Institution: University College London

Unit of Assessment: 12- Engineering

Title of case study: Gowerlabs – advancing optical brain imaging for neuroscience applications in industry

Period when the underpinning research was undertaken: 2001 - 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:
Nick Everdell	Senior Research Associate	2001 - date
Jeremy Hebden	Professor of Biomedical Optics	1992- date
Robert Cooper	Research Fellow	2007- date
Samuel Powell	Research Fellow	2009- 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

Research and innovation at UCL's Biomedical Optics Research Laboratory has led to the first commercially available wearable brain imaging devices (LUMO). The high-density optical brain imaging system developed at UCL has been commercialised via a UCL spin-out company – Gowerlabs. The LUMO system, which allows brain activity to be measured under almost any conditions for the first time, is used by tech giants (Facebook, Apple), the healthcare technology sector (Philips) and medical research institutions (Sahlgrenska University Hospital, Sweden). The technology is opening up new avenues for studying brain activity which have been widely publicised in the media. Gowerlabs, which employs 5.0 FTE, has achieved worldwide sales exceeding [TEXT REMOVED FOR PUBLICATION] since August 2013.

2. Underpinning research

Diffuse Optical Tomography (DOT), also known as functional near-infrared spectroscopy (fNIRS), measures brain activity using low levels of near-infrared light that travels through the brain cortex via the scalp and skull. It is delivered using an array of sources and detectors that are placed on the head. DOT devices measure the intensity of the light that is diffusely reflected back from the brain cortex and which is sensitive to localised changes in blood volume and oxygenation that result from neurological activity. Recorded data can be presented as maps of changes that result from sensory stimuli and cognitive activity, as well as from certain neurological disorders and brain trauma. The near-infrared light used for DOT is non-ionizing, so repeated exposure is completely safe. Whilst DOT and functional MRI both use haemoglobin as the source of biological contrast, DOT devices are a fraction of the cost and size of a conventional MRI scanner. The small form factor of these systems also makes them ideal for portable and wearable applications.

Dr Nick Everdell and his multidisciplinary group at the UCL Biomedical Optics Research Laboratory (BORL) have made significant improvements to this technology. The original benchtop device – the Near-Infrared Tomography System (NTS) – was developed by Dr Nick Everdell, Professor David Delpy and Professor Jem Hebden, in the BORL – at UCL for the development of optical and photoacoustic technology in medical imaging – with support from a Wellcome Trust grant in 2005 (**R1**). This project established the efficacy of their chosen multiplexing technology – frequency encoding. This type of encoding facilitates rapid imaging rates (up to 10Hz) by allowing all the light sources to be illuminated simultaneously,

while allowing the detectors to discriminate between them. This higher rate is important as it prevents the possibility of interference from the cardiac pulsation of blood vessels.

Their novel encoding system meant that the optical sources and detectors could be flexibly placed wherever was convenient on the head, unlike most competitor systems at that time. This enabled EEG electrodes to be easily interleaved with the sources and detectors, allowing straightforward integration of the two technologies to give a multimodal imaging system. Singh *et al*. (**R2**) were the first to demonstrate an association between neonatal seizures and large, localised changes in haemoglobin concentration within the cortex of the infant brain. This was one of several clinical research findings that were made possible by this system.

In 2013 the group was awarded a Healthcare Technology Challenge grant by EPSRC (EP/K020315/1) and GBP400,000 was committed to the development of a next-generation imaging system. The aim was to develop a high-density, wearable and wireless device that would significantly increase imaging resolution and be applicable in a real-world setting. The system developed (microNTS) was the first ever miniaturized, fibreless DOT system, able to generate high quality images with a flexible array configuration. This world-leading device dispensed with the heavy optical fibres of the benchtop design and placed the light sources and detectors directly on the scalp (**R3**). This improves signal quality as well as providing a wearable system that greatly expands the potential range of applications of the technology. As part of this grant, a multi-wavelength wearable device was also developed, specifically measuring changes in cytochrome oxygenation in addition to the haemoglobin changes that the first device measured. Cytochrome oxidase is a biomarker of cell metabolism and, unlike haemoglobin, its measurement can give valuable information about the internal environment of the cell. Chitnis *et al*. (**R4**) describes the first ever multiwavelength wearable system designed for this purpose.

Brain imaging systems, including DOT, are calibrated using phantoms – materials that have similar properties to human tissue and can be designed to mimic brain activation. Dr Everdell's research group pioneered development of tissue-equivalent optical phantoms. The group developed the first multimodal phantom to allow simultaneous EEG and near-infrared measurements (**R5**). They also developed the first electrically activated dynamic phantom for near-infrared measurements (**R6**).

This underpinning research led to successful knowledge transfer via the founding of Gowerlabs as a spin-out company from BORL. Dr Everdell was recognised as an exceptional innovator by the Royal Academy of Engineering and was awarded an Enterprise Fellowship in 2015.

