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Safer anaesthetic rooms: Human factors/ergonomics analysis of work practices

by M Davis, S Hignett, S Hillier, N Hames and S Hodder

Correspondence address: Prof. Sue Hignett, Professor of Healthcare Ergonomics and Patient Safety, Loughborough Design School, Loughborough University, Loughborough, LE11 3TU. Email: S.M.Hignett@lboro.ac.uk

The aim of this study was to analyse the design of anaesthetic rooms using human factors and ergonomics (HFE) methods. The methods used were hierarchical task analysis, link analysis and anthropometry. The study found several latent design errors which negatively affected drug and patient preparation tasks. Recommendations include anaesthetic room layout design modifications and system level changes. HFE principles provide generic recommendations but specific design details may not be generalizable. Further research is needed to explore the implementation of system changes.

Introduction

The physical environment of healthcare facilities has a significant impact on the safety and effectiveness of healthcare services and has been linked to errors, inadequate care, inefficient systems, operational failure and wastage (Ulrich et al 2008).

In the UK, many safety critical tasks are carried out in anaesthetic rooms. At present there is a lack of understanding and guidance of how this working environment should be designed to maximise safety and efficiency and minimise error. Examples include placement of anaesthetic monitoring equipment (Seagull et al 2004) physical layout and space to work (Harper et al 1995), standardisation of medication drawers (Schultz et al 2010), drug syringe errors (Cooper et al 2002) and workflow through the anaesthetic room (Sandberg et al 2005).

This project aimed to:
a) explore the design of anaesthetic rooms at one UK hospital with respect to preoperative tasks.

b) identify possible changes to the anaesthetic room environment to maximise safety and efficiency and minimise errors.

Background

The adverse effects of human error in anaesthetic practice have been recognised for many years (Biebuyck et al 1990, Williamson et al 1993, Cooper et al 2002, Abeysekera et al 2005). Despite the suggestion that changes to the anaesthetic workspace could reduce errors, there has been little research into possible changes (Phipps et al 2008).

In Australia and USA, preoperative tasks are carried out in multi-functional operating rooms (OR) due to patient safety concerns. However in the UK, despite these concerns, it has been reported that the majority of UK anaesthetists believe that the benefits of an anaesthetic room outweigh the risks to patient safety and therefore support the use of anaesthetic rooms for the induction of anaesthesia (Bromhead & Jones 2002, Velzen et al 2015). An exploration of anaesthetic room tasks using human factors/ergonomics (HFE) methods could be valuable for this debate to give an increased understanding of anaesthetic room usage.

Literature review

A literature review was carried out to evaluate previous relevant research.

Electronic databases (Web of Science, Medline and Ergonomics Abstracts) were searched using a search strategy (Figure 1) informed by medical and HFE literature (Weinger & Slagle 2001).

Seven hundred and twenty-one titles were identified, of which only 8 were directly relevant (Harper et al 1995, Held & Krueger 2000a,b, Seagull et al 2004, Sandberg et al 2005, Phipps et al 2008, Lu & Hignett 2009, Shultz et al 2010). Only one paper considered the physical environment of the anaesthetic room (Phipps et al 2008), however, several others focused on anaesthetic workspaces in alternative settings, such as the OR mostly to consider patient safety, using error data as the outcome metric.

Phipps et al (2008) suggested that the anaesthetic room tasks were the most demanding and that making changes to the physical design of the work environment could reduce errors. Redesign was also supported by the results from Shultz et al (2010) to reduce medication errors and improve safety with a standardised layout of anaesthetic medications. The workflow analysis by Sandberg et al (2005) demonstrated improved efficiency with an anaesthetic room (more cases per day).

Overall, it was suggested that the safety and efficiency of anaesthetic practice could be improved by optimising the physical workspace in the anaesthetic room

Ergonomics abstracts	
Research area	Search words
Anaesthesiology	an#esthesia OR an#esthetic* OR an#esthetist* OR an#esthesiologist OR administ* OR prepar* OR patient* OR operation* OR suger* OR sedati*
Anaesthetic work environment	Anaesthetic room OR induction room OR physical environment OR equipment* OR workspace* OR work area* OR layout* OR requirement* OR regulation* OR dimension* OR OR*; department* OR theatre*
Design	Human factor* OR Ergonomics OR task analys* OR link analys* OR safety OR performance OR assessment* OR risk* OR error*

Web of Science and Medline	
Research area	Search words
Anaesthesiology	Anaesthesia OR anaesthetic* OR anaesthetist* OR anaesthesiologist
Design	Design OR human factors OR ergonomic* OR workstation* OR workspace OR work area

