Institution: Keele University

Unit of Assessment: UoA12 Engineering

Title of case study: Measurement and modelling of human movement & performance to optimise rehabilitation and prevent injury

Period when the underpinning research was undertaken: 2000 - 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:
Prof Anand Pandyan	Professor of Rehab Technology	2002 - present
Dr Caroline Stewart	Senior Research Fellow	2013 - present
Dr Edward Chadwick	Senior Lecturer	2012 - 2019
Dr Dimitra Blana	Research Fellow	2013 - 2019
Dr Fraser Philp	Lecturer	2018 - present
Mr Richard Barnett	Lecturer	2005 - present
Robert Taylor	Research User Group	n/a

Period when the claimed impact occurred: 2014 - 2020

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

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

Our interdisciplinary research team has worked with stakeholder groups to advance methods of measurement and modelling of human movement and performance and informed practice across areas, including: the health care sector (rehabilitation, assistive technology, and neurosurgical intervention), elite performance (i.e., injury prevention and risk minimisation algorithms), and government policy (Ministry of Justice). This has changed clinical practice (Spasticity Assessment protocol in SATH), informed industry strategy (new indications for use of drug), and changed restraint policy in the youth justice systems, both in the UK and Internationally. The knowledge gained from our research underpins state-of-the-art education and CPD training delivery.

2. Underpinning research (indicative maximum 500 words)

Interdisciplinary biomedical engineering research has evolved from a long-standing partnership between engineers, clinical scientists, and therapists; and is informed by community-based patient groups. The research is recognised, nationally and internationally, for innovative measurement (3D clinical movement analysis, modelling, and non-invasive clinical assessment methodology), assistive technology (orthoses, hybrid orthoses, and electrical stimulation) and statistical modelling. This broad portfolio of research and the key programmes that have underpinned the impact are summarised as follows:

- 3D movement analysis and modelling research underpins clinical work at the Orthopaedic and Locomotor Research Unit (ORLAU) and routinely informs surgical practice in children with cerebral palsy (CP) [3.1]. ORLAU was the first centre in the UK to perform Selective Dorsal Rhizotomy (SDR) for children with CP, publishing detailed patient selection criteria based on 3D movement analysis. In SDR the surgeon cuts the sensory nerves that provides signals to the spinal cord - the theory being that by reducing the input to the spinal cord, one can reduce spasticity (unwanted and excessive muscle activity) that can interfere with function, cause pain, and lead to limb deformities.
- Spasticity is also a common clinical condition in stroke patients and contributes to complications in 50% of stroke survivors. We have developed non-invasive bedside methods to clinically quantify and classify spasticity and joint stiffness [3.2]. Data from this work was central to the redefinition and classification of spasticity. Our data has shown that spasticity

occurs earlier than predicted previously and, if untreated, leads to complications of both limb deformity and pain [3.2]. We have since conducted clinical studies that have demonstrated that the early treatment of spasticity, using either Electrical Stimulation (ES) or Botulinum Toxin (BoNT), prevented deformities from developing and reduced pain [3.3 & 3.4]. Further, we demonstrated that treatment with electrical stimulation facilitated recovery of function and treatment with BoNT did not cause any risk of harm [3.3 & 3.4].

- Expanding the methods of modelling with computation analysis and simulation, we have developed advanced models of the upper limb musculoskeletal system to optimise the design of assistive technologies such as implanted electrical stimulation for spinal cord injury and advanced prosthetic devices for limb loss [3.5]. Real-time simulation of movement has enabled research exploring personalised hybrid orthotic solutions (i.e., using a combination of nerve graft surgery and assistive technology), to facilitate functional recovery in severely disabled patients with SCI (Spinal Cord Injury) [3.5].
- Research on 3D measurement and modelling of human performance has also been extended to study performance capabilities in elite sports (i.e., football) and evaluate the currently used performance measures (Functional Movement Screen – FMS). Advanced statistical model application has demonstrated that the FMS lacked validity, both as a measure and a predictor. The existing injury risk prediction algorithms based on the FMS measures were shown to be ineffective leading to the development of new injury prediction models based on routinely collected match play data [3.6].

