Institution: University of Salford

Unit of Assessment: 3

Title of case study: Transforming products and improving practice in human movement and rehabilitation

Period when the underpinning research was undertaken: September 2009 – June 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. Richard Baker	Professor of Clinical Gait Analysis	January 2010 – September 2019
Prof. David Howard	Professor in Biomedical Engineering	June 1989 – Present
Prof. Richard Jones	Professor in Clinical Biomechanics	February 2003 – Present
Prof. Laurence Kenney	Professor in Biomedical Engineering	October 2000 – Present
Prof. Chris Nester	Professor of Foot Health	September 1996 – Present
Dr Daniel Parker	Lecturer in Digital Health	December 2013 – Present
Dr Carina Price	Research Fellow in Footwear	May 2011 – Present
Dr Anita Williams	Reader in Podiatry	December 1999 – Present

Period when the claimed impact occurred: March 2015 – December 2020

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

1. Summary of the impact

Salford's Human Movement and Rehabilitation team works with industry across the globe to improve the lives of people with mobility problems. This ranges from people who have difficulty walking and rely on gait analysis to inform diagnosis and treatment, to the millions of workers who stand for long periods at work and suffer musculoskeletal pain and to the survivors of stroke, for whom regaining limb movement is key to their daily activities. In addressing these issues, Salford's research led to the first major update to clinical gait analysis methods in 40 years, impacting the work of 1,000 clinical laboratories worldwide, some 80% of the global sector; it challenged the occupational footwear sector's focus on accident prevention, redirecting it toward footwear to protect musculoskeletal health, resulting in a new company, strategy and products (>60,000 sold); and it produced a patented rehabilitation technology that provides high-quality physical therapy without the need for highly skilled staff, resulting in a spin-out company in China, investment of GBP2,000,000 and benefitting 1,350 patients in its first 18 months.

2. Underpinning research

Research into human movement and rehabilitation at the University of Salford has led to advances in (1) the clinical assessment of gait problems and therapies, (2) occupational footwear and musculoskeletal health and (3) limb rehabilitation post-stroke:

2.1. Global improvements in the accuracy and reliability of clinical gait assessment

Assessment of mobility problems in approximately 1,000 clinical laboratories across the world relies on accurate measurement of gait. Previously, however, the accuracy and reliability of data on skeletal movements was highly sensitive to the clinician correctly locating measurement devices on patient limbs. In addition, the mathematical models used to calculate the data were known to contain large errors, potentially larger than clinical effects. These issues were particularly problematic in clinics run by less experienced staff and those treating obese patients

(approximately 30% of the patient group). Furthermore, standard models for the upper body were not available. These issues raised clinical governance issues, made data sharing between sites difficult and impacted on diagnosis, treatment planning and evaluation (e.g. orthopaedic surgery).

Research led by Baker, Jones and colleagues, in collaboration with a team in Melbourne (Australia), produced wide-ranging novel methods and models that reduced measurement error and improved data reliability. Made available open source to the global gait research and clinical community (>1,000 laboratories), it was the first major advancement in the field for 40 years. Measurement errors in joint centre location were reduced by over 25% at the hip joint **[3.1]**, achieved through more accurate equations and use of the largest data set ever available for this purpose (computed tomography (CT) data on 157 cadavers). The lower limb model was extended to include the upper body for the first time, producing the first validated method for measuring trunk movements **[3.2]**. The team also solved the major problems with how force variables were normalised, improving consistency of data reporting.

2.2. Workplace footwear impacts on musculoskeletal health

At the start of the REF census period the occupational footwear sector was exclusively focussed on reducing workplace injury by avoiding accidents. Research led by Nester proved that many workers (e.g. in NHS surgical theatres, hospitality, and catering) were at increased risk of musculoskeletal injury due to their occupational tasks, identifying that footwear can reduce injury risk.

