Institution: Queen's University Belfast

Unit of Assessment: 4

Title of case study: Improving movement performance: from clinical rehabilitation to elite sports

Period when the underpinning research was undertaken: 2009-2020

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:
Richard Carson,	**Professor**	**RC: 2006 – present**
Mihalis Doumas,	**Lecturer**	**MD: 2011 – present**
Matthew Rodger,	**Senior Lecturer**	**MR: 2012 – present**
Joost Dessing,	**Lecturer**	**JD: 2012 – present**
Cathy Craig	**Professor**	**CC: 2005 – 2018**

Period when the claimed impact occurred: 2013 - 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Movement is so fundamental to our existence that we tend only to notice exceptional cases, either when movement is dysfunctional—as in the pathologies that result from stroke and typify Parkinson's disease, or when it seems perfect—in the elite performance of sports stars and artists. The QUB Perception and Action group use state-of-the-art technology—virtual reality, motion capture, and neuroimaging—to understand sensorimotor skills in these exceptional cases and develop new interventions to improve functional capability. The SMART Arm device alleviates the impairments of stroke survivors (commercialized through SMART Arm Pty. Ltd.); dance-based interventions aid Parkinson's sufferers. Elite training strategies in football, rugby and cricket proposed by the group have interested many professional organizations, resulting in several collaborations (e.g., Ulster Rugby) and Prof. Craig went on to found the company INCISIV based on her research.

2. Underpinning research (indicative maximum 500 words)

The impact of QUB's Perception and Action group is derived from theoretical understanding and practical knowledge of motor control and learning, multisensory integration, and the neural mechanisms underpinning movement. The team has a unique combination of disciplinary backgrounds and expertise in the use of diverse but complementary state-of-the-art measurement systems and analytical tools. The interventions they have developed target two key contexts, clinical rehabilitation (for stroke and Parkinson's disease) and elite sports and performance (football and rugby).

Improving movement for clinical rehabilitation

Stroke Rehabilitation: It is widely recognised that participation in intensive and repetitive task-oriented training promotes recovery of upper limb function after stroke. The key problem addressed by Richard Carson's research is that the severe muscle weakness (paresis) suffered by many stroke survivors prevents task-oriented training. Carson and colleagues in Australia developed the SMART (SensoriMotor Active Rehabilitation Training) Arm device to allow stroke survivors to engage in intensive and repetitive reaching practice. The research concerns the exploitation of neural plasticity in motor relearning—the means by which the brain can adapt and compensate for injuries—and optimising rehabilitation therapy in hospital and community settings. The SMART Arm is designed to make task-oriented, independent practice possible for stroke survivors with severe paresis. Randomised clinical control trials with chronic and acute stroke survivors have established its efficacy, showing the recovery of functional capacity **[R1]**. Hayward et al. (2017)**[R2]**

substantiated the neural mechanisms that mediate the positive outcomes of SMART Arm assisted training. This research exploited adjuvant techniques such as functional electrical stimulation (FES), and employed non-invasive brain stimulation and imaging of structural brain connectivity, to ensure that the clinical deployment is based on evidence of both neural and behavioural adaptation.

Parkinson's disease: Cathy Craig, Matthew Rodger and Mihalis Doumas have assessed movement control in Parkinson's disease at QUB for 10 years. They showed that ecologically valid sounds improve gait in people suffering from the neurodegenerative condition better than more typical metronome cueing devices **[R3, R4]**. Current work builds on this to investigate effects of Dance for PD®—a well-established programme of dance classes specifically designed for people with Parkinson's—on motor symptoms such as disordered gait and non-motor quality-of-life symptoms.

