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Radiography as a sociotechnical system – Improving patient identification with a multi-level human factors approach

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A R T I C L E I N F O

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A B S T R A C T

Irradiation of the wrong patient or wrong site is a reportable adverse event for hospitals. Improvement efforts to date have been narrowly targeted, often without consideration of wider contextual factors. This study applied a systems human factors/ergonomics (HFE) approach in an NHS trust to develop interventions across micro, unit and organisation levels.

At the micro level, the workspace was adapted to reduce distractions during safety critical work. At the unit level a standard operating procedure for patient identification was designed with staff alongside the introduction of wristband barcode scanners. At the organisation level safety workshops were run for staff in the radiology directorate. These introduced a systems approach to managing risk, encouraged near miss reporting and employed scenario-based exercises to raise discussion of risk-efficiency trade-offs.

Following implementation interruptions in the control rooms decreased by 34% (from a mean of 4.91/10 min). Interrupted time series analysis showed that the interventions were associated with a decrease in patient identification incidents (rate ratio = 0.37), and an increase in near miss reporting (rate ratio = 2.5), representing an additional 4.7 reports/month. The workshops raised a wide range of system components that influenced the imaging task and provided examples of situated and structural resilience attributes. The safe provision of imaging across different modalities and physical locations is a challenge for many radiology departments; this study indicates that a multi-level systems approach can reduce risk.

1. Introduction

Radiology units in the UK successfully scan millions of patients each year, yet radiological exposure of an incorrect patient or incorrect site are widespread adverse events and are reportable to the regulator. In the most recent UK Clinical Quality Commission (CQC) annual report 1009 notifiable incidents were made to the regulator, and of the 796 that related to diagnostic radiology, 51% concerned irradiation of the wrong patient (Ionising Radiation (Medical Exposure) Regulations Annual Report 2018/19).

From a safety science perspective what is striking about the regulator's report is the categorisation of reportable incidents: ten of the fifteen error categories are labelled as either "referrer error" or "operator error". In the 2019 report 92% of notifications were assigned against one of these two "human error" types. Implicit in this categorisation, whether intended or not, is the suggestion that the "root cause" of the incident is an individual's error. This is clearly at odds with contemporary human factors engineering and safety science research which view failure as frequently a *consequence* of system design rather than as solely attributable to human action (Hopkins, 2006; Karsh et al., 2006; Leveson, 2011; Svedung and Rasmussen, 2002; Lunde and Njå, 2021).

1.1. Study aims

The management team of a radiology directorate in a large teaching hospital in the UK approached the authors to review current practice following a series of reportable incidents. A systems human factors/ergonomics (HFE) approach was taken, that is we studied the imaging process as a work system of interacting components and made changes across organisational levels. An action research methodology was followed (Eden and Huxham, 1996) such that interventions were developed with the close collaboration of staff in the Radiology directorate.

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To date there has been no systems-based HFE research in the radiology domain, as such this study contributes new knowledge about managing risk in this domain.

The primary aims of the project were to reduce patient identification adverse events and to increase near miss reporting. A secondary aim was to introduce a systems approach to incident reporting through teaching and exercises. In particular, we sought to shift thinking about incidents away from single 'root cause' reasoning and towards a wider consideration of sociotechnical factors such as norms of practice, technology and workspaces.

1.2. Patient misidentification

Patient misidentification has been an ongoing patient safety concern for many years and has received attention in particular from the surgical specialisms (Stahel et al., 2010) and national safety bodies. The US Joint Commission developed a Universal Protocol for surgery, which advises a verification process, including a patient identification check, immediately prior to incision (Joint Commission on Accreditation of Health Care, 2003), a procedure also followed in the UK. A systematic review reported procedure non-adherence and communication problems as the two most frequent contributors to wrong-site or wrong-patient surgery adverse events (Hempel et al., 2015). However reducing such reports to independent problems risks the oversimplification of work processes with interacting person, equipment and task factors.

In radiology, interventions to address misidentification are few, and those reported have been narrowly targeted with specific tools. Flug and colleagues used an ink-stamp on radiography order forms as a prompt to check for the correct patient and exam, and deployed left-right stickers placed on the patient for extremity imaging (Flug et al., 2018). Another study incorporated patient identification into a checklist, although without measurement of the impact on adverse events (Koetser et al., 2013). In a lab-based experiment coupling patient photographs with chest radiographs improved the detection of wrong-patient errors (Tridandapani et al., 2014). This intervention has subsequently been implemented, although data on effectiveness has yet to be published (Tridandapani et al., 2020).

A study that did measure outcomes implemented a two-person verification system to read back patient details from a wristband, without which examinations were not allowed to proceed. Following a pilot phase and some workflow adjustments the system was introduced across multiple departments in a tertiary care paediatric hospital. This was associated with a statistically significant reduction in the incidence of wrong patient/wrong study events from 9.4 to 2.9 per 100,000 examinations (Rubio and Hogan, 2015).

1.3. Interruptions

Radiography units handle a high throughput of cases and spend a relatively short period with each patient, furthermore, as emergency cases take priority pre-planned lists must be changed at short notice. The drive for efficient throughput requires flexible team working and radiographers may switch between conducting patient identification checks in the scanning room and operating imaging equipment in the control room. In this context ensuring the correct patient receives the correct imaging procedure demands sustained attention and vigilance – yet interruptions and distractions are common.

Research on interruptions and distractions in radiology has exclusively concerned duty radiologists rather than radiographers (Kansagra et al., 2016). In one experiment radiologists examined radiographs for pneumothorax, with some image interpretations subject to a secondary task interruption, while the others were conducted under a control condition. The interruptions increased reading times and reduced accuracy for subtle cases (Wynn et al., 2018).

Phone calls are recognised as a common source of interruption and unnecessary calls require the same initial attention as important calls. In an audit of 288 calls to reporting radiologists it was found calls asking for image request vetting were the most frequent and the majority (54%) were judged as inappropriate (Watura et al., 2019), a similar rate to the 52% reported by Muir and Patel (2013). The most comprehensive study of an intervention to reduce interruptions for radiologists implemented a telephone triage system in which administrative staff filtered incoming calls (Bell et al., 2018). This was associated with a reduction in radiologist interruptions from a mean of 87 to 48.9 per 24-hours – a 43.7% reduction, although a limitation was that interruptions were self-reported rather than recorded by independent means.