Note: For Web of Science the symbol # was replaced by $

Figure 1 Search strategy

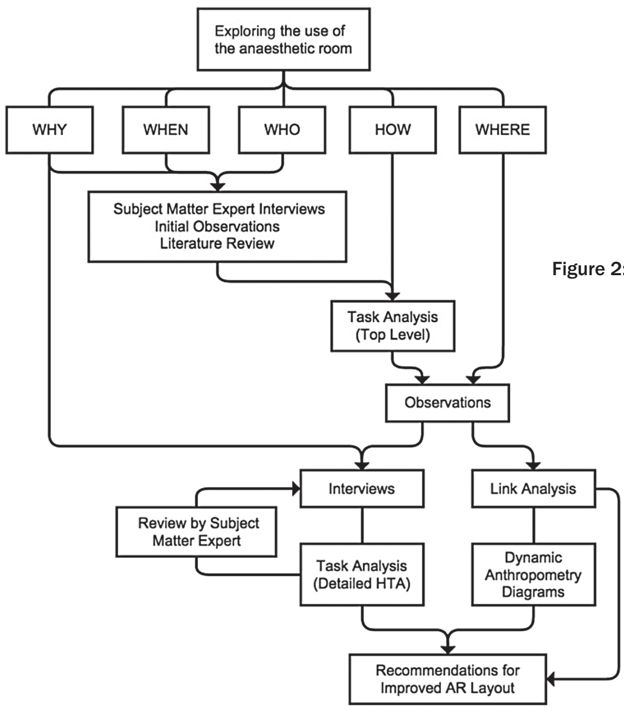

Figure 2: Data collection protocol

Some papers used task analysis, in combination with other analyses, to gain an understanding of the tasks performed in the workspace (Held & Krueger 2000a,b). Link analysis was used for analysing spatial aspects of the task (Harper et al 1995, Held & Krueger 2000a, Lu & Hignett 2009).

Overall, it was suggested that the safety and efficiency of anaesthetic practice could be improved by optimising the physical workspace in the anaesthetic room. Despite the lack of high quality data, it was evident that the use of multiple methods was necessary to ensure a comprehensive set of data, and that HFE methods would be the most effective approach for this project.

Methods

Data were collected in three anaesthetic rooms of one UK hospital over 6 days (with preceding pilot to verify the protocol) to compare different layouts on task activities and variance (Figure 2). This enabled sufficient data to be collected to achieve theoretical saturation.

Eight naturalistic observations were undertaken in each anaesthetic room with 14 follow-up interviews. Participants (anaesthetists and operating department practitioners) were recruited using a mixed purposeful sampling strategy to give a range of experience, job roles, ages and sexes.

Hierarchical task analysis (HTA) was used to describe the sequence of actions during a task to identify task variance, potential conflicts with the anaesthetic room layout and additional points for further investigation. Link analysis (LAs) was used to capture the spatial aspects by providing visual representations of the task activities and relationships between task elements.

Approval was obtained for this service evaluation (current practice) from Loughborough University ethical advisory committee and the hospital as part of the anaesthetic training programme. Two anaesthetists (Hames and Hillier) facilitated visits and assisted with data collection by taking on the role of subject matter experts (SMEs) for the duration of the project.

Observations

The anaesthetic room teams were comprised of at least one consultant anaesthetist and one ODP, but could

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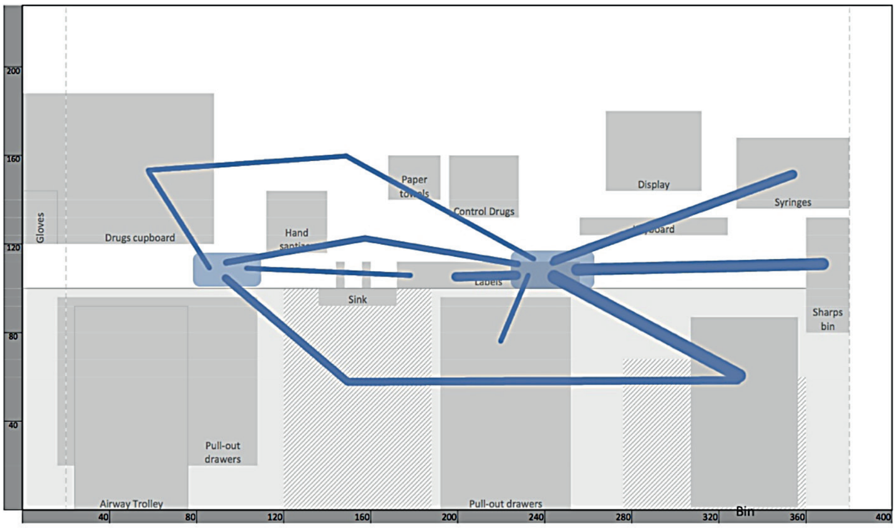

