

<b>Institution:</b> University of Stirling		
<b>Unit of Assessment:</b> 24. Sport and Exercise Sciences, Leisure and Tourism		
<b>Title of case study:</b> From laboratory to field: improving elite athletic preparation and performance through neural measurement		
<b>Period when the underpinning research was undertaken:</b> 2007-2018		
<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>
Dr Angus Hunter	Reader	02/2002 - Present
Dr Lewis Macgregor	Lecturer (postdoc first year)	02/2016 - Present
Prof David Donaldson	Professor	01/2001 - 01/2020
<b>Period when the claimed impact occurred:</b> 2014 – 2020		
<b>Is this case study continued from a case study submitted in 2014?</b> No		
<b>1. Summary of the impact</b>		
<p>Coaching, training, and performance of Scottish elite international athletes has all been enhanced by University of Stirling (UoS) neural research. Our applied work using Tensiomyography (TMG) and electroencephalogram (EEG) techniques has led to:</p> <ul style="list-style-type: none"> <li>• <b>Impact 1:</b> the development of a gold-standard model for achieving evidence-based practice with sportscotland Institute of Sport (SIS).</li> <li>• <b>Impact 2:</b> improvements in coaching practice and decision making around the condition of internationally-competitive elite athletes (swimming and shooting).</li> <li>• <b>Impact 3:</b> increases in the sales and uptake of TMG technology globally, including 18 units in the UK alone between 2011-2019 (compared to 1 unit sold in the previous 8 years).</li> </ul>		
<b>2. Underpinning research</b>		
<p><b>Background:</b> Research on processes governing skeletal muscle function and resultant knowledge transfer by enhancing practitioners' (coaches, physiotherapists, medics) and athletes' understanding of elite sport performance is an important contributory factor for increasing success in competition. However, laboratory-based research is often isolated from the sporting field, because of locational separation and concerns about invasiveness – this dissociation gives rise to sports support practices that are not evidence-based and are potentially costly. Tensiomyography (TMG) has been developed over the last 15 years as a non-invasive technique, making use of a portable device that assesses different properties of skeletal muscle in response to electrical stimuli. This technique can monitor change in passive tension as a result of muscle length changes, detect muscle damage following certain exercises, monitor muscle alterations following fatigue, and assess recovery strategy effects. Also, our mobile electroencephalogram (EEG) technique tracks and records brain wave patterns in relation to a given movement.</p> <p><b>Context of Research:</b> UoS's inter-disciplinary team aligns local research expertise with the needs of high-performance sports by collaborating directly with SIS - the national agency responsible for Scottish athlete high-performance sport funding and athlete support services. A number of these athletes represent Scotland and Great Britain on the world stage. Expertise is delivered in situ within environments for sports training and competition. Knowledge is also shared and transferred within high performance sport review meetings and through coaching and support staff continual professional development conferences organised and delivered by SIS.</p> <p>Research paper <b>R1</b> (supported by [G1]) explored the efficacy of 2 novel devices (TMG and Myometer) claiming to measure mechanical and contractile properties of skeletal muscle. To establish this, the biceps femoris (hamstring) was measured under different length conditions by altering knee angle for sensitivity and repeated over two separate days for inter day reliability. This clearly demonstrated that TMG was <b>sufficiently sensitive</b> to detect relatively small changes in muscle length and had acceptable inter day reliability.</p> <p>Research paper <b>R2</b> (also supported by [G1]) explored validity of TMG to detect exercise induced muscle damage (EIMD) and subsequent recovery. This clearly demonstrated that TMG was an <b>effective and accurate</b> measure for detecting EIMD. This was important as many elite athletes suffer with EIMD which is commonly associated with muscle adaptation. UK Sport were interested in using TMG to inform coaches of elite athlete muscle "status" prior to training and competition.</p>		

Research paper **R3** (supported by [**G2**]) **established stability** of TMG under rested and fatigued conditions. These results demonstrated that TMG was sufficiently stable to support the Scottish High-Performance Swim Programme for essential muscle screening of elite athletes.

Review article **R4** (supported by [**G4**]) established evidence for EEG signals that either identify neural signals associated with expertise in sport or provide neurofeedback to enhance performance. The review **identified a mismatch** between laboratory tasks and real sporting activity and proposed that recent developments in mobile EEG technology could bridge the gap. This informed a programme of work with elite Scottish Shooters using mobile EEG to enhance performance.