Improving movement for elite sports

Joost Dessing and Cathy Craig (now CEO at INCISIV) led the movement for elite sports research using custom virtual reality-based simulators for various sports, such as football, rugby and cricket. A key line of investigation focuses on the performance of goalkeepers in football during free kick scenarios. The group has used their virtual reality-based goalkeeping simulator to address many scientific and practical questions. The research showed that when a defending wall obstructs the goalkeeper's vision in free kick scenarios it negatively affects the goalkeeper's performance. This result should motivate goalkeepers and trainers to critically evaluate the balance between benefits and downsides of placing the wall—possibly with the aid of a virtual reality goalkeeping simulator—and consider omitting it in extreme cases **[R5].** Another line of investigation focused on how attacking rugby players perceive opportunities–passable gaps between defenders–and how defending rugby players perceive or are tricked by deceptive passing movements of attackers **[R6].**

3. References to the research

Stroke rehabilitation:

R1. Barker, R.N., Hayward, K. S., **Carson, R. G**., Lloyd, D., & Brauer, S. G. (2017). SMART Arm training with outcome-triggered electrical stimulation in subacute stroke survivors with severe arm disability: A randomised controlled trial. *Neurorehabilitation and Neural Repair*, 31(12) 1005–1016. doi: 10.1177/1545968317744276

R2. Hayward, K. S., Brauer, S. G., Ruddy, K. L., Lloyd, D., & **Carson, R. G.** (2017). Repetitive reaching training combined with transcranial Random Noise Stimulation in stroke survivors with chronic and severe arm paresis is feasible: a pilot, triple-blind, randomised case series. *Journal of Neuroengineering and Rehabilitation*, *14*(1), 46. doi: 10.1186/s12984-017-0253-y

Parkinson's Disease

R3. **Rodger M. W., Craig C. M.** (2016). Beyond the metronome: auditory events and music may afford more than just interval durations as gait cues in Parkinson's disease. Front Neurosci. 10: 272. doi: 10.3389/fnins.2016.00272.

R4. Young W. R., **Rodger M. W., Craig C. M.** (2014). Auditory observation of stepping actions can cue both spatial and temporal components of gait in Parkinson's disease patients. Neuropsychologia. 140-53. doi: 10.1016/j.neuropsychologia.2014.03.009. doi: 10.1016/j.neuropsychologia.2014.03.009

Elite Sports

R5. Valkanidis, T., **Craig C. M**., Cummins, A. & **Dessing, J. C**. (2020). A goalkeeper's performance in stopping free kicks reduces when the defensive wall blocks their initial view of the ball. PLoS ONE 15(12): e0243287. doi: 10.1371/journal.pone.0243287

R6. Correia, V., Araújo, D., Cummins, A., & **Craig, C. M.** (2012). Perceiving and acting upon spaces in a VR rugby task: expertise effects in affordance detection and task achievement. *Journal of Sport and Exercise Psychology*, *34*(3), 305-321. doi: 10.1123/jsep.34.3.305

4. Details of the impact

Clinical stroke rehabilitation impact

Stroke rehabilitation – SMART Arm

80% of stroke survivors lose arm and hand function, a long term issue for 60%. Over 50% of stroke survivors depend on others for everyday activities (Royal College of Physicians National Sentinel Stroke Clinical Audit, 2010). Informal care costs alone were estimated at EUR15,900,000,000 billion or 35% of the total EU stroke costs in 2015. Productivity losses were estimated to be EUR5,400,000,000 billion (The Burden of Stroke in Europe Report). Healthcare systems have limited human personnel capacity to address this burden and stroke survivors often have insufficient residual function for independent practice.

The SMART Arm actively engages stroke survivors to re-learn stroke compromised arm and hand movements. Active engagement is required to capitalise on the adaptive neural plasticity of the brain to restore everyday action abilities and reinstate independent living.

SMART Arm Pty Ltd launched in July 2012 to further develop, manufacture and market the technology. A provisional patent for the invention was filed in September 2016. Pre-commercial prototypes have been in use for several years in two clinical stroke units located in Queensland, Australia **[C1]**. NeuroMotion Pty Ltd are acquiring the rights to the SMART Arm product to complete 31-03-21 with a goal of the device to be market ready by June 2023. While the economic impact is in progress, the SMART Arm has had extensive impact in clinical training for stroke rehabilitation. Carr and Shepherd included the device in their widely used text 'Neurological Rehabilitation: Optimising Motor Performance', compulsory in all Australian Physiotherapy programs and Departments of Rehabilitation, and in many other countries **[C2]**. Also, the SMART Arm is covered extensively—embedded video, photographs, and illustrations of clinical outcomes—in Kleim (2012) Neural plasticity: foundations for neurorehabilitation **[C3]**.