1.4. Systems human factors/ergonomics

Studies that have implemented change to reduce patient misidentification in radiology are to be commended, yet they have used narrow interventions. Safety improvement can be more effective when studied across system levels recognising the inter-relations between them (Karsh et al., 2014; Rasmussen, 1997; Wahlström and Rollenhagen, 2014). The human factors/ergonomics (HFE) discipline concerns the study of the interactions between humans and their working environment informed by a knowledge base in psychology, physiology and design (Dul et al., 2012; Hignett et al., 2013). The application of HFE to the healthcare domain has been gaining momentum over the last few years, yet it has been argued that it needs to develop beyond localised interventions to examine organisational influences (Waterson and Catchpole, 2016).

Systems HFE looks beyond a micro-setting to wider factors and includes principles from systems thinking such as: conducting analysis across work system levels, treating components as interconnected rather than isolated, and recognising that system behaviour is emergent – exhibiting processes and outcomes not foreseen by its planners (Leveson, 2011; Waterson, 2009; Wilson, 2014). A sociotechnical framework established for the healthcare domain defines system levels as: person (micro), unit/work system, organisation and external environment (Karsh et al., 2006). For example, activity at the micro (person-task) level, such as requesting imaging, will be disrupted by the introduction of new technology at a unit level. Local micro adaptations will emerge as the affordances and constraints of the technology are realised, these in turn will shape and inform unit level procedures. A cross-level approach has, for example, been applied to the study of infection outbreaks in hospitals (Karsh et al., 2014) and the food industry (Nayak and Waterson, 2016).

One principle of resilience engineering is that safety is fostered by enabling an organisation to detect and adapt to situations where the boundaries of the safe working envelope are pushed (Woods and Cook, 2006). This provides an example of a cross-level relationship that can be effective or dysfunctional: near misses at the micro level provide signals to the organisation level that the system is operating close to its boundaries, yet too often this information is not brought to light or analysed (Woods, 2006). Near misses are indeed significantly less likely to be reported than incidents that result in harm (Kreckler et al., 2009). An interview study with radiographers and other hospital staff in the UK found that, "healthcare professionals regard incident reporting not only, or even primarily, as a tool for organisational learning" (Sujan, 2015). Instead, other motivations including taking personal responsibility and meeting legal obligations, were reported.

Known barriers to incident and near miss reporting in radiology departments are: inter-personal authority gradients, fear of retribution, and a lack of clarity about who is responsible for reporting and how (Siewert et al., 2019). In a study of radiologists, the most frequently cited reason for not speaking up about a safety concern was a 'high reporting threshold', particularly when there is some ambiguity about the 'correct' practice (Siewert et al., 2019). Organisational issues such as time constraints, poorly designed reporting software and insufficient or absent feedback are further disincentives for reporting safety incidents or concerns. Reducing these barriers is not a straightforward process, but can be achieved through reframing reporting as an opportunity to learn, rather than as threat to authority or competence (Siewert and Hochman, 2015).

2. Methods of study

2.1. Setting and overview

The setting was the radiology directorate in a large UK NHS foundation trust with four hospitals and 1.47 million annual attendances (2019–20). Each hospital had separate radiology units at different locations that provided various imaging services. The project was conducted with the close cooperation of senior radiographers and managers, some working across the whole trust, others based in specific units. Table 1 summarises the diagnostic units (therapeutic services were out of scope) and the role titles of key collaborators.

The directorate management team requested a particular focus on computerised tomography (CT) as the majority of reportable incidents had occurred in this modality. The project was registered as a service evaluation with the trust (reference 5798); permission and approval for data collection was provided by the directorate clinical audit lead. Interventions were developed and implemented at three levels: micro (person-task), unit (work system) and organisation levels. The interventions and the methods used to support each are summarised in Table 2. For each area of study relevant system components are listed with reference to the Systems Engineering Initiative for Patient Safety (SEIPS) framework (Holden et al., 2013). This describes structural aspects in a work system (such as teams, technologies and environment) and emphasises that the interactions between these components constitute the effectiveness or otherwise of a work system.

2.2. Micro level

Field observations were conducted in three separate workspaces (CT unit at the main hospital, plain film unit at the main hospital and a CT scanner in a small district hospital) to familiarise the researchers with the current work system. Workspaces were selected as representative of a typical unit. For the CT units three imaging sessions were observed from within the control room using diagrams to record tasks, roles, layout and equipment. In each case a minimum period of four-hours was spent observing and two sessions were co-observed with a doctor to aid with clinical explanations.

Table 1
Hospitals, radiology units and key individuals.

Site	Diagnostic units*	Key roles who collaborated on the project
Trust level		Radiology Clinical Governance Managers (two roles) Radiation Physics and Protection specialist Operational Services Manager
Main hospital	Plain film units × 3 (one adjacent to ED) CT units × 2 (total 3 scanners, 2 adjacent to ED)	Plain Film Reporting Radiographer Modality Manager Superintendent Radiographer CT Imaging
		Senior radiographers (two key roles)
	Angiography	
		Radiology Clinical Unit Operations Manager (responsible for all units)
Hospital 2	Plain film unit	
Hospital 3	Plain film unit × 2 CT units × 2 Angiography × 2	Radiology Manager
Hospital 4	Plain film unit CT unit (one scanner)	Radiology Manager

CT = computerised tomography ED = emergency department
* Excluding MRI – out of scope

These observations and discussions with radiographers highlighted that distractions and interruptions in the CT control rooms during the imaging process were an issue. At the main hospital two imaging units were located close to the emergency theatres and, as a regional trauma centre, the demand from clinical teams for urgent answers was another source of pressure and interruptions.

Thus, structured observation sessions were conducted to record the number, type and severity of distractions in the unit's two CT control rooms. Data was collected across two periods, pre and post intervention with an equivalent duration of on-task time observed for each condition (pre: 18 procedures across 220 min, Oct 2016 - May 2017; post: 17 procedures across 220 min, Feb – June 2019). An observer sat in the room and recorded distractions in a pre-formatted template. Severity was recorded using an established 9-point scale (Healey et al., 2006). Low level distractions (levels 1–3) represent potentially distracting events (e.g. tannoy announcement); medium level (4–6) record a distraction of a team member (e.g. a radiography assistant answers an incoming phone call); high level (7–9) represent interruptions to the radiographer (e.g. someone enters room and asks a question). The scale was originally developed for use in operating theatres thus it was adapted slightly to tailor the language to radiology.