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

3.1 Laracca E, Stewart C, Postans N, Roberts A (2014) The effects of surgical lengthening of hamstring muscles in children with cerebral palsy – The consequences of pre-operative muscle length measurement. Gait & Posture;39: 847-851.
3.2 Malhotra, AD Pandyan, S Rosewilliam, C Roffe, H Hermens (2011) Spasticity and contractures at the wrist after stroke: Time course of development and their association with functional recovery of the upper limb. Clinical Rehabilitation, 25(2), 184 – 191
3.3 Cousins E, Ward A, Roffe C, Rimington L, Pandyan A. (2010) Does low-dose botulinum toxin help the recovery of arm function when given early after stroke? A phase II randomized controlled pilot study to estimate effect size. Clinical Rehabilitation; 24: 501–513. doi.org/10.1177/0269215509358945
3.4 Rosewilliam S, Malhotra S, Roffe C, Jones P, Pandyan AD. (2012) Can surface neuromuscular electrical stimulation of the wrist and hand combined with routine therapy facilitate recovery of arm function in patients with stroke? Archives of Physical Medicine & Rehabilitation, 93, 1715-21 e1. doi.org/10.1016/j.apmr.2012.05.017
3.4 Chadwick EK, Blana D, Kirsch RF, van den Bogert AJ. (2014). Real-time simulation of three-dimensional shoulder girdle and arm dynamics. IEEE Trans Biomed Eng, vol. 61(7), 1947-1956.
3.5 Chadwick EK, Blana D, Kirsch RF, van den Bogert AJ. (2014). Real-time simulation of three-dimensional shoulder girdle and arm dynamics. IEEE Trans Biomed Eng, vol. 61(7), 1947-1956.
3.6 Philp F, Blana D, Chadwick EK, Stewart C, Stapleton C, Major K, Pandyan AD (2018) Study of the measurement and predictive validity of the Functional Movement Screen. BMJ Open Sport Exerc Med 4(1): e000357. http://dx.doi.org/10.1136/bmjsem-2018-000357

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

Establishing Innovative practice in the UK and beyond

Our 3D movement measurement and models [3.1] are now routinely used to plan surgery in children with CP [5.1] and the standard operating procedures at ORLAU have informed the UK wide gait lab accreditation guidelines [https://cmasuki.org/cmas-working-groups/]. ORLAU established the first SDR service in the UK, using gait analysis as the precursor for determining suitability for SDR, which meant that children and their families no longer had to travel internationally or pay for this treatment. The robust patient selection criteria has meant that most patients benefited from treatment and that benefits have been maintained during the rapid growth phase of adolescence and patients continue to be monitored via a bespoke longitudinal database [5.1].

Improving outcomes in patients with severe levels of disability
We demonstrated that limb deformities and pain, a common problem in severely disabled neurological patients (e.g., those with a severe stroke or in a disordered state of consciousness), can be reduced by measuring and appropriately treating these patients with a combination of BoNTA and electrical stimulation [5.2, 5.3, 3.2 & 3.3]. NICE are updating their guidelines on Stroke Rehabilitation in adults to include the use of BoNTA as a result of our randomised clinical trials [5.2, 5.11]. Further, our research demonstrated that early treatment has the potential to facilitate the recovery of arm function. We have informed clinical guidelines [5.3, 3.2 & 3.3] and the management of patients in states of disordered consciousness [5.4, 5.5 & 3.2 to 3.5]. The assessment protocols and devices developed through our research are being implemented in specialist spasticity clinics within the NHS and the third sector [5.4 & 3.2]. Our research [3.5] has underpinned the concepts that have pushed development of the concept of ES combined with brain-computer interface, to be used to control arm function in patients with tetraplegia [5.5, 3.5]. The world-first, successful proof of concept is now in clinical trials (An Early Feasibility Study of the ReHAB System; https://www.clinicaltrials.gov/ct2/show/NCT03898804).

Informing restraint policy
The methods of measurement, initially developed for use in the health care sector (3.2), have been used to test whether restraint practices used across juvenile custodial settings (Young Offender Institutions, Secure Training Centres, Secure Children homes), court transport services, and border force agencies are safe. The methods of restraint used in the justice system or secure NHS facilities, risks causing death or substantive injury to the person being restrained. Eliminating the need for restraint is an ideal scenario, however, if this is not possible the aim is to ensure that the restraint techniques used cause no harm. Our research has examined current practice and has identified restraints positions that can be harmful to a child [5.6]. Research from Keele has been directly responsible for a range of restraint techniques being withdrawn from use both nationally and internationally [5.7].

Mr Stirling (Senior VP, Crisis Prevention Institute) has said "*In 2019, over 1.3 million professionals around the world completed our programme and as a result of our collaborative work, I can say that this has translated into safer approaches*." He goes on to conclude that the research has "*... mitigated as much as is reasonably practicable, the chances of a physical intervention taught within a CPI programme leading to an adverse outcome*." [5.7]

Modelling to improve injury prevention/treatment algorithms
The injury risk of a player, particularly in elite football and rugby, is based on a specialised screening test: Functional Movement Screening (FMS). The FMS is currently considered the industry standard test. Since the publication of our seminal work on proving that the FMS was not valid [3.6] our researchers have been invited to conduct in-service training to Sports and Exercise Medicine teams in premiership football clubs on how to use our research findings to update their algorithms to screen, predict risk of injury and return to plan in the premiership [5.8 & 3.6]. The Lead EDS Physiotherapist from Manchester City Football Club has said "*information presented from your research had a positive impact on how we approach screening from an injury management perspective and also how Functional Movement Screening is viewed*." [5.8]. These statistical methods of analysis have application beyond elite sports and are being used to develop improved algorithms for the clinical management and prevention of falls in the frail elderly care home population [5.9].