Figure 3: Drug preparation link analysis

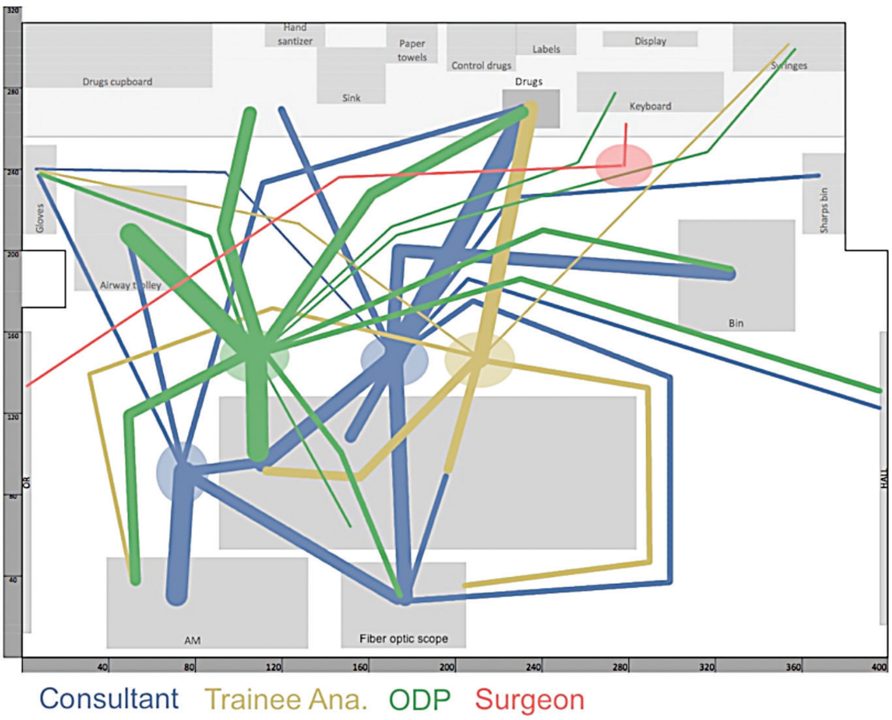

Figure 4: Patient preparation link analysis showing the spatial and task movements during a complex case (Blue = consultant anaesthetist, Yellow = trainee anaesthetist, Green = operating department practitioner, Pink = surgeon)

include up to four people if trainees were present. Participants performed their usual tasks in the anaesthetic room and were not interrupted by the observer at any point. The observations were conducted in two parts.

1. Observations of spatial activities and relationships during drug preparation tasks carried out by the anaesthetist recorded as LAs (elevation template) for the anaesthetic room worktop area.
2. Observations of the main patient preparation tasks by the entire anaesthetic room team using all parts of the room. These complex tasks (many procedures) began when the patient entered the anaesthetic room and ended with transfer to the OR. They were recorded as LAs (plan template) for the entire anaesthetic room.

The LAs were reproduced on a computer software programme to visualise the frequency of links between task elements using line thickness – the thicker the line, the more links. In addition to mapping the task activities, other data about the anaesthetic room use were collected in observation notes and reviewed during the interviews to inform the development of the HTA.

Interviews

An anaesthetist and/or ODP took part in each semi-structured interview to explore how the anaesthetic room environment and layout of equipment both affected their tasks and any reasons for observed task variance.

Modelling with anthropometric data

An anthropometric analysis was carried out using a human modelling tool SAMMIE (System for Aiding Man Machine Interaction Evaluation) based on anthropometric data from DTI ADULTDATA (Peebles & Norris 1998).

Anthropometry is the study of human body sizes and physical abilities (Feathers et al 2015) with physical anthropometric dimensions available as internationally published standards (ISO 1996). Body measurements include stature, arm and leg segments in different functional positions and activities. Determining critical design criteria requires both knowledge of task activities and the user population (different body sizes and abilities). For example, *The interviews highlighted three additional issues relating to the physical environment: the design of the anaesthetic machines (eg the monitor position), the height of anaesthetic room equipment causing difficulties for shorter people, and the design of patient trolleys*

arm reach (to design workstations with activities within a comfortable arm distance) is usually measured to accommodate a smaller person (5th percentile female for specified age range and culture), whereas clearance may be designed for a larger user (95% percentile male).

Room measurement and anthropometric data were combined to recreate the physical aspects of tasks to give recommendations accommodating a more anthropometrically diverse population of potential anaesthetic room users.

Results

Data were collected from 24 observations (12 drug preparation LAs and 12 patient preparation LAs) and 14 interviews to identify aspects of the physical environment that caused difficulties in the anaesthetic room.

Drug preparation

The number of movements (links) varied between both the three anaesthetic rooms and individual participants. There were fewer links when firstly, the workspace layout was arranged with all or most pieces of drug preparation equipment within the participants' reach distance and secondly, the participants were efficient with movements by collecting together all the items needed to complete the task from one area.