2.2.1. Interventions

Two interventions were made to minimise interruptions and these are classified as micro level as they were targeted at two specific workspaces. The first updated a hospital phone directory app such that the control room telephone was not listed as the principal point of contact for the unit. The second installed access-control for the doors to the two CT control rooms so only radiography team members could freely enter; other roles (for example doctors, porters, visitors) were required to knock and wait. An existing radiation warning light outside the door indicated when imaging was in progress.

In the same CT control rooms a 'day list' was used to record procedures, many of which involved the injection of contrast medium. During observations staff had raised issues with the list's usability – for example insufficient space to fix contrast labels to the sheet (to record the substance injected) without obscuring other information. An improved day list was produced through iterative design with feedback via email and one-to-one discussions with the radiographers. The changes were: improved legibility, sufficient space for contrast labels and the addition of a column for the radiographer to add their initials to confirm a patient ID check had been completed.

2.3. Unit level

2.3.1. Failure mode and effects analysis (FMEA)

A Failure Mode and Effects Analysis (FMEA) was conducted for the CT imaging process. FMEA is a prospective risk analysis method that systematically considers hazards at different points of a process (DeRosier et al., 2002; Habraken et al., 2009). The following five standard steps were undertaken.

Step 1 Determine topic

The CT imaging process was selected in consultation with the radiology directorate managers.

Step 2 Assemble the analysis team

A team was gathered comprising two senior CT radiographers, a radiography unit manager and two researchers (one clinical, one human factors engineer). The three radiographers had a minimum of 5 years' experience each, the HF engineer had experience of conducting hazard analyses.

Step 3 Graphically describe the process

The field observations were developed into a preliminary task analyses using a swim lane notation to indicate task by location (Jun et al., 2009). Task analysis is a method to formally decompose and describe a work process, in this case to form the basis of a systematic risk assessment. These analyses were printed at large scale for reference and in a

Table 2
Summary of interventions.

Level	Area of study	Intervention	Interactions (with reference to SEIPS components)	HFE method/s
Micro	Interruptions in the CT control rooms. CT patient treatment recording	Access control installed on the doors. Changed phone directory app so CT control rooms were not the primary contact point. Improvement to the CT day list.	Person-task-environment-communication	Structured field observations.
Unit	Patient identification procedure	Co-design of a standard operating procedure (SOP) Implementation of wristband barcode scanners in some areas.	Person-task-tool-technology	Failure Mode and Effect Analysis (FMEA), document review, co-design workshop.
Organisation	Raise awareness of a systems approach to patient safety. Explore task trade-offs.	Programme of systems HFE workshops, delivered across the directorate. Scenario-based discussions of patient identification practice.	Team-organisation-task (reporting)	Scenario walk-throughs and discussions, teaching, risk exercises using SEIPS 2.0 and Ischikawa/fishbone contributory factors.

2-hour workshop the task steps and sequence were developed and verified with the team.

Step 4 Conduct a hazard analysis

A second 2-hour workshop was conducted with the same team using the verified analyses for structure. Potential failures were identified for each step and a judgement of the relative frequency of failure and severity of harm was elicited from the participants. As with other healthcare studies, a simplified scoring scheme (high, medium, low) was used for frequency and severity ratings to make scoring easier and to reduce the time required of clinicians (McElroy et al., 2016). Failures that had a combination of medium-high or high-high scores were identified as high risk; this established that checking patient identification was, in relative terms, a high risk task. See Fig. 1 for an overview diagram.

Step 5 Identify actions

Discussions were held among the analysis team and with the wider group of radiographers and managers to generate ideas for potential interventions. The research team promoted the concept of applying both local (micro) and broader (organisational) interventions, and the hospital team looked for practicable solutions.

2.3.2. *Document review*

Existing documentation relating to patient identification was reviewed for their contribution to and suitability for the identification task. The documents were: "employer's procedures" (a legal document to record the trust's interpretation of the national radiology regulations), a poster intended to prompt for radiography safety checks, a 'day list' used to record which patient had received which investigation and the trust-wide patient identification policy. Two main issues were identified: poor accessibility to this information for radiographers, and the length and format of the documents made them unwieldy to use.

2.3.3. *Intervention*

Considerable variation in the procedure for identifying patients across different units and hospitals was observed. Some variation was warranted, for example due to the use of patient wrist bands in some units and not others. In other cases, such as when some radiographers stated rather than asked for a patients name and date of birth, it

