P. [Co-Principal Investigator], & Bezodis, N. [Co-Principal Investigator]. (2018-2019). Development of heated garments for athletes Phase 2. English Institute of Sport. GBP48,883.
- [G7] Kilduff, L.P., & Bezodis, N. [Co-Principal Investigators]. (2018-2021). Performance Optimisation in international Swimmers. Swim Wales. GBP76,280.
- [G8] Kilduff, L.P., & Bezodis, N. [Co-Principal Investigators]. (2019-2021). AFM<sup>2</sup> – Application of Functionalised Micro & Nano materials – Scale up to volume production. Welsh Government. GBP1,838,659.

### 4. Details of the impact

The impact and the underpinning research being described in this impact case study are primarily a reflection of Professor Kilduff's overall contribution in developing and driving the competition day performance preparation domain and in particular his pioneering ability to translate these findings from controlled research situations to real world elite sporting environments. Notably, prior to Prof Kilduff's research, no passive heat maintenance or morning priming exercise strategies were being used, which highlights the novelty, reach and significance of the impacts achieved. Professor Kilduff's strategy for achieving such impact is to ensure his work has an applied performance solution focus through continued engagement with key stakeholders at all stages of the research process, as evidenced by the letters of support and significant industry funding associated with this case study. The above strategy has led to the underpinning research having a significant impact on practitioners from a wide range of elite and professional sports, by developing optimal competition day strategies that have been exploited for valuable performance gains. These novel strategies are unrivalled in providing significant changes to practitioners' competition day practice at the very highest level of international competition. Ultimately, the research findings have underpinned current preparation strategies for numerous top international rugby teams (e.g., New Zealand and French Rugby Federation) and elite Winter (e.g., Skeleton Bobsleigh) and Summer (e.g., Team GB) Olympic sports teams, ultimately playing a key role in contributing to their recent successes at the Commonwealth Games (Glasgow 2014 and Gold Coast 2018), Winter Olympic Games (Sochi 2014 and PyeongChang 2018), Summer Olympic Games (Rio 2016) and Rugby World Cups (England 2015 and Japan 2019).

### Impact at the Commonwealth Games

The research findings on passive heat maintenance have been applied to enhance performance by competitors for Team Wales in a significant number of sports, at both the Glasgow (2014) and Gold Coast (2018) Commonwealth Games. The impact of this work is evidenced by the quotes below.

National Performance Director for Swim Wales [C1]:

*“Professor Kilduff's research underpinned our competition days strategies centred around warm-up, passive heat maintenance and morning priming, this research coupled with the expertise of our coaches and performance staff had a significant impact on two of our most successful overall*

commonwealth games performances. **Professor Kilduff's** research has had important significance and impact on our practice at Swim Wales."

Head of Coaching and Performance (2012-2018) for Welsh Athletics [C2]:

**"Professor Kilduff's** research focusing around the application of passive heat maintenance strategies to elite athletes and specifically it's application during "heat loss" windows in competition allowed us to gain a performance advantage over our competitors. Probably the best example of this was during the women's pole vault final where the temperatures were between 15-16 degrees Celsius with heavy rainfall during an evening session in Glasgow. **Sally Peake used the heat maintenance techniques as part of her competition strategy to great effect and saw her win the silver medal; finishing well above her ranking and even attempting a National record despite the poor weather conditions."**

### Impact on the Winter and Summer Olympic games

This research has also had a significant impact during the Summer (Rio 2016) and Winter (Sochi 2014 and PyeongChang 2018) Olympic games, as evidenced by the following excerpts from letters of support:

Director of Performance Innovation (English Institute of Sport) [C3]:

*"The impact his research has delivered in the area of warm up and 'competitive readiness' in elite athletes has directly impacted applied practice and performance on GB's winter and Summer sport programmes through the implementation by our expert practitioners. This research work has been incorporated into the preparation and competition day strategies for Sochi (2014), PyeongChang (2018) and Rio (2016). In addition, athletes and coaches from a high number of Summer and Winter sports team are currently revisiting this performance priority in preparation for the Summer Olympic Games in Tokyo 2020 and Winter Olympic Games in Beijing 2022. Specifically, his research (papers listed below) around the application of passive heat maintenance during competition day heat loss windows has transformed our competition day strategies and these changes have led to significant performance gains for our athletes."*

Further support for this comes from the Head of Performance Innovation and Applied Research (British Bobsleigh and Skeleton Association) [C4]:

*"The research conducted directly within our World Class Performance athletes has allowed our athletes physical performance on the world stage to make tangible improvements. Over the years this work has led to significant improvements in our start time KPI test (see Cook et al below paper for quantification). This has had a dramatic impact on overall performance and end ranking."*

A further advancement in this area is our work around printed wearables for passive heat maintenance and the Director of Performance Innovation, English Institute of Sport [C3] states:

*"In addition, the recent work we have supported (grants below) in collaboration with **Dr Bezodis** and Professor Claypole around the development of a graphene based printed heater will give us a significant performance advantage in our training and preparation strategies and is providing a bespoke performance solution to a major performance issue our sports identified. Approximately 60% of our sports will be using this advancement in wearable heated technology during either the training phases coming into the games and on competition days at the games, based on initial testing it is clear it will have a significant impact on their performances."*

### Impact on International Rugby

Finally, Professor Kilduff's work in the area of passive heat maintenance and the influence of morning exercise on afternoon performance has had significant reach and impact on the international rugby stage.

The Heads of Performance and Strength and Conditioning coaches from 6 of the top 11 international rugby teams (World rankings (2016, 2019), the Rugby Football Union, New Zealand Rugby, Italian Rugby Federation, Australia Rugby, Georgia Rugby and the French Rugby Federation [C5-10], together have stated the following, which clearly highlights the adoption and impact of our work described above.

*"Professor Kilduff's research into the application of passive heat maintenance (between the warm-up and start of competition, during half-time and for our match day substitutes) and also the use of game day primers has helped transform our game day preparation's and I feel this is now an extremely important part of our performance programme."*

The Head of Performance for the French Rugby Federation [C5] went further and stated:

*"Since implementing our competition day strategies based on his work, we have consistently seen improvements in our movement characteristics (as assessed by GPS) and key performance indicators (as assessed by performance analysis statistics) at the beginning of the game and immediately after the half-time break. We are confident these improvements are down to the implementation of the passive heat maintenance and priming strategies outlined (key papers listed below) in Professor Kilduff's research."*

### 5. Sources to corroborate the impact

Letters of support from the following organisations and in what capacity they are involved with the impact follows in brackets:

- [C1] National Performance Director, Swim Wales (Reporter)
- [C2] Head of Coaching and Performance (2012–2018), Welsh Athletics (Reporter)
- [C3] Director of Performance Innovation, English Institute of Sport (Reporter)
- [C4] Head of Performance Innovation and Applied Research, British Bobsleigh and Skeleton Association (Reporter)
- [C5] Head of Athletic Performance, French Rugby Federation (Participant – collaborator on underpinning research AND Reporter)
- [C6] Head of Athletic Performance, Australia Rugby (Reporter)
- [C7] Head of Strength & Conditioning, New Zealand Rugby (Reporter)
- [C8] Strength & Conditioning Coordinator, Rugby Football Union (Reporter)
- [C9] Head of Athletic Performance, Italian Rugby Federation (Reporter)
- [C10] Lead Strength & Conditioning Coach, Georgia Rugby (Reporter)