Research paper **R5** (supported by [**G3**]) established the validity of TMG for **detecting skeletal muscle fatigue**. These results demonstrated that TMG could establish skeletal muscle fatigue status without exacerbating functional decrement of the muscle. This was an important publication to inform UoS's ongoing work with elite Scottish Swimmers.

**R6** was the first review paper to consolidate research performed by us and others and provide comment on TMG effectiveness for measuring skeletal muscle contractile properties. The paper produces useful evidence and interpretation for advantages and disadvantages for using TMG for both clinical and athletic populations.

### 3. References to the research (Stirling authors in bold text)

#### Publications

- R1.** Ditroilo M, **Hunter AM**, Haslam S, De Vito G. 2011. The effectiveness of two novel techniques in establishing the mechanical and contractile responses of biceps femoris. *Physiol Meas* 1;32(8):1315–26. DOI: [10.1088/0967-3334/32/8/020](https://doi.org/10.1088/0967-3334/32/8/020)
- R2.** **Hunter AM**, Galloway SD, Smith IJ, Tallent J, Ditroilo M, Fairweather MM, *et al.* 2012. Assessment of eccentric exercise-induced muscle damage of the elbow flexors by tensiomyography. *J Electromyogr Kinesiol* 22(3):334–41. DOI: [10.1016/j.jelekin.2012.01.009](https://doi.org/10.1016/j.jelekin.2012.01.009)
- R3.** Ditroilo M, Smith I, Fairweather M, **Hunter AM**. 2013. Long-term stability of tensiomyography measured under different muscle conditions. *J Electromyogr Kinesiol* 23(3):558–63. DOI: [10.1016/j.jelekin.2013.01.014](https://doi.org/10.1016/j.jelekin.2013.01.014)
- R4.** Park JL, Fairweather MM, **Donaldson DI**. 2015. Making the case for mobile cognition: EEG and sports performance. *Neurosci Biobehav Rev* 52:117–30. DOI: [10.1016/j.neubiorev.2015.02.014](https://doi.org/10.1016/j.neubiorev.2015.02.014)
- R5.** **Macgregor LJ**, Ditroilo M, Smith IJ, Fairweather MM, **Hunter AM**. 2016. Reduced Radial Displacement of the Gastrocnemius Medialis Muscle After Electrically Elicited Fatigue. *J Sport Rehabil* 25(3):241–7. DOI: [10.1123/jsr.2014-0325](https://doi.org/10.1123/jsr.2014-0325)
- R6.** **Macgregor LJ**, **Hunter AM**, Orizio C, Fairweather MM, Ditroilo M. 2018. Assessment of Skeletal Muscle Contractile Properties by Radial Displacement: The Case for Tensiomyography. *Sport Med* 48(7):1607–20. DOI: [10.1007/s40279-018-0912-6](https://doi.org/10.1007/s40279-018-0912-6)

#### Grants

- G1.** **Hunter AM** (2004) GBP64,000 UK Sport: The reliability and validity of tensiomyography.
- G2.** **Hunter AM** (2012) GBP45,000 sportscotland: Provision of Tensiomyography Support.
- G3.** **Hunter AM** (2016) GBP104,000 sportscotland: The Tensiomyography Project.
- G4.** **Donaldson D** (2013) GBP93,164 SIS Foundation: EEG and Future Innovations.

### 4. Details of the impact

#### Impact 1: Influencing SIS to develop a gold-standard model for achieving evidence-based practice in elite sport.

A key high-level outcome for SIS is to deliver success in international competitions. Evidence-based practice in sport is viewed as a vital mechanism to support this success. The collaboration between UoS and SIS is founded and funded upon delivery of evidence-based sport practice. To date, applied research findings from UoS have led to specific changes in training and evaluation of performance, leading to informed and enhanced success at major international events (the model developed as a result of our applied research is presented in Figure 1). We have delivered two strands of evidence-based enquiry and support, to target neuromuscular function (TMG) and cognitive function (EEG) across different sports.