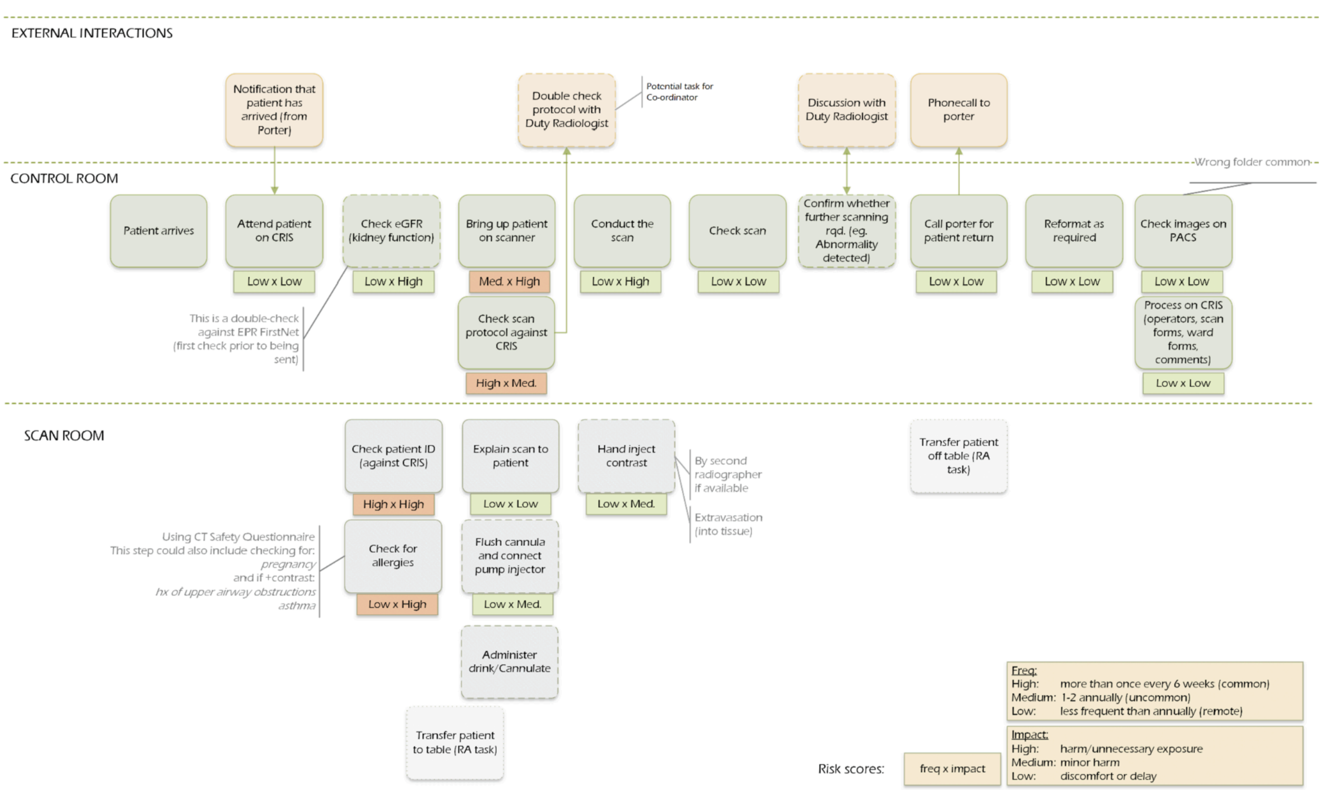

Fig. 1. Task steps and failure ratings for the CT imaging process.

introduced risk. Furthermore, the directorate was incrementally introducing barcode scanners to some units to read inpatient wristbands. The technology automatically transferred data to the radiography administration system, creating task variation between units.

Given this variation in practice and the obtuse procedures it was agreed to develop a simple patient identification standard operating procedure (SOP) to provide an accessible prompt to good practice. This 'technical' intervention was developed in line with user-centred design principles. The first principle was to elicit input and critique from end-users (radiographers) at each stage of development. The second principle was to design the SOP based on how the task was conducted 'on the ground' in the context of different work environments (Blandford et al., 2014).

This was initiated with a co-design workshop facilitated by a human factors engineer. Seven radiographers, all with experience of CT imaging participated. Participants generated four ideas for an artefact to aid with patient identification with a brainstorming exercise. These were discussed and ranked by each participant - a one-page procedure/flowchart was ranked highest. Initial content was sketched out at the workshop, the researcher subsequently developed a draft version in a software drawing package. A third principle - to reduce cognitive load - was sought by using a simple flowchart rather than blocks of text, and using familiar and consistent terminology. Further feedback on the SOP was received through a series of training workshops, as described below.

2.4. Organisation level

2.4.1. Incidents and near misses

Incidents and near misses related to patient identification were tracked through the trust's DATIX incident reporting software. Summary data was extracted by the medical physics and clinical governance teams as part of a monthly reporting process in which incidents were reviewed and counted. The numbers concerning patient identification failures were made available to study team. Data was analysed using a Poisson regression model for level change (a direct pre-post intervention comparison) and also as a monthly interrupted time series. A Poisson model was selected as it is commonly used for count data where there is no expectation of a normal Gaussian distribution, as in this case. Analysis was conducted in the R software package.

2.4.2. Intervention

With the support of the trust, a series of systems human factors and patient safety workshops were run over a 6-month period for radiology staff across the four hospitals. These were designed and delivered by the research team with the following goals: a) to raise awareness of systems human factors/ergonomics when addressing patient safety, b) to encourage the reporting of near misses and, c) to raise frank discussions about the patient identification task and the new SOP.

The workshops were a combination of presentation-led teaching and group work exercises; a summary of the content is given in Table 3. The first half of the workshop introduced the concept of a work system using the Systems Engineering Initiative for Patient Safety (SEIPS) 2.0 model (Holden et al., 2013). The second half of the workshop employed a simulation method in which staff worked in groups of three to walk-through (role play) a series of common scenarios using the SOP. Eight pre-developed patient identification scenarios were designed using A6 size script cards to raise situations in which identification was not straightforward. For example, conflicting information on site of investigation combined with a patient exhibiting confusion; or, an unaccompanied patient unable to identify themselves but wearing a hospital wristband. Following the scenarios a facilitated group discussion was used to discuss task trade-offs, points of ambiguity, and the benefits and limits of the SOP. Staff gave verbal and written feedback which was integrated into SOP design iterations.

To measure the reach of the workshop programme attendance was recorded by date, location and profession. A sample of work system factors raised in the group exercises was recorded by taking photographs of post-it notes and the whiteboards used. Additionally researcher field notes were made to record examples of the discussed task adaptions. Attendees anonymously completed a course feedback sheet.

Table 3
Workshop Content.

Component	Content	Intended learning outcome or output
Human factors and systems	Examples of good and poor human-equipment-workspace interactions.	To recognise human behaviour is influenced by the work system (equipment, information, task and environment)
A human factors framework	Introduction to the SEIPS 2.0 model. Exercise to reflect upon strengths and weaknesses of the staff's own work system.	To think broadly when considering the components of risk.
Contributory factors exercise	Use of Ischikawa/fishbone diagrams to analyse a radiography incident.	To think broadly when considering the components of risk.
The regulators	A review of how the regulators and the trust view incidents.	To raise awareness of the frequency of incidents and the potential for learning from near misses.
Patient identification	Review of current guidance. Introduction to one-page standard operating procedure (SOP). Walk-through simulation of the patient ID procedure.	To raise discussion on the patient identification task and where variation may be required. To gain feedback and engagement upon the patient identification SOP.

3. Results

The micro level interventions were applied to one radiology unit in the main hospital and preceded the wider initiative. The unit and organisation level interventions were incrementally applied across several units and hospitals within the same NHS trust from October 2017 onwards, Fig. 2 provides a timeline. The scope included diagnostic radiography and excluded interventional and therapeutic units.

3.1. Incidents and near misses

The frequency of patient identification incidents that occurred in the radiology units (i.e. excluding referral failures) is plotted by month in Fig. 3. The start of the unit-level safety interventions is represented by the dashed vertical line and was associated with a four-fold reduction in mean monthly incidents (pre = 0.48, post = 0.12, $p = 0.03$). The interrupted time series analysis, which takes account of trend, did not however return statistical significance (rate ratio = 0.37, 95% CI 0.04 to 3.36, $p = 0.38$).

The frequency of near miss (or good catches) per month is presented in Fig. 4, the dashed vertical line represents the start of the trust-wide implementation of the patient safety workshops. A direct pre-post comparison showed that the intervention was associated with a significant increase in the mean number of monthly reports (pre = 2.75, post = 7.46, $p < 0.001$). The interrupted time series analysis showed that the intervention was associated with an increase in the ratio of reports of 2.50 (95% CI 1.29 to 4.81, $p = 0.006$). This was as anticipated as the programme emphasised the value of reporting near-misses as an indicator of safety concerns.