Salford's research revealed the high prevalence of back and lower limb pain in jobs involving prolonged standing and the interaction between the environmental demands of specific workplaces and musculoskeletal pain **[3.3]**. This explained previous results revealing that workers associate their feet and footwear with musculoskeletal injury. The research subsequently revealed why workers with different occupations have different footwear needs and that footwear affects workplace comfort. New footwear products were researched and evaluated, with results evidencing an association with positive musculoskeletal outcomes for workers **[3.4]**.

2.3.Technology-driven solutions to the global shortage of physical therapists

Gold standard post-stroke arm rehabilitation is expensive, relying on intensive support from highly skilled clinical staff (e.g. physiotherapists). This is a barrier to its delivery in the NHS and countries with less developed health systems.

Howard and Kenney developed a now patented system **[3.5]** for performing functional electrical therapy, which uses electrical stimulation of arm muscles **[3.6]** to enable stroke patients with weak or paralysed muscles to practise upper limb tasks themselves, while simultaneously providing automated feedback on their performance. Crucially, they demonstrated that the system could be used in a range of different care settings, requiring only therapist assistants for its delivery **[3.7]** and therefore reducing skill and cost barriers to implementation at scale.

3. References to the research

3.1. Leboeuf F, Reay J, **Jones R**, Sangeux M. (2019) The effect on conventional gait model kinematics and kinetics of hip joint centre equations in adult healthy gait, *Journal of Biomechanics* 87: April 2019, pp. 167-171. https://doi.org/10.1016/j.jbiomech.2019.02.010

3.2. Leboeuf F, **Baker R**, Barre A, Reay J, **Jones R**, Sangeux M. (2019) The conventional gait model, an open-source implementation that reproduces the past but prepares for the future, *Gait & Posture* 69: March 2019, pp. 235-241. https://doi.org/10.1016/j.gaitpost.2019.04.015

3.3. Anderson J, **Nester C**, **Williams A** (2018) Prolonged occupational standing: the impact of time and footwear, *Footwear Science*, 10:3, pp. 189-201. https://doi.org/10.1080/19424280.2018.1538262

3.4. Anderson J, **Williams AE**, **Nester C.** (2020) Development and evaluation of a dual density insole for people standing for long periods of time at work, *Journal of Foot and Ankle Research,* 13(1):42. https://doi.org/10.1186/s13047-020-00402-2

3.5. Kenney L, **Howard D**, Sun S, Smith C. A System for Performing Functional Electrical Therapy, Patent, GB1522721.8 (Granted December 2019)

3.6. Sun M, Smith C, **Howard D**, **Kenney L**, Luckie H, Waring K, Taylor P, Merson E, Finn S. (2018) FES-UPP: A flexible functional electrical stimulation system to support upper limb functional activity practice, *Frontiers in Neuroscience*, 2018;12:449. https://dx.doi.org/10.3389%2Ffnins.2018.00449 **(REF2)**

3.7. Smith C, Sun M, **Kenney L**, **Howard D**, Luckie H, Waring K, et al. (2019) A three-site clinical feasibility study of a flexible functional electrical stimulation system to support functional task practice for upper limb recovery in people with stroke, *Frontiers in Neurology*, 2019;10:227. https://dx.doi.org/10.3389%2Ffneur.2019.00227 **(REF2)**

Associated grants:
Howard D, **Kenney L**, Smith C, Williamson T, Thies S. An advanced FES rehabilitation tool for upper limb therapy after stroke. NIHR New and Emerging Applications of Technology programme (L030) for GBP470,753 (September 2009 – May 2013)
Kenney L, **Howard D**, Hardiker N, Williams T, Taylor P, Finn S. A practical, yet flexible functional electrical stimulation system for upper limb functional rehabilitation. NIHR Invention for Innovation grant (II-LB-0313-20002) for GBP568,894 (January 2014 – July 2017)
Nester C, **Williams A**. Embedding an applied research function into product development resulting in world class footwear for demanding environments. Innovate UK (Toffeln KTP 9994) for £115,140 (March 2015 – August 2018).

4. Details of the impact

Research by Salford's Human Movement and Rehabilitation team **[2.1 – 2.3]** has benefitted people who suffer mobility problems by influencing practice across the global clinical gait analysis sector, shaping individual companies and their products and services at a sector level, and introducing innovative health technologies into new territories, with immediate impact on patients.