As well as Dr Everdell, the following people have significant input into Gowerlabs:

- Professor Jeremy Hebden – former Head of Department - joined UCL in 1992
- Dr Robert Cooper – EPSRC Research Fellow - joined UCL in 2007
- Dr Samuel Powell – RAEng Research Fellow - at UCL between 2009 and 2018, currently employed by the University of Nottingham.

3. References to the research

Diffuse Optical Tomography

R1 **Everdell NL**, Gibson AP, Tullis I, Vaithianathan T, Hebden JC, Delpy DT. (2005) A frequency multiplexed near-infrared topography system for imaging functional activation in the brain. *Review of Scientific Instruments.* 76(9) DOI: 10.1063/1.2038567.

R2 Singh RJ, Cooper CW, Lee L, Dempsey A, Edwards S, Brigadoi S, Airantzis D, **Everdell NL**, Michell A, Holder D, Hebden JC, and Austin T. (2014) Mapping cortical haemodynamics during neonatal seizures using diffuse optical tomography: a case study, *Neuroimage: Clinical*. 5, 256-265, DOI: 10.1016/j.nicl.2014.06.012.

R3 Chitnis D, Cooper RJ, Dempsey L, Powell S, Quaggia S, Highton D, Elwell C, Hebden JC, **Everdell NL**. (2016) Functional imaging of the human brain using a modular, fibre-less, high-density diffuse optical tomography system. *Biomedical Optics Express.* 7(10):4275-4288 DOI: 10.1364/BOE.7.004275.

R4 Chitnis D, Airantzis D, Highton D, Williams R, Phan P, Giagka V, Powell S, Cooper RJ, Tachtsidis I, Smith M, Elwell C, Hebden JC, **Everdell NL** (2016). Towards a wearable near infrared spectroscopic probe for monitoring concentrations of multiple chromophores in biological tissue in vivo. *Review of Scientific Instruments.* 87(6):065112 DOI: 10.1063/1.4954722.

Tissue equivalent phantoms

R5 Cooper RJ, Bhatt D, **Everdell NJ**, Hebden JC.(2009) A tissue-like optically turbid and electrically conducting phantom for simultaneous EEG and near-infrared imaging. *Institute of Physics and Engineering in Medicine* *Physics in Medicine & Biology*. 54(18). DOI https://doi.org/10.1088/0031-9155/54/18/N01

R6 Hebden JC, Joanna Brunker, Teresa Correia, Ben D Price, Adam P Gibson, **Everdell NL**. (2008) An electrically-activated dynamic tissue-equivalent phantom for assessment of diffuse optical imaging systems, 2008, *Physics in Medicine & Biology* 53(2). DOI: 10.1088/0031-9155/53/2/002

Intellectual Property

Registered EU design rights granted by the EUIPO for the wearable imaging system in 2017 (registration number 004038206).

Patent W0/2018/033751 filed 2017 and published 2018, Measuring apparatus and device for measuring changes in chromophore concentration (Everdell, N).

4. Details of the impact

Human brain imaging is critical for both clinical practice and neuroscience research. The technologies currently in use, such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) are expensive, immobile and require designated hospital space or research facilities. For example, the systems cannot be used to monitor the brain at the hospital bedside, at home, or in an ambulance. Also, they are unsuitable for studying the brain during a task involving movement, or during human interactions. These systems also require the subject to remain motionless for several minutes during the procedure, inhibiting studies of the developing brain in babies and toddlers. Through UCL-led innovations and commercialisation via a UCL spin-out company, Gowerlabs, the DOT system has been adapted and developed to provide high-quality, real-time images of human brain function in a truly wearable package that is now in use worldwide, both for research and development and by large corporations such Facebook and Apple. The products have generated revenues of GBP2,762,000 to date and are providing new ways to explore brain activity in real time.

Product innovation and application

Building on UCL-led research, Gowerlabs has developed three key product lines:

1. The benchtop NTS brain mapping system (**R1**)
2. The patented, wearable and fibreless fNIRS brain imaging system LUMO (**R3**)
3. A range of optical phantoms that mimic human tissues (**R5, R6**).

The NTS benchtop imaging system has had significant clinical impact and is considered to have "*paved the road towards a new understanding of neuroplasticity mechanisms following reconstructive surgery"* (**S1**). However, in common with most existing DOT devices, it requires a large number of bulky optical fibres to carry light to and from the head, which

limits its possible applications. To address these limitations, Gowerlabs built on the early microNTS work (**R3**) to develop the world's first commercial, high-density, fibreless DOT system, LUMO, which provides significantly higher resolution imaging than any other commercially available DOT device. The system's novel design enables high-quality images of the brain to be obtained in almost any environment and the products have been used by companies and research institutions in Africa, Australia, China, Europe, UK and the US. To help DOT device users validate new array designs and assess system performance, Gowerlabs has also developed the world's first anatomically correct head phantoms. These have proven useful for both companies and clinicians. Vilber Lourmat, a Gowerlabs client, considers Gowerlabs to be "*the only company that can supply optical phantoms of the types we need for our application*" (**S2**).