This approach (Figure 1) has delivered a gold-standard model for achieving evidence-based practice through longitudinal enquiry. Malcolm Fairweather, the Head of Performance Solutions (SIS) since 2001, has expressed the value of this collaboration:

“our initial approach with UoS and UK sport at the outset was pioneering at that time, and still represents best practice today.” (S1, S7)

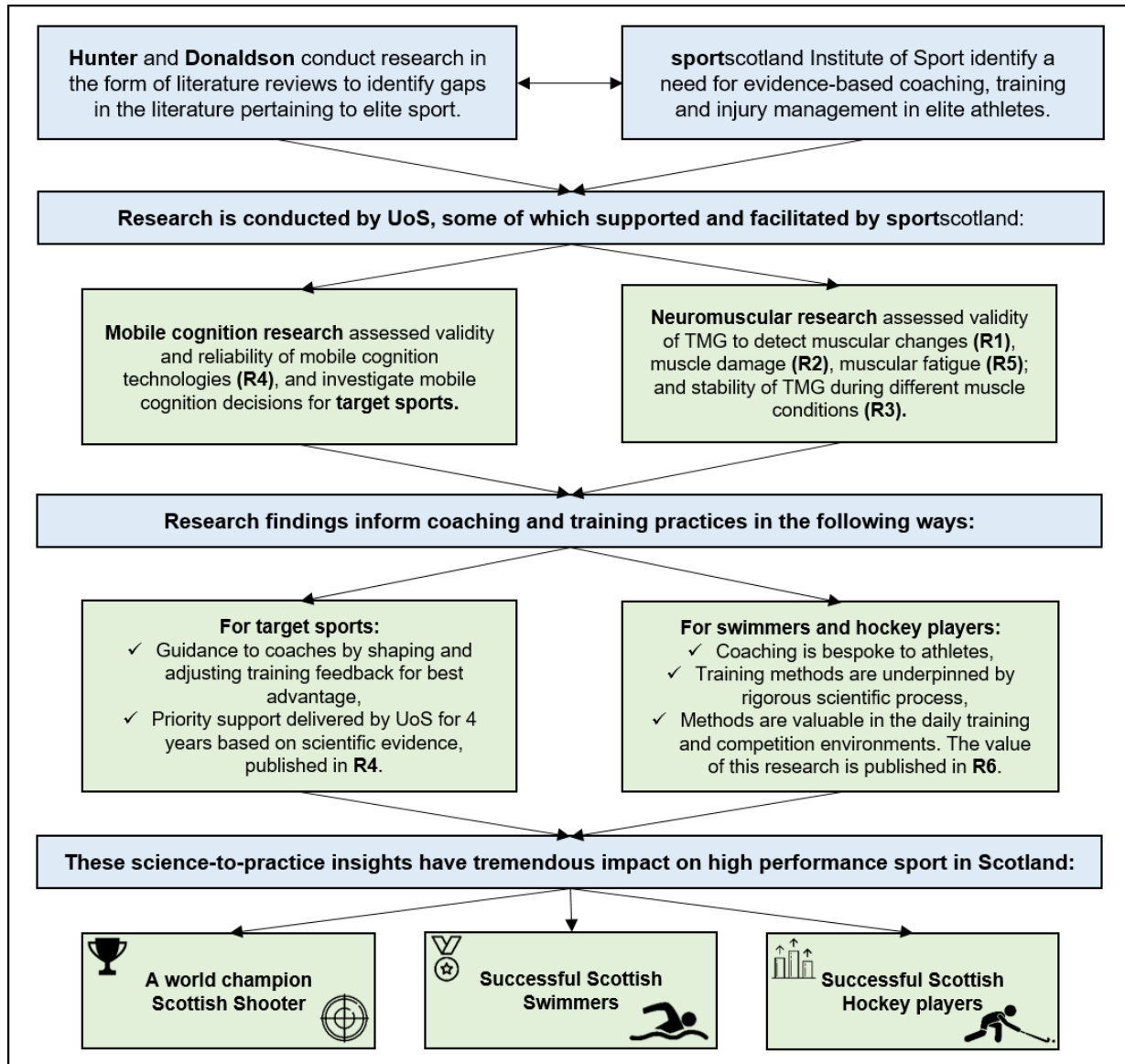


Figure 1. Evidence-based practice in elite sport: Translating science to inform practice.