3.2. Patient safety workshops

In total 156 staff attended the training across 16 workshops against an original target of 180 staff. 74% (116) were radiographers or sonographers, 10% (15) were radiography assistants and 16% (25) were

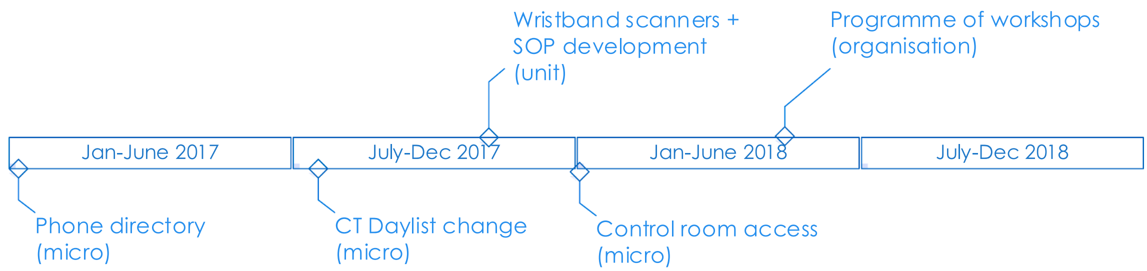

Fig. 2. Timeline of improvement interventions.

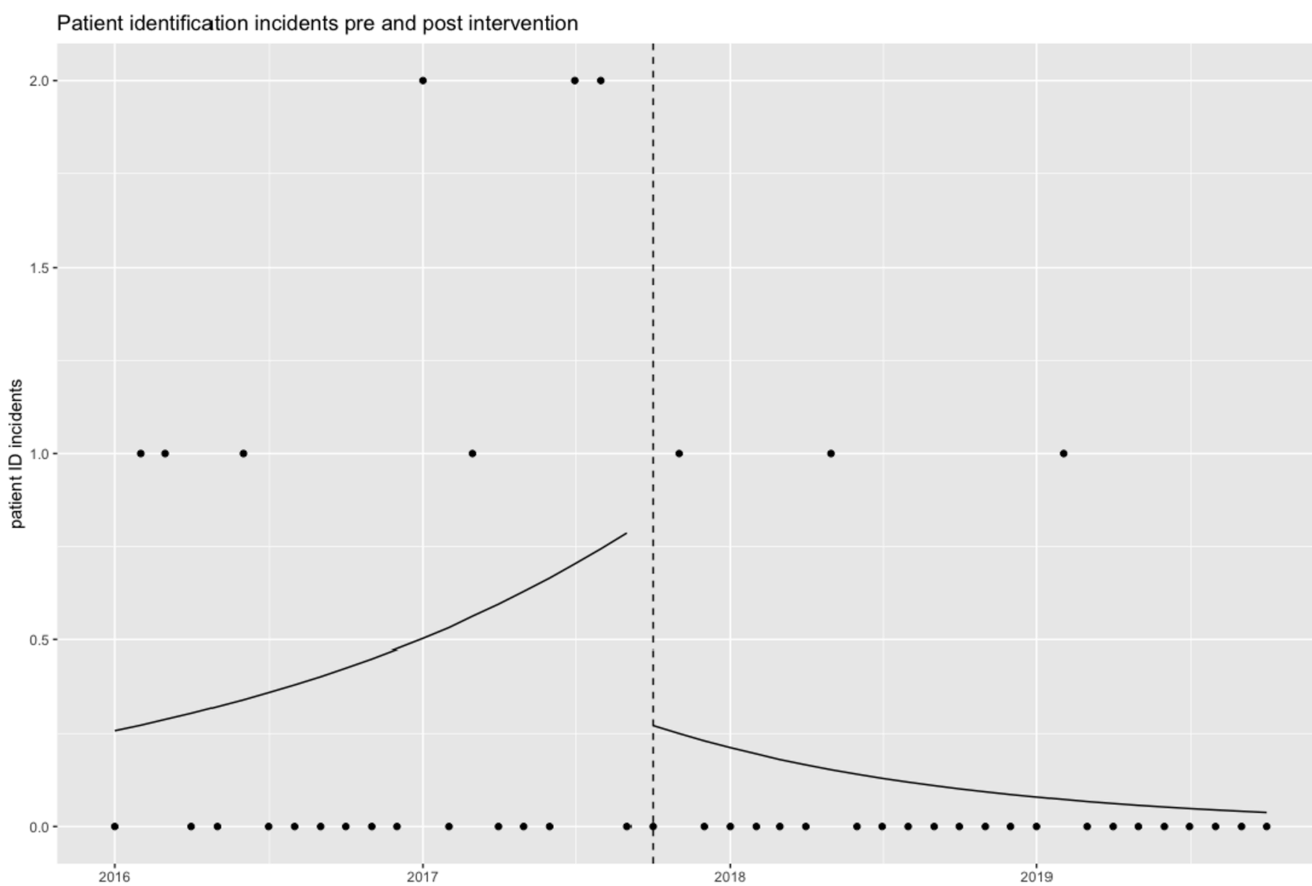

Fig. 3. Patient ID incidents per month with interrupted time series regression.

managers or in administrative roles. During group exercises participants recorded factors that influenced their capacity to complete the imaging task; a sample is given in Table 4 below.

The scenario walk-throughs explored the applicability and limitations of trust procedures. The trade-off between proceeding with imaging – to get the primary task done and maintain workflow – versus halting the process to reduce the risk of misidentification, was a frequently raised point (expanded in the discussion). Following the workshops attendees were asked to anonymously respond to statements on a five-point scale from 'strongly agree' to strongly disagree'. In response to the statement, "I have a better awareness of the human factors perspective on safety" 141/151 (93%) answered 'agree' or 'strongly agree'. For, "I am briefed to the level I need on the radiology patient identification checking procedure" 143/151 (95%) answered 'agree' or 'strongly agree'.

3.3. Distractions

The mean number of distractions was lower in the post condition, pre = 4.91/10 min (SD = 3.26); post = 1.95/10 min (SD = 1.21). The Wilcoxon rank sum test reported statistical significance ($W = 385$, $p < 0.001$).

Fig. 5 summarises distractions by source using the following notation: door – someone entering the control room (other than core radiographer/RA team), chat – non-work chat within team, call – phone call or bleep, tannoy – loudspeaker address system, non-team – noise and other distractions from non-team members, knock – someone knocking on the door, equip – problem with equipment.