4.1. Developing the industry standard for clinical gait analysis

Researchers at Salford provided the first major update to the clinical gait model and methods for 40 years, transforming the quality of data and measurement standards globally **[see 2.1]**. Indicative of the transformational impact of Salford's research, the **new model was adopted by the two global leaders in gait analysis software:** Vicon and Qualysis, who supply approximately **80% of the clinical gait laboratories across the world [5.1, 5.2]**. The new standards are now relied upon by **1000 clinical laboratories worldwide [5.1, 5.2]**, with the Salford model and methods hailed as *'a significant turning point'* and *'universally welcomed'* by the sector **[5.2]**, producing **more accurate and reliable data on approximately 250,000 patients per year**. A Product Manager at Qualysis attests that *'the quality of the science [at Salford] has led to a renewed confidence in what laboratories can achieve for patients'* **[5.2]**. The Head of Product Management at Vicon confirms that the new model *'offers a very global and inclusive solution to how the sector might avoid future long periods without innovation. Perhaps this is the greatest impact that will bear out over time'* **[5.1]**. Qualysis adds that *'the fact the Salford model has been implemented by all other major motion capture manufacturers firmly establishes it as the* ***first industry standard for clinical gait analysis****'* **[5.2]**.

Even before the official academic publication in 2018/2019, the methods and models produced by Salford were being adopted and **transforming user connectivity within the global clinical gait analysis sector [5.3, 5.4]**. The global community of approximately 1000 clinical laboratories now has a **free and stand-alone alternative** to the software offered by vendors. This means that gait data is, for the first time, **compatible between clinical centres across the world** and historical **barriers to national and international standardisation and collaboration have been removed [5.3, 5.4]**. The Australian laboratory community has commenced national roll-out of the Salford model as a minimum standard **[5.3]**, and equivalent United Kingdom and European Associations provide workshops to facilitate roll-out **[5.3]**.

Furthermore, Salford's research has led to the **removal of major barriers to future innovation of the model and its applications [5.3]**: critically for clinical users, the **model is easier to use and data is backward compatible**, which means that old and new data sets work seamlessly together – this is a key issue in tracking the progress of patients over time **[5.1, 5.2]**. The lack of backward compatibility of solutions proposed by other researchers meant that users faced making their existing clinical data (often collected over 20 or more years) unusable, and hence innovation stalled over several decades **[5.1, 5.2, 5.3]**. This has now been permanently addressed in the new Salford model. This is **crucial for clinical governance** because data on movement problems and treatments must be tracked over time, so a change in model could invalidate all prior patient measurements.

4.2. Improving workplace musculoskeletal health and footwear, leading to new business opportunities and products

Researchers at Salford evidenced a need to produce footwear that protects against musculoskeletal injuries that occur due to workplace *tasks*, rather than workplace slip, trip and fall accidents **[see 2.2]**. This new focus was highly disruptive to a tightly regulated and therefore conservative sector (EN ISO 2347, 2345), drawing the attention of the Health and Safety Executive to an issue largely ignored to date **[5.5]**.

By forging this new space in the occupational footwear sector, Salford's research enabled a top 3 UK occupational footwear company (Toffeln Ltd.) to completely **rethink its business strategy** after 30 years in the sector **[5.5, 5.6]**. The company split, creating a new company, WearerTech Ltd., in August 2017, with a business plan based entirely on the **new market space and new footwear products** developed through the research **[2.2]**. This attracted **GBP500,000 of external investment** and executive talent from outside the footwear sector for the first time, with the impact of Salford's research on the business being described as *'transformational'* by its Co-owner **[5.5]**.

The new company **created 9 jobs** (headcount: 9; FTEs: 9, including an applied researcher role), has approximately **GBP2,000,000 annual turnover** and distributes to approximately **30 countries [5.5]**. Some **70% of their product range** (and therefore business) is derived from Salford's research, with one Salford product selling **60,000 pairs** since its launch in April 2019 alone **[5.5]**.

