Institution: Loughborough University (LU)

Unit of Assessment: UoA 11 – Computer Science & Informatics

Title of case study:
Improving the detection of early breast cancer by UK radiologists

Period when the underpinning research was undertaken: 2005-2018

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 Alastair Gale	Professor of Vision Sciences	7/3/2005-31/12/2016
	Emeritus Professor of Applied Vision	1/1/2017 - date
Dr Yan Chen	Senior Research Fellow	4/1/2010-30/4/2019

Period when the claimed impact occurred: August 2013 - date

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

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

One in eight women will get breast cancer. Annually, over 2 million UK women are screened using mammography and, on average, 8.4 cancer cases are found for every 1,000 women screened. The low incidence makes it difficult for radiologists to detect cancer accurately. Research at Loughborough University detailed key visual mammographic image features, which underpin radiologists' ability to identify early cancer. These findings underpinned an online self-assessment training scheme called PERFORMS, leading to the following impacts:1) PERFORMS was adopted and funded by NHS Breast Screening programme, implemented nationally by Public Health England, mandated for every UK practitioner, endorsed as CPD by the Royal College of Radiologists, with reach extended into US, Belarus, Poland, Israel, and several EU countries, via partners including the World Health Organization; 2) PERFORMS improved the ability of radiologists to identify breast cancers and improved healthcare outcomes for women in the UK.

2. Underpinning research (indicative maximum 500 words)

Whilst screening is crucial to early cancer detection; the very low breast cancer incidence rate at screening (< 1 in 100), compounds difficulties radiologists have, both in identifying early signs of abnormality, and awareness of their own screening performance levels. Research by Prof Alastair Gale and Dr Yan Chen since 2005, investigated how to use HCI, image analysis and statistical techniques for the performance analysis and comparison of radiologists, resulting in the design and implementation of an on-line training and quality assurance tool for radiologists. The specific contributions of research are as follows:

Feature Identification: Based on rigorous HCI supported experimental study of expert radiologists' interpretation of potential cancerous regions in mammographic images, Gale et al.'s research, since 1988 has confirmed key mammographic features that radiologists must correctly identify in order to determine the presence of a cancer [R1]. Supported by algorithms, PERFORMS effectively use these features to compare the performance of each radiologist to that of expert radiologists [R2].

Eye Tracking: The HCI centred design and functionality of PERFORMS has directly benefitted from the use of knowledge originally generated by Gale's research in the use of eye-tracking in image perception [R3], which confirmed that errors during interpretation of medical images occurred in mainly the discovery or the recognition phase, and less commonly in the scanning phase of radiologic image inspection. Such research has contributed to PERFORMS and has helped in better understanding radiologists' behaviour during assessment, in particular the ability of PERFORMS to critically investigate underperforming individuals.

Error Estimation: A novel approach to accurate error estimation was developed by Gale et al. [R4], based on firstly having expert radiologists annotate accurately the outline Area of Interest (AOI) of the abnormality and then making judgements about users' indicated location marks as judged against this AOI. A *Best Fit Error Margin* algorithm was proposed to build annuli polygons around AOIs and uses an empirical method to judge the best fit error margin for each mammographic feature of interest. Rigorous analysis has proven that this is a better solution than using a simple distance measure of a user's indicated location to the centre of an abnormality and helps in understanding some of the reasons for errors when difficult cases are examined.

Outlier Removal: A key aspect of measuring performance is statistically to identify underperforming individuals and help them improve. In the early stages of development of PERFORMS it was required that all UK screening radiologists take part in assessment before their data could be analysed comparatively to identify outliers. However, Gale et al.'s research [R5], developed a new approach based on the inner and outer statistical fences of ROC (Receiver Operator Characteristics) measures, which determine the cut-off limits for ascribing either mild (inner fence) or severe (outer fence) underperformance. This approach helped predict potential outliers as soon as only 25 radiologists had participated, therefore impacting on improving training across the UK.