Gowerlabs DOT systems are being used in clinical settings (eg Medlink, Australia) R&D settings (eg McMaster University Canada and Vilber Lourmat for cancer research), and by technology companies such as Facebook Reality Labs and Apple for their computer-brain interface research; and other technology companies such as Philips and Kingfar International Inc., China.

Gowerlabs systems has enabled "*modern machine learning techniques to accelerate brain computer interface (BCI) development for many different applications"* (**S3**) with improved accuracy when measuring brain activity in real time. For example, the application of the LUMO system allowed Facebook Reality Labs research on translating neural activity into text to achieve "*average error rates as low as 3% when tested with vocabularies of up to 300 words"* compared to the previously "*limited error rates north of 60% for 100-word vocabularies*" (**S3**).

The Gowerlabs brain imaging systems have also enabled novel research on new-born babies' brains, revealing new insights into infant malnutrition and autism, and have been featured in films on social media including *Seeing Signs of Autism in Infrared* by UCL Engineering (2013) and *Brain Imaging Tool Seeks Signs Of Infant Malnutrition* by SciDevNet (2015), engaging over 4,000 viewers in the process (**S4**). Other coverage of how Gowerlabs DOT systems have been used in cutting edge research include: *Brain Imaging Technology Designed for Babies – (November 2020), BBC News website; The Wonderful World of Babies – Episode 2* (2018; [TEXT REMOVED FOR PUBLICATION]); *BBC World News Horizons 4, Episode 16 – The Brain* (2014); *BBC World Service Health Check – Babies' Minds: The Truth about Life and Death* (2014); *BBC Horizon – Living with Autism* (2014; [TEXT REMOVED FOR PUBLICATION]) (**S4**).

Economic impact and sector development

Gowerlabs brain imaging systems have been purchased by technology industry leaders, such as Philips, Apple and Kingfar Int. and by academic institutions, such as Magdeburg University, Germany and Sahlgrenska University Hospital, Sweden, reaching an annual turnover of approximately [TEXT REMOVED FOR PUBLICATION] (**S5**). Since August 2013, total sales of the NTS benchtop imaging system have reached [TEXT REMOVED FOR PUBLICATION], with more than two-thirds of products sold outside the UK. Total sales of the LUMO system since its launch in April 2019, have reached [TEXT REMOVED FOR PUBLICATION] to date and sales of tissue equivalent phantoms have reached [TEXT REMOVED FOR PUBLICATION] since December 2016.

The DOT imaging systems (NTS benchtop system and LUMO) have had a worldwide reach with units being sold in the UK (14 units), North America (8 units), China (6 units) Europe (9 units), Australia (3 units), Gambia (1 unit) and Bangladesh (1 unit). One of Gowerlabs' Chinese distributors reports that "*The Lumo system has generated a great deal of interest throughout China*" (**S6**).

Gowerlabs has grown steadily since 2013 and currently employs full-time and part-time personnel equivalent to 5.0 FTE. Since 2013, interns and employees have joined the

product development process "*from the first design concepts through to mass manufacturing*" (**S7**), through which "*invaluable skills and experiences*" (**S8**) were gained and transferred across the engineering industry as these personnel progressed on from Gowerlabs. A former employee with a consumer-focused design background stated: "*…(At Gowerlabs) I was exposed to several new engineering fields, including flexible printed circuit design, embedded system electronics and near-infrared optics… I have gained many important new skills and experiences from being immersed in the full range of their activities*" (**S8**).

5. Sources to corroborate the impact

S1. Testimonial from Sahlgrenska University Hospital
S2. Testimonial from Vilber Lourmat
S3. Media coverage of Gowerlabs products relating to Facebook Reality Labs research
S4 Media coverage of Gowerlabs BBC News website: Brain Imaging Technology Designed for Babies https://www.bbc.co.uk/news/av/technology-55062221
BBC2: The Wonderful World of Babies https://www.bbc.co.uk/programmes/b0btxs5s
BBC World News Horizons 4, Episode 16 – The Brain
http://www.bbc.co.uk/mediacentre/worldnews/2014/horizons-adam-shaw
BBC World Service Health Check - Babies' Minds: The Truth about Life and Death
http://bbc.in/1pPWEiX
BBC Horizon – Living with Autism http://www.bbc.co.uk/programmes/b0404861
UCL Engineering - Seeing signs of autism in infrared
https://www.youtube.com/watch?v=dFyt03HRhPo
SciDevNet – Brain imaging tool seeks signs of infant malnutrition
https://youtu.be/Fw0WMNNp3zY
Clare Elwell – Gates Foundation Grand Challenges talk
https://www.youtube.com/watch?v=DUnW4_aD1j8
Viewership data for BBC programmes via BARB, available upon request.
S5 Gowerlabs financial report, available upon request
S6 Testimonial from Kingfar International
S7 Testimonial from Gowerlabs employee
S8 Testimonial from intern student researcher