Parkinson's Disease, Auditory cues and Dance

QUB research established that action-relevant sound cues improve movement and gait in people with Parkinson's disease, and demonstrated how musical sounds can guide and enhance movement in general **[C4]**. The positive links between sound and movement skills led to the development and testing of a series of dance-based interventions to improve movement and well-being in people with Parkinson's disease. The Dance for PD® interventions are co-designed with people with Parkinson's in the local community funded by an involvement award from Parkinson's UK, Thouron award and a Fulbright scholarship. From September 2018 the first weekly Dance for PD® classes started in Northern Ireland. Ten to fifteen people with Parkinson's disease participate in each class with over forty participants taking part in these interventions. The dance programme is tailored to the needs of people with Parkinson's in the local community (see video for details) with immediate impact for the participants based both on their impressions of the programme, for example one Parkinson's participant stated that the dance intervention was *"…a revelation… the mobility was beginning to reappear, and the flexibility was certainly more pronounced than it had been…"* **[C5, C6]**. Long term and global impact comes from the scientific assessment of the efficacy of Dance for PD as an intervention programme for improving motor, non-motor symptoms and quality of life for people suffering from Parkinson's disease.

Improving movement in elite sports

QUB's Movement Innovation lab has been a key facility in sports research—football, rugby and cricket players have participated to understand their perceptual and motor capabilities.

A long-term relationship with Ulster Rugby has allowed impact by contributing to science-based training instructions **[C7].** In addition, several movement games were designed for the Ulster Rugby Nevin Spence Interpretive Centre motivating public interest in STEM in sport. These games allow the public to interact with science-driven content and engage young people in STEM subjects.

Work with English Cricket Board captured in the Sky Sports documentary MindGames (Episode 4 16.35) allowed virtual practice in real world stadiums such as a virtual reality recreation of Lord's cricket ground **[C8]**.

In football, Joost Dessing's and Cathy Craig's virtual reality goalkeeping research has questioned commonly held views on the use of "the wall" in free kicks. This has led to extensive media attention **[C9]** and generated interest from many organizations (e.g., Royal Dutch Football Association, NI Goalkeeping Academy, Larne FC [both Northern Ireland]), already resulting in collaborations (and NI Goalkeeping Academy, Larne FC [both Northern Ireland]). Future training strategies suggested by this research can involve virtual reality tools, such as those marketed by Cathy Craig's company INCISIV. INCISIV is a sports analytics start-up company founded by Cathy Craig that aims to improve movement decision-making in professional sports people [C10].

5. Sources to corroborate the impact

Stroke rehabilitation:
[C1] ABC TV Catalyst program – SMART Arm.
http://go.qub.ac.uk/SmartArmABC

[C2] Janet Carr Roberta Shepherd (2010) Neurological Rehabilitation: Optimising Motor Performance. 2nd Ed. Churchill Livingstone (pp152).

[C3] Kleim, J. A. (2012). Neural plasticity: foundations for neurorehabilitation. TANAS, Scottsdale. (Interactive ebook, The Smart Arm appears in Chapter 7 with Video 7.3).
http://go.qub.ac.uk/KleimSmartArmBookVideo

Parkinson's disease
[C4] Euronews Futuris – Parkinson's disease and gait
http://go.qub.ac.uk/EuronewParkinsonsFeature

[C5] Parkinson's disease in dance video
http://go.qub.ac.uk/ParkinsonsDanceVideo

[C6] Letter from the Northern Ireland Area Development Manager for Parkinson's UK.

Elite sport
[C7] RTE One Rugby in the Movement Innovation Lab
http://go.qub.ac.uk/RTE1RugbyMovementLab

[C8] Sky Sports in the Movement Innovation Lab
Episode Four 16.35
http://go.qub.ac.uk/SkySportsCricketMILab
http://go.qub.ac.uk/SkySportsCricketMILab2

[C9] Public Outreach and Media document

[C10] INCISIV
http://go.qub.ac.uk/CathyCraigCompany