In the pre-condition the proportion of distractions that were high or medium level was 48.6%; in the post intervention condition this reduced to 26.7%. A Chi-square test indicated a significant association between pre-post condition and severity of distraction (Chi-square(2) = 10.4, $p < 0.01$).

4. Discussion

In this article we have described interventions across system levels to reduce the risk of patient misidentification in radiology. Prior

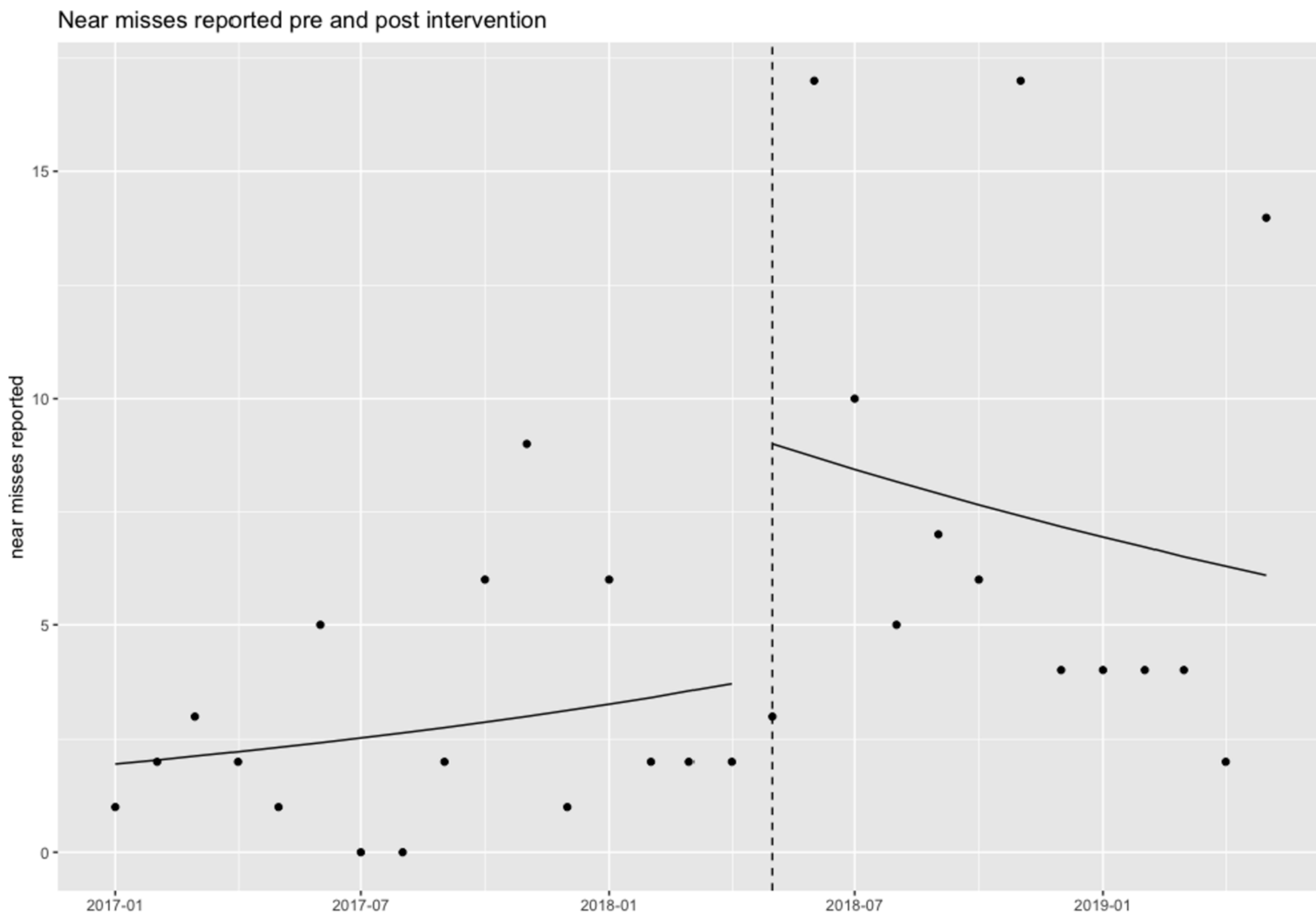

Fig. 4. Near miss reports by month with interrupted time series regression.

Table 4
Work influencing factors raised during workshops.

SEIPS Category	Specific factors recorded
Task	Poor control over workflow due to emergency bookings. Rushed or poor handover from ward staff to radiographer. Control room crowded with people talking during imaging – distracting. Frequent interruptions from telephone. Initial referral request wrong. Patients placed on wrong list.
Person/team	Cover staff unfamiliar with processes and wards. Switching team member responsibility for the patient identification step. Lone working – less capacity to meet demand. Fatigue. Rotating through different modalities.
Tools and technology	Portable computers with radiology administration software time-out too quickly – discourages checking. Several areas without barcode scanners. Insufficient quantity of portable workstations.
Environment	Computers in inconvenient position – discourages checking. Switching between different imaging suites. Documents from previous patient left in work area – potential for confusion. Insufficient space for patients on trolleys. Poor siting of emergency call bells.
Organisation	Pressure from senior management to achieve high throughput. Shortage of radiographers. Reception not staffed on evening shifts.

endeavours to improve safety in radiography have typically used narrow interventions (Flug et al., 2018; Rubio and Hogan, 2015) which may be a reflection on resource constraints and a tendency for clinician-led projects to ‘find and fix’ localised, manageable problems.

Our study followed broader lines of enquiry and viewed the radiography units as part of a sociotechnical system, in which formalised mechanisms of safety control interacted with group norms and embedded practice. We developed a combination of technical interventions, in the form of procedure and workspace design, and a social-organisational intervention, through the delivery of workshops to encourage systems thinking and reporting. Of interest from a resilience engineering perspective was the reporting of near misses – that is the detection of specific unsafe situations before a patient came to harm – which the clinical governance team re-phrased as “good catches”.

It has been highlighted that human factors approaches have the potential to improve safety in radiology (Siewert and Hochman, 2015). This study complements other HFE work that has focussed on equipment design. A usability study of radiotherapy equipment collected workflow data to redesign the user interface to incorporate an electronic checklist. This reduced the frequency of errors in a laboratory experiment; yet the ongoing challenge is to get such innovations realised into software releases (Chan et al., 2010). Taking a broader scope Bernardes et al. used task and work environment analyses to provide context to an assessment of hazards including an evaluation of the scanning equipment user interface (Bernardes et al., 2018). In common with our research, they identified that there were no restrictions on who entered the control room, resulting in safety concerns.