**Impact 2: Improving coaching practice and decision making around the condition of internationally-competitive elite athletes through TMG**

**Improving coaching practice**

The longitudinal impact of our collaboration across several sports is that athletes who are presently World, Olympic and international medallists have benefited from insights, applied research and support processes provided by Hunter, Macgregor and Donaldson’s co-production with SIS. A primary impact is our applied TMG work with high performance swimmers, coaches and their support teams. UoS research has improved coaching and practice to objectively understand conditions of high-performance athletes’ recovery, adaptation and performance status on an athlete-by-athlete basis (Figure 1). This is beneficial to these athletes during their preparation for high-profile international competitions, as training and recovery services can be altered to enable athletes to perform at their best. Describing the benefits of collaboration with Stirling, Malcolm Fairweather stated:

“performance sport, coaches, athletes, service providers know that TMG support is quality assured by this fundamental research in the background ... This group of high performance

people have embraced the TMG practitioners into their performance programmes and into the front line in performance sport.” (S1)

This real-time feedback approach informs coaching programming decisions including the design of warm-up, recovery, training load-volume programming and the application(s) of TMG to help prevent and detect injury. Neil Shanks, Physical Preparation Lead for Scottish Swimming, highlights here how Stirling researchers influence his programme development:

“One of the key skills that they [UoS] have got is obviously their ability to carry out the TMG testing and then take that information and dissect it, divulge and articulate it really well to myself to then make programming decisions based on that.” (S2)

### ***Improving injury management***

There is also a wider adjustment across service areas such as the informed management of recovery from training and injury. The Head Performance Swimming Coach of the University of Stirling, Steve Tigg, who was part of Team Scotland for the Gold Coast 2018 Commonwealth Games and is currently part of the Team GB coaching setup for the Tokyo 2020 (now 2021) Olympics, states the importance of TMG when helping his athletes recover from injury:

“We had an ACL [(anterior cruciate ligament) injury] with Kathleen Dawson and ... some ankle ligament injury on Duncan Scott and the TMG research played a really import role on steering the development and the recovery process linking in with both strength and conditioning, with the physiotherapist and then ourselves as to where we were on that journey to recovery.” (S2)

Neil Shanks concurred on the importance of TMG for athlete recovery:

“we had an ACL injury two years ago with one of the swimmers where we used TMG, and because we had previous profile information on that athlete we could use TMG to find out from a recruitment point of view, comparing left to right leg (an injured to a non-injured leg), what were the main differences and it provided us information to inform her required recovery period for return to sport, a good measure that we could keep in place to check our programme is delivering what we need to because there’s other measures you can’t collect, especially strength measure until full recovery from injury, so TMG definitely helped us.” (S2)

The influence of our approach in changing elite sporting practice has coincided with successes in international competition: since Glasgow 2014 Commonwealth Games, Scottish Swimming has seen a multitude of high performance success that has been rising exponentially; this is evidenced by recent performances at the Gold Coast Commonwealth Games 2018 where Scottish swimmers were awarded 18 medals of which 13 were from athletes UoS directly supported (72%). Testimonials from coaches, athletes, service providers and sport stakeholders substantiate the influence of TMG research and this feedback couples with confidence gathered from changes in process variables when preparing with evidence-based support. Malcolm Fairweather explains here how UoS research has provided athletes with improved training:

“the key for performance sport is that we, we know, firstly that the measurements that are provided through TMG data capture are reliable, they’re valid and importantly to us in performance sport, they’re meaningful... The great thing about TMG is we can look at through data windows and note objectively at when an athlete is back to their baseline state, or close enough to a baseline state for a particular type of training output or intensity to be implemented.” (S1)

### ***Improving shooting coaching***

In mobile cognition, we initially reviewed the case for applications within high performance sport upon the request of SIS (Figure 1). This review helped guide SIS’s mobile cognition decisions for target sports. Priority support has been delivered for four years in shooting; during this collaboration, focused mobile cognition profiling has helped support a world champion Scottish shooter. The shooter’s coach (Donald Macintosh) has confirmed the value of guidance provided by our neural assessment support and the influence of this support in altering coaching practice. The metrics used to judge elite shooters within the programme were re-assessed ensuring coaching focussed on the areas of performance which award athletes the best advantage:

“There was a consistency of message ... from session to session and also between athletes... I think the most useful thing that came out of it all was actually, David [Donaldson] challenged that fundamental question about hold numbers and said that we’re not convinced that you’re actually looking at the right thing. And one of the other figures we get from the same training device is a measure of the quality of shot release. So if you think of shooting as simply trying



to keep the rifle as still as possible [hold], aiming it in the middle and then releasing the shot without disturbing the first two, then that's a really simple model of shooting, but one that underpins everything I do. And actually, they've [UoS] done some correlations and come back to us and say the one on the end, the quality of the trigger release is the one that we see the biggest relationship between outcome and the sporting statistics... So it very much has shaped what we've done with our very, very best athletes and they both won serious international medals over the last few years, and I think this did contribute to that.” (S3)

### **Impact 3: Influence on increased sales and uptake of TMG across the UK and Europe**

Our work pioneered UK sales of a support device measuring skeletal muscle contraction now known as TMG. Jure Jemec is the CEO/General Manager of TMG-BMC Ltd., the sole manufacturer of TMG measuring technology. He states how Stirling and the Institute's research into elite athletes added something unique:

“Additionally Dr Hunter was able to present the technology to SIS which allows me to get a new aspect of the application used, *i.e.* practically on the athlete, ... and this gave additional dimension particularly with Olympic sports and we also used this ... for acceleration of the business you know.” (S4)

Jure goes on to say that Stirling played a big role in bringing TMG to the UK, with 18 units sold to UK-based customers between 2011-2019 (compared to 1 unit sold in the previous 8 years):

“Yes of course, for sure I mean Stirling was first reference for TMG in the UK.” (S4)

Our research reached further afield as the Fitness Trainer for Girondins de Bordeaux Football Club (French top division), Rafael Maldonado, states when asked if he is aware of UoS research:

“I read their research yes... all of them give me ideas or confirm some of them to train. For this reason, I use TMG for three main goals: 1) to help in rehabilitation process (especially during the last phases); 2) To detect excessive muscle stiffness and compare with/complement the medical test; 3) to make individual strength programs to activate 'weak muscle' before the training session on the pitch.” (S5)

Our research in this area has also impacted commercial companies. Boštjan Šimunič, Head of the Institute for Kinesiology at Science Research Centre in Koper, Slovenia spoke of two companies that sought his support to start using TMG, after having read UoS research:

“when I'm visiting some physiotherapy departments, I usually have some lectures and of course I mention those studies that were done by your team. Ok, at this point I think that exercise-induced muscle damage study [R2] is really intrigued by a company that produces rehabilitation methods on this radio-waves, this is a Spanish company, and I was contacted by them... So this is, I think, something that really influenced them, this Spanish company, it's called INDIBA® ... But this is exactly because they found the study performed by Angus about DOMS and they contacted me then... The same idea of collaboration came also from an innovative multinational company AHA Hyperbarics. In mid-2020, they invited us on the meeting about research collaboration. They have an idea to perform a randomised study on DOMS treatment with 5 consecutive 2.7 bar 2 hour treatments. They also pointed out TMG evaluation tools based on Angus's article. The study will be done in 2021, the same as the study for INDIBA®.” (S5)

### **5. Sources to corroborate the impact**

**S1. Testimonial:** Malcolm Fairweather, Head of Performance Solutions at SIS, (Lines: 72, 80, & 181).

**S2. Testimonials:** (a) Neil Shanks, Senior Physical Preparation Coach and Physical Preparation Lead for Swimming at SIS; and (b) Steve Tigg, part of Team Scotland for Gold Coast 2018 Commonwealth Games, Team GB coach for the Tokyo 2020 Olympics.

**S3. Testimonial:** Donald McIntosh Scottish Shooting Team Manager, (Lines: 74, 78, & 119).

**S4. Testimonial:** Jure Jemec, CEO/General Manager of TMG-BMC Ltd. (Lines: 80 & 121).

**S5. Testimonial:** Rafael Maldonado, Fitness Trainer for Girondins de Bordeaux Football Club (Line: 73).

**S6. Testimonial:** Boštjan Šimunič, Head of the Institute for Kinesiology at Science Research Centre in Koper, Slovenia (Line: 127 & 143).

**S7. sportscotland coaching documents** including our measurement techniques for athlete preparation.