The Salford-created, unique 'musculoskeletal injury' market proposition and footwear products were pivotal in **opening access to previously inaccessible global corporations [5.6]**. WearerTech is the **only brand in Europe using the scientific and health merits of their footwear** to underpin their marketing. As a result, WearerTech now **supplies the world's two largest catering organisations** (Compass and Sodexo, which have annual revenues of GBP40 billion), with the Culinary Director at Sodexo stating his '*instant attraction'* to the concept of footwear that addresses pain in the workplace *'because of the research done with Salford University'* **[5.5, 5.7]**. Other new partners include the Hilton and Marriott hotel chains, who are normally only accessible if there is an '*exceptional market proposition*' **[5.5]**.

4.3. Delivering high-quality, low-cost physical therapy through technology investments in China

The stroke rehabilitation sector in China is inadequate in scale and coverage and typically delivered using traditional, labour-intensive approaches **[see 5.8]**. High intensity practice of functionally relevant tasks is seen as the 'gold standard' in upper limb rehabilitation and Salford's post-stroke rehabilitation technology **[see 2.3]** was recognised as a solution which could be scaled faster than alternative routes (for example, through the training of more physiotherapists).

Salford's research led to the **creation of a University spin-out company**, BetR Medical Technology Co., in February 2018 through a **GBP690,000 investment** resulting from a successful pitch at a prestigious Chinese innovation investment competition **[5.8]**. The company was established to meet the huge demand for stroke rehabilitation in China, which records 2,000,000 new stroke cases each year **[5.8]**. Since its inception the company has **created 9 engineering jobs** (headcount: 9; FTE:9) and has **delivered technology-enabled stroke rehabilitation to approximately 1350 patients** via a contract with Minzu Hospital in Jinan, China, with contracts in place with two further hospitals to support the therapy **[5.8, 5.9]**. The service is **growing at 25% per year** and provides an estimated **40% improvement in service efficiency** compared to traditional therapy **[5.9]**.

The company has now attracted **a further GBP1,400,000 in investment from angel and government investors**, to produce a new upper limb functional electrical stimulation system, at the core of which lies the controller developed in Salford **[5.8]**. BetR Medical has established a **new dedicated factory** (measuring 2105m^2), which is being equipped to manufacture the new functional electrical stimulation system **[5.8]**.

5. Sources to corroborate the impact

5.1. Testimonial: Vicon Motion Systems Ltd. (February 2021), on the importance of Salford's research on clinical gait analysis to the sector in general and Vicon's business specifically (4.1)
5.2. Testimonial: Qualysis Motion Capture Systems (February 2021), on the importance of Salford's research on clinical gait analysis as the first industry standard (4.1)
5.3. Testimonial: Gait Laboratory, University Hospital of Nantes (February 2021), on Salford's clinical gait model removing barriers to internationalisation and innovation in the sector (4.1)
5.4. Testimonial: BG Clinic Ludwigshafen, Germany (February 2021), on the impact of Salford's clinical gait model in addressing the limitations of previous models (4.1)
5.5. Testimonial: WearerTech Ltd. (February 2021), on the transformational impact of Salford's KTP on its business strategy and product range and access to new customers (4.2)
5.6. Video: *'The Wearer Innovation Loop'*, available at: https://www.youtube.com/watch?v=jHwiTzxK7_Y, explaining the product innovation created through the KTP project, with descriptions from WearerTech's Head of Product Design (4.2)
5.7. Video: *'Introducing the WearerTech and Sodexo Partnership'*, in which the Culinary Director at Sodexo explains the reasons for the company adopting the footwear technology, available at: https://www.youtube.com/watch?v=iC3C9INkT04 (4.2)
5.8. Testimonial: Shandong BetR Medical Technology Co., Jinan, China (February 2021), on the impact of Salford's research on enabling technology-enabled stroke rehabilitation to be implemented in China and further investment to produce a new stimulation system (4.3)
5.9. Testimonial: Minzu Hospital, Jinan, China (January 2021), on the delivery of Salford's technology-enabled stroke rehabilitation technologies in the hospital (4.3)