PERFORMS has been implemented as a software service underpinned by the abovementioned research, supported by web-based user interfaces and cutting-edge database technology that ensures secure and effective storage, indexing and access of data [R6].

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

[R1] Darker Iain, Chen Yan, Gale Alastair, "Health professionals agreement on density judgements and successful abnormality identification within the UK Breast Screening Programme", Proc. of the SPIE Medical Imaging 2011: Image Perception, Observer Performance and Technology Assessment, 2011, Vol. 7966, 796604, doi: 10.1117/12.878761

[R2] Chen, Y., & Gale, A. "Performance Assessment Using Standardized Data Sets: The PERFORMS Scheme in Breast Screening and Other Domains", In E. Samei & E. Krupinski (Eds.), The Handbook of Medical Image Perception and Techniques (pp. 328-342), 2018. Cambridge: Cambridge University Press. doi:10.1017/9781108163781.022

[R3] Chen, Yan, Alastair G. Gale, Ann Turnbull, and Jonathan James, "Is Image Manipulation Necessary to Interpret Digital Mammographic Images Efficiently?", Proc. of the SPIE Medical Imaging, 2011, Vol. 7966, 79660S. doi:10.1117/12.878753

[R4] Dong, Leng, Yan Chen, and Alastair G. Gale, "Breast Screening: Understanding Case Difficulty and the Nature of Errors", Proc. of the SPIE Medical Imaging 2013: Image Perception, Observer Performance and Technology Assessment, 2013, Vol, 8673, 867316, doi: 10.1117/12.2007919

[R5] Dong, Leng, Yan Chen, Alastair G. Gale, and Dev P. Chakraborty. "A Potential Method to Identify Poor Breast Screening Performance". Proc. of the SPIE Medical Imaging 2012: Image Perception, Observer Performance and Technology Assessment, 2012, Vol. 8318, 831819, doi: 10.1117/12.913610

[R6] Gale, Alastair & Chen, Yan, "A review of the PERFORMS scheme in breast screening", British Journal of Radiology, 2020, Vol 93 (1112), doi: 10.1259/bjr.20190908

The underpinning research was funded by the NHS Breast Screening Programme (2005-2014) and subsequently Public Health England (2014-2018) to a value of £ 4.62 M. The Handbook of Medical Image Perception and Techniques is a peer-reviewed and edited book, also published online by the Cambridge University Press. The SPIE Medical Imaging is the largest annual

conference in the field of Medical Imaging. All papers were peer reviewed. The SPIE Proceedings had a 0.56 IF and H-index of 151, SJR 0.238, in 2018.

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

Prof Gale has strong and sustained relationships with the NHS Breast Screening Programme as a result of his long-standing expertise being sought in assessing radiologists' skills in image interpretation. His research on visual mammography and HCI underpinned the development of PERFORMS, which addresses the challenges of accurate diagnosing in breast cancer screening and, ultimately, saves women's lives. The scheme compares individual screening radiologists to advanced practitioners' skills in reading sets of very difficult screening cases and provides immediate feedback to the individuals, which then helps them both improve and maintain their real-life screening performances. **Pathways** to the current impact originate in previous iterations of the PERFORMS scheme, which has been continually funded by the NHS for 32 years and the online version appeared in 2010 [S2]. The current version benefits from Computer Science research and it is the impact of this version which is reported here. PERFORMS is a Loughborough University-registered trademark and has led to the following impacts.

Impact 1: Adoption of PERFORMS online self-assessment training scheme by NHS Breast Cancer Screening Programme and its use in quality assurance in breast cancer screening

PERFORMS was adopted in 2010 by Public Health England (PHE) [S1, S2], an executive agency of the Department of Health and Social Care and by Royal College of Radiologists [S3, S9], who lead, educate and support doctors who are training and working in the specialties of clinical oncology and clinical radiology and of which Dr Chen is an Honorary Fellow. PERFORMS was funded by the by NHS Breast Screening Programme (including Scottish Breast Screening Programme; Public Health Agency, Northern Ireland). It was mandated for use in Service Specification 24 [S8] for the NHS Breast Screening Programme (2017) and is a requirement for all screening mammography readers in the NHS Breast Screening Programme's Quality Assurance Guidelines for Breast Cancer Screening Radiology [S7].