These previous HFE studies covered only the system analysis stage, the current study moved beyond this to implement and evaluate change. We began with localised study and then broadened scope with an action

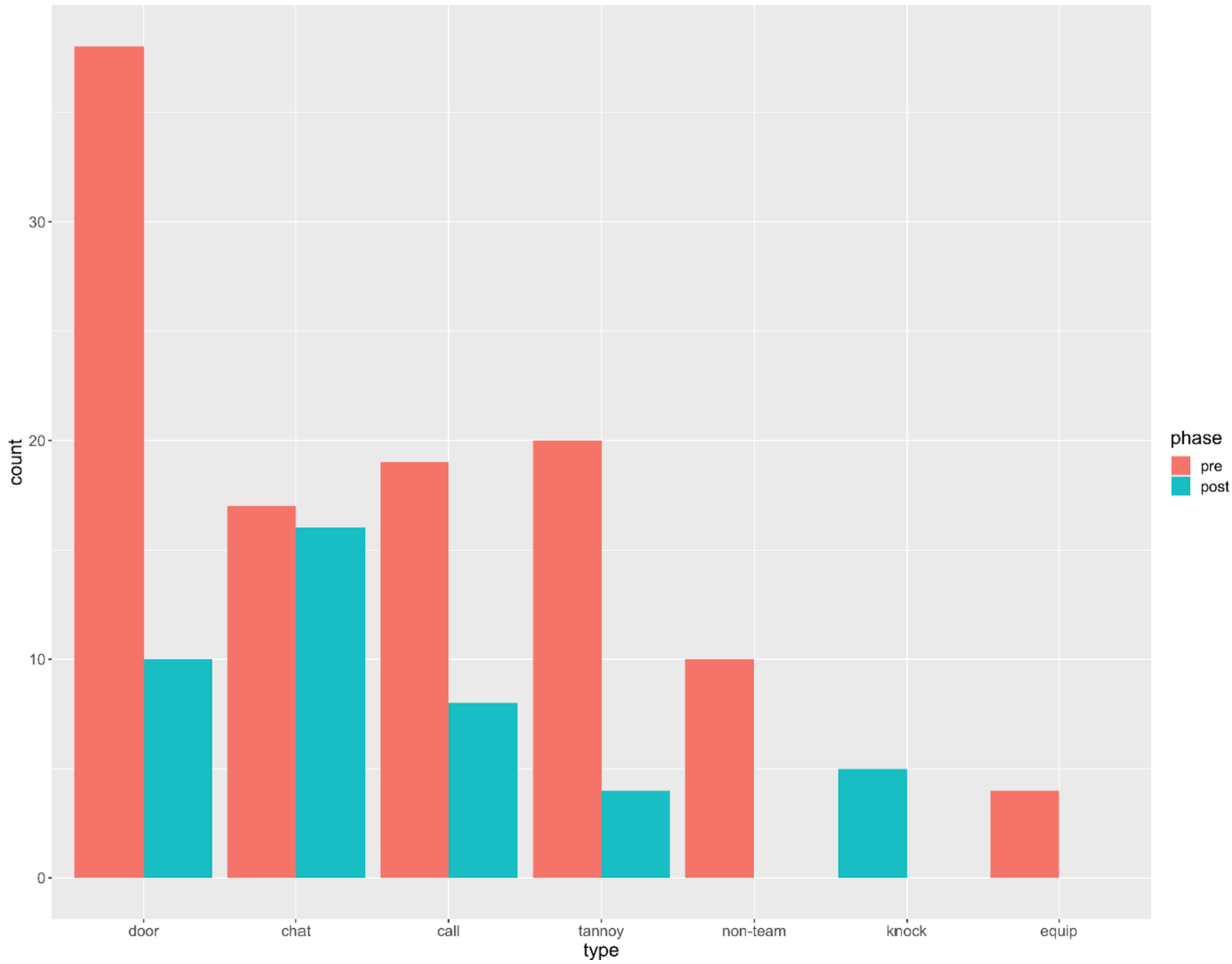

Fig. 5. Distractions by type.

research approach. The application of task analyses to delineate workflow was a practical method to identify potential problems, as has been found by other HFE studies in radiology scanning suites (Bernardes et al., 2018).

At the unit level a review of the existing trust level policy for patient identification revealed that procedures were buried in a 30-page trust level document, which was not readily accessible or commonly read. A poster produced at a national level called "Pause and Check" was posted in some control rooms, but from a usability perspective was flawed. The poster included 30 checks presented as a list, printed in small typeface that was illegible from typical viewing distances. Safety critical checks, such as 'pregnancy', were mixed in with routine prompts, such as 'are additional images required?' with no distinction between them. This diminished the impact of the tool as a whole, and as the regulator has noted, "this concept has not had the impact we thought it might… we continue to receive notifications of incidents where a simple 'stop moment' could have prevented an unintended or over-exposure" (Ionising Radiation (Medical Exposure) Regulations Annual Report 2017/18, 2018). Our project addressed this by developing a standard operating procedure developed with a user-centred design approach. This engaged staff in the development, aligned the procedure steps with existing workflow and applied usability principles.

Our interventions at the micro level reduced the frequency of distractions and staff anecdotally reported a calmer working environment. An associated proposal to designate a radiography coordinator to triage incoming requests and reduce interruptions was explored, but due to an already stretched staffing pool, this was seen as unfeasible. This has been successfully used elsewhere in radiology, with either junior or senior radiologists acting as a filter to minimise disruptions in the reading room (Kansagra et al., 2016; Mamlouk et al., 2015).

The significance of our relatively straightforward micro-level interventions is that they provided control to the radiographers over *when* to deal with requests/interruptions, which is less disruptive that having no control (Li et al., 2012). Importantly, during periods of higher working memory load, such as retaining patient information, interruptions could be avoided. A systematic review of studies in the psychology and human factors literature reports that overall, interruption has a negative effect on task completion time, resumption lag, decision-making process and error rates (Li et al., 2012).