Impact on training and clinical practice
The team has internationally recognised expertise and individual members are routinely invited to conduct CPD training courses for clinicians both nationally (i.e., Biannual Liverpool Spasticity Course at the Walton Centre) and internationally (e.g., Indian Federation of Neurorehabilitation, Singapore Rehabilitation Congress) [5.10]. Further, Caroline Stewart has served (since 2012) as lead station writer for Rehabilitation Engineering (one of three specialisms of clinical engineering), served on the National School of Healthcare Science exam board for clinical engineering, and was a part of the 2020 team that redesigned the clinical engineering curriculum and gait analysis

competencies (Meet the Lead Editor http://curriculumreview.nshcs.org.uk/?programme=stp&tracker=clinical-engineering).

Impact on industry
Our work with botulinum toxin has impacted industry [5.11]. We work with two (Abbvie (previously Allergan) and Merz) of the three manufacturers of botulinum toxin; we are members of their clinical advisory boards and train their staff on the early use of botulinum toxin in post stroke spasticity [5.10]. An industry professional has said that the following in relationship to our work "*... the EUBOSS data will be extremely valuable for HCPs especially in countries like the US and France etc. The Americans in particular are very excited about this data*." [5.11]

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

5.1 The 3D movement and modelling was central to establishing UK wide guidelines and underpinned the setting up of the first SDR service in the country that is now being used to monitor long term outcomes. *McFall, J., et al. "Changes in gait which occur before and during the adolescent growth spurt in children treated by selective dorsal rhizotomy." Gait & posture 42.3 (2015): 317-322* – the Database of patients who have undergone SDR at RJAH is available via Dr Caroline Stewart the Manager of ORLAU

5.2 Finding from the Phase II study that followed from 3.2 and 3.3 (*Lindsay C et al (2020). Can the early use of botulinum toxin in post stroke spasticity reduce contracture development? A randomised controlled trial. Clinical Rehabilitation https://doi.org/10.1177/0269215520963855*) Trial Registration EudraCT (2010-021257-39) and ClinicalTrials.gov-Identifier: NCT01882556 (EUBoSS).

5.3 Our research has informed a range of clinical guidelines and clinical practice handbooks and this is one example of a NICE accredited guideline: "*Splinting for the prevention and correction of contractures in adults with neurological dysfunction", published by the College of Occupational Therapists 2015, in conjunction with the Association of Chartered Physiotherapists in Neurology (ACPIN).*

5.4 Our research has changed practice in a range of clinical settings where patients with complex neurological disability are managed, an example of this impact is provided in this *testimonial from Rasheed Meeran, Director of Clinical Services, Holy Cross Hospital, Haselmere.*

5.5 Our research has contributed to leading developments in brain-controlled muscle stimulation for hybrid orthoses (as illustrated by *Restoration of reaching and grasping movements through brain-controlled muscle stimulation in a person with tetraplegia: a proof-of-concept demonstration* - https://www.thelancet.com/journals/lancet/article/PIIS0140-6736%2817%2930601-3/fulltext) and other telerehabilitation technologies.

5.6a Independent review of the use of pain-inducing techniques in the youth secure estate (https://www.gov.uk/government/publications/independent-review-of-the-use-of-pain-inducing-techniques-in-the-youth-secure-estate) The review by Charlie Taylor included recommendations based on our research (Barnett).
5.6b The Government (Ministry of Justice) has adopted the recommendations in the report, based on this research.

5.7 Based on 5.6, the Crisis Prevention Institute (CPI), an international training provider for safe management of disruptive and assaultive behaviour, has updated all of their training manuals and procedures to reflect the findings from our research (see *testimonial from Chris Stirling Senior Vice President of Crisis Prevention Institute, UK).*

5.8 *Testimonial from Nick Oakley, Lead Physiotherapist at Manchester City Football Club.*

5.9 Editorial: https://link.springer.com/article/10.1007/s41999-020-00384-1 (Ihama F, Pandyan A,

Roffe C (in press). Assessment of fracture risk tools in care home residents: a multi-centre observational pilot study. European Geriatric Medicine.)

5.10 Industry engagement, CPD / Training and curriculum development. Log of CPD activity delivered and informed by the research team.

5.11 Communication from Mark Fredericks, Senior Medical Affairs Manager, Allegan International on the impact of the EUBoSS trial [5.2] on NICE guidance for Stroke Rehabilitation.