As the former Director of the NHS Breast Screening Programme, Prof. Julietta Patnick reported in 2020 [S2] that:

> "PERFORMS is fully embedded within the national breast screening programme as an external quality assurance and training platform. It functions to raise and maintain the high skill level of the NHS workforce. All UK breast screening radiologists, advanced practitioner radiographers and consultant radiographers (circa 1,000 individuals) participate in this scheme annually."

Because of the instant feedback loop provided to Public Health England (PHE) of the (anonymized) performance of radiologists, it also enables improved quality assurance methods; the ability to measure regional and national performance against the same test set, and ability to address particular training gaps or issues such as low specificity (i.e., too many false positives leading to unnecessary recall of patients for further testing) [S1].

A unique capability of PERFORMS is the possibility of early identification of outliers in breast cancer screening radiology. In [S1], Jacquie Jenkins, PHE's National Breast Screening Programme Manager, wrote:

> "Early identification of underperforming individuals allows services the opportunity to apply early interventions to improve performance before real life performance data is available for analysis, due to the time lag between reporting activity and audit. This has made an enormous difference to individual image reader performance."

PERFORMS has been accepted internationally as an External Quality Assurance (EQA) scheme in breast cancer screening due to its long-term, continuous and very successful adaptation, within

the NHS Breast Cancer Screening Programme. Dr Suzette Delaloge, Chair of MyPeBS ('My Personal Breast Screening'), a collaborative project between 26 institutions in seven countries including, Israel, United States, UK and four EU countries, Belgium, France, Italy and Netherlands, wrote that:

> "The PERFORMS scheme is ideal to be used as an external quality assurance scheme (EQA) in this ongoing Europe-wide MyPeBS project to ensure the equivalence of radiological reading quality and reporting standards. PERFORMS has a clear and important positive impact on the quality assessment in MyPeBS" [S4].

The ability of the international users of PERFORMS scheme to compare their performance with UK breast screening radiologists is seen as an enabler for its adaptation internationally. In [S5], Dr Olga Trusova, Alexandra National Cancer Centre, Belarus [S5] wrote:

> "The facility of comparing their skills to that of UK breast screening radiologists when examining the same screening cases has additionally been found to be very educational and of immense benefit to the establishment of effective national breast screening in Belarus."

In [S6], Dr Vitaly Dmelov, Medical Officer, NCD Management, WHO/Europe, reported that:

> "Feedback from all the radiologists from both workshops has been extremely positive and the scheme has definitely aided these radiologists to gain confidence in their cancer detection abilities which in turn has improved the implementation of national breast screening in Belarus.", *and*

> "While the budgets of national partners across the Region dedicated to quality control in screening are insufficient, the existing scheme an excellent tool to evaluate the knowledge of radiologists at the "entry" point of (national or pilot) screening programme(s), to help to elaborate further the training activities, on the national or sub-regional scale."

The PERFORMS scheme has benefitted countries that have established a national breast cancer screening programme such as Belarus (as above, 2017) and Poland (training delivered in 2018). For such countries, PERFORMS has provided a starting EQA for assessing breast screening radiologists, allowing them to be trained in reference to a UK expert radiologist and subsequently contributing to the establishment of an internal quality assurance scheme. The reach of the PERFORMS scheme was also extended internationally via a major training course in the USA (Society for Breast Imaging, Florida, 2015), as well as providing comparative screening performance metrics across the EU [S5, S6] via the MyPeBS project.