A comprehensive review of field-based interruption studies in healthcare found that the majority had been conducted in operating theatres and emergency departments, and none in radiology settings (Rivera-Rodriguez and Karsh, 2010). A systematic review of studies in the emergency department concluded that interruptions have typically been studied in isolation and generally lack an evaluation on outcome measures, whether proximal or distal (Werner and Holden, 2015). Of the 15 articles reviewed, the majority measured interruption frequency, but not downstream effects on patients or clinicians. Surprisingly few studies considered the role of the work environment on interruptions, with just one proposing an "interruption-free zone" for high risk tasks. In a ward environment physical barriers, such as screens, have been deployed to effectively reduce interruptions during medication preparation (Colligan et al., 2012).

At the organisation level the programme of patient safety workshops sought to raise awareness that multiple components of a work system can influence radiography safety. The value of assessing these factors when submitting an incident or near-miss report was emphasised as an opportunity to provide “a window on the system” rather than to find a single root cause (Vincent, 2004). The Systems Engineering Initiative for Patient Safety (SEIPS) model provided a relatively simple framework to communicate the concept of a work system and was readily accepted by participants for the risk identification exercises. Even though the model has gained widespread use it has only recently been used to categorise incidents, finding application in cataract surgery (Loh et al., 2017) and radiology (Lacson et al., 2019).

4.1. Cross-level interactions

This study illustrates the influence of cross-level interactions on the risk of wrong site or wrong patient irradiation. Environmental factors negatively interacted with the conduct of micro level safety critical tasks, such as selecting imaging protocols. Doors left open, cramped space behind the control station and the presence of the unit’s main contact telephone resulted in distractions. Simple changes to the ‘environment’ aspect improved the ‘task’ component through fewer distractions.

The patient identification SOP was developed with a sensitivity to the tension between trust policy (organisation) and task demands (micro level). We facilitated discussions between roles at different organisational levels via the workshops in which operators and administrators could air their experiences of the procedures and the tensions therein. Three types of scenarios were frequently raised where these tensions occurred. The first was when a physical indication of injury on one laterality was accompanied by an imaging request for the opposite side. A pro-active radiographer may choose to image the obviously injured side (to meet task demands) rather than cause frustration for all by turning the patient away (as stated in policy). Secondly, there were cases of an unaccompanied patient, often elderly, who had some difficulty in identifying themselves but was ultimately able to do so; professional judgement was required. The third, and most commonly cited difficult case, was when an unaccompanied inpatient was unable to identify themselves yet was wearing a hospital identification band. The policy stated imaging should not proceed, yet this situation occurred frequently due to a shortage of ward staff to accompany the patient. Not progressing the imaging – considering the wrist band provided the identifying information – was in conflict with the goal to maintain throughput.

The concept of multi-level interactions is also found in the field of resilience engineering where it has been noted that adaptation occurs in different time scales. The Integrated Resilience Attributes Framework maps resilience potentials (anticipating, monitoring, responding, learning) against different levels of the organisation, labelled: situated, structural and systemic (Anderson et al., 2020). Our study provides empirical examples against this framework. The day-to-day adaptations made by operators, for example to deal with sedated, unaccompanied patients, represent a case of “situated resilience” by responding to case by case demands. Radiographers conducted extra work, not covered by standard procedures, to chase-up for accompanying ward staff and in some cases went on to report a near miss. Radiographers would sometimes switch responsibility for conducting patient identification within the team – identified in the framework as “re-allocating team tasks”. Here again is an example of a trade-off between delivering efficient output – by switching – and minimising risk – by having a single accountable person conduct the identification task. Being able to discuss safety and risk in these relatively informal settings has been identified as an important form of organisational learning about safety (Sujan, 2015).

The programme of HFE and patient safety workshops and the constructive engagement of the clinical governance team to encourage near miss (or good catch) reporting are examples of “structural resilience”. The programme was realised through interactions between staff attendees (the person level), the walk-through scenarios used to review practice (work system level) and the resource to run the workshops (organisation/management level). In a climate in which the regulator classifies the majority of incidents as operator/referrer error, the training sought to broaden reporting from first person accounts to those attuned to latent safety threats in the working environment. Some influence *across* the levels was evident as by shining a light on the tension between maintaining throughput and following procedure the organisation was able to learn and reflect. The intention was to close the loop, so the organisation could develop a better sense of work conducted at the sharp end. This enacted structural resilience activities of “providing mechanisms for discussing and sharing” and “learning from experience”, as described in the Integrated Resilience Attributes Framework (Anderson et al., 2020).

4.2. Limitations

Although the frequency of near miss reporting increased, it is not possible to determine if the breadth of reported contributory factors widened as no content analysis was conducted. This would be a useful avenue for future research into efforts to improve near miss reporting. Related to this, the quantitative data indicated good engagement and learning outcomes from the programme of workshops, but no attempt to measure the influence on opinions to safety reporting was made. A more prolonged period of pre intervention data would have provided a better baseline from which change could have been evaluated. Alternatively, a controlled experiment in which some areas were excluded from the intervention but included in the data collection might have allowed more definitive confirmation of the value of the intervention, but neither was practicable.

The distraction data was collected in relatively few observations periods so there may have been a sensitivity to particularly quiet or busy days. The mix of procedure types is similar for both pre and post periods which provides some assurance that a consistent set of tasks were conducted. A practical challenge with the research was maintaining communication across a directorate organised by imaging modalities and working across different physical sites. Ultimately the clinical governance team were an essential communication hub for the interventions and their engagement was pivotal.

5. Conclusion

Many safety interventions in radiology have been narrowly targeted, changing one element of a work system in isolation. In contrast, this study applied social and technical interventions at different system levels to pursue the goal of reducing the risk of patient misidentification. The project started with a localised analysis of a CT unit and this initiated an action research approach which broadened enquiry into factors such as procedures and incident reporting. Inherent in this approach was engagement with both radiographers practising technical work, and managers holding some influence over budgets and incident reporting responses.

The tension between safety and throughput goals was evident and is not unique to healthcare. The field of resilience engineering has argued that to deal with this tension adaptive behaviour occurs across temporal and spatial scales. This study found examples of both situated (micro level) and structural (organisation level) resilience. In particular, the willingness of the trust to support our intervention – in which the role of near miss reporting and system-level contributory factors were conveyed – demonstrated a commitment towards delivering a safer service. The safe provision of imaging across different modalities and physical locations is a challenge for many hospitals; this study indicates that a multi-level systems approach can reduce risk.

CRediT authorship contribution statement

Matthew Woodward: Conceptualisation, Formal analysis, Investigation, Methodology, Visualisation, Writing - original draft. **Rounaq Nayak:** Investigation. **Peter McCulloch:** Conceptualisation, Funding acquisition, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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