Impact 2: Improved the ability of radiologists to identify breast cancers and improved healthcare outcomes for women in the UK

LU research has changed the way radiologists develop their skills to conduct breast screening. The incidence of cancer at screening is very low as each breast-screening radiologist usually sees <40 cancer cases per year, out of approximately 5,0000 screening cases. However, PERFORMS exposes them to 80-90 cancer cases per year (including unusual cancers), which is the equivalent to 2-3 years of on-the-job experience. Hence PERFORMS acts as a training tool for radiologists allowing them to gather essential experience at a rapid phase.

In [S1], Jacqui Jenkins, Manager, National Breast Screening Programme stated that:

> "The PERFORMS online self-assessment training scheme has helped maintain high levels of screening sensitivity and also improved specificity."

Every breast-screening professional (predominantly radiologists, ~1000) across the UK take part in PERFORMS training annually (of whom around 23% tend to be new to the role). Immediate feedback is given, including expert opinions on the cases for participants to learn from. Any

individuals with poor results are offered additional support and training. Training is fully embedded as CPD recommendations in Royal College of Radiologists [S3]. In [S3], Dr M.J.Michell, Consultant Radiologist, reported that:

> "A key instrument for driving up the quality of radiology was the invention and development of the PERFORMS scheme by Professor Gale …" *and*

> "Each year a small number of underperforming individuals (statistical 'outliers') are identified confidentially by the PERFORMS team and offered help to assist them improve their cancer detection abilities. This is an important and key impact of the scheme, as given the low incidence of cancer at screening, and that the screening process occurs every three years, then without the PERFORMS scheme such individuals would not be identified and helped so quickly – possibly for some considerable time."

Since the start of the on-line provision of PERFORMS in 2010, it has evolved to be a system that can be accessed anywhere, anytime and displayed on any screen. The much-needed additional database support and data encryption has been incorporated. Via careful HCI designs training content is provided to the radiologists in a user-friendly manner.

In [S2], Prof Julietta Patnick, former Director NHS Breast Screening Programme stated that:

> "Subsequent HCI advancements have enabled immediate detailed online feedback to participating radiologists and other readers about their reporting skills, as well as comparative statistics relating their skills to that of their peer group."

In [S5], Dr Olga Trusova, Alexandra National Cancer Centre, Belarus, also reported:

> "46 key national radiologists involved in setting up the national screening programme were presented with details of the PERFORMS scheme and were then able to take part in this self-assessment scheme and have their skills in identifying early breast cancer signs detailed which then helped enable them to improve their cancer detection abilities."

PERFORMS is a vital part of the UK Breast Cancer Screening programme. It acts as a training tool for radiologists and helps in quality assurance in breast screening. It has impacted directly on performance improvement in breast screening, early diagnosis and hence reducing the need for mastectomy or chemotherapy and has therefore contributed to saving lives of women. As Jacquie Jenkins, National Breast Screening Programme Manager concluded:

> "Approximately 18,000 cancers per year are diagnosed via this route and 1300 lives are saved as a direct result of breast screening." [S1, S10]

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

[S1] Jacquie Jenkins - PHE, Programme Manager, National Breast Screening Programme, 3/1/2020.
[S2] Prof Julietta Patnick– former Director, National Breast Screening Programme, 16/12/2020.
[S3] Dr Mike Michell – Chair, National Breast Screening Radiology QAC, 2/12/2020.
[S4] Dr Suzette Delaloge – Chairwoman, MyPEBS Project, EU, Gustave Roussy, 8/1/2021
[S5] Dr Olga Trusova – Lead Radiologist, Belarus breast screening programme, 21/12/2020.
[S6] Dr Vitaly Smelov, Division of Country Health Programmes, WHO/Europe, 6/1/2021.
[S7] Mandated in Quality Assurance Guidelines for Breast Cancer Screening Radiology" (2011)
[S8] PERFORMS specified in Service Specification 24, NHS Breast Screening Programme (2017)
[S9] Royal College of Radiologists professional standards guidance, recommending "Participate in an approved radiologists' performance quality assurance scheme for mammography"
[S10] PHE blog on breast screening rates and number of cancers found, accessed 25/11/2020.