Participants tended to use a small area on the worktop from which they centred their movements; these two locations are indicated by the two blue shaded areas in Figure 3 with all links starting/ending from these positions. The eight key pieces of equipment interacted with were the drugs cupboard, drug label boxes, pile of trays, infusion trolley, syringe dispenser, general waste bins, recycling bins and sharps bin.

The most complex of the 12 drug preparation LAs (Figure 3) shows a participant making a relatively high frequency of movements to the key pieces of equipment.

Patient preparation

The observations of the patient preparation tasks produced complex LAs that represented the movements of the entire anaesthetic room team. It was observed that the role of each member of the anaesthetic room team could be different for each case.

Figure 4 shows a patient preparation LAs for a complex case in which a fibre optic scope was used to intubate a patient with a small airway. The team consisted of two anaesthetists (consultant and trainee), an ODP and a surgeon to discuss intubation options. The team members could adopt more than one working position (coloured circles). For example, consultant anaesthetists (shown in blue) could have two positions, either at the head end of the trolley or alongside the patient. The ODPs often worked from a position beside the patient, near the head end of the trolley.

The LAs varied in the level of complexity due to the large range of potential tasks and differences in the anaesthetic room team (number and competencies). The time taken to complete the patient preparation tasks ranged from 8 to 59 minutes, with the longer duration cases often including difficult intubation and/or additional procedures. For these complex cases additional equipment or staff were brought into the anaesthetic room which reduced the space for the anaesthetic room team to work and move around.

Interviews

Fourteen interviews were carried out with 12 anaesthetists and 2 ODPs. NVivo 10 (qualitative analysis software) was used to thematically analyse (code) the interviews and run queries to explore the data in more detail.

Anaesthetists were positive about the anaesthetic room layout in two of the anaesthetic rooms, but highly critical of the third. This was attributed mostly to the arrangement of the key equipment for drug preparation tasks.

For patient preparation tasks, both anaesthetists and ODPs agreed that the space in the anaesthetic rooms was adequate for simple cases but not for complex cases where additional equipment and larger teams were involved. Patient safety issues were a common theme in the interviews, with five anaesthetists expressing a preference for performing patient preparation preoperative tasks in the OR rather than the anaesthetic room. The major driver was safety concerns during patient transfer to the OR. One anaesthetist described this transfer procedure as *'...a disaster waiting to happen'* (Participant 8).

A drug preparation safety issue was the use of refrigerated emergency drugs. These drugs were brought to the anaesthetic rooms in the morning to be left on the worktop throughout the day. There were concerns that, by keeping the drugs at a temperature (above their recommended storage temperature), there was an increased risk of the drugs becoming ineffective.

The interviews highlighted three additional issues relating to the physical environment: the design of the anaesthetic machines (eg the monitor position), the height of anaesthetic room equipment causing difficulties for shorter people, and the design of patient trolleys.

Hierarchical task analysis

An inclusive HTA was developed using an iterative review process of the data sets with subject matter experts (Hames and Hillier). Figure 5 shows the top level tasks performed in the anaesthetic room. Each observed task was analysed in detail and included all the procedures (sub tasks).

The HTA highlights the large number of possible steps that may occur during the drug and patient preparation tasks. The HTA plans show the variance in task step order, and those task steps which

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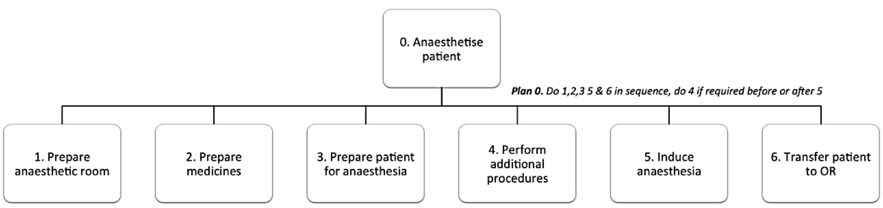

Figure 5: The top level HTA, as a summary of task activities carried out in the anaesthetic room

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could be repeated or omitted by different anaesthetic room teams. This could be due to differences in patient requirements, anaesthetists' technique and personal preferences, room layout, and/or the composition of the anaesthetic room team.

Anthropometric analysis

The observations and interviews provided data for the anthropometric analysis with five items of equipment causing difficulties for anaesthetists:

- Drugs cupboard (difficult to reach top shelves)
- Sharps bin (too close to eye height)
- Computer (difficult to reach the touchscreen monitor, awkward posture to use the keyboard)
- Anaesthetic machine display (requires anaesthetist to turn away from the patient)
- Syringe dispenser (awkward access when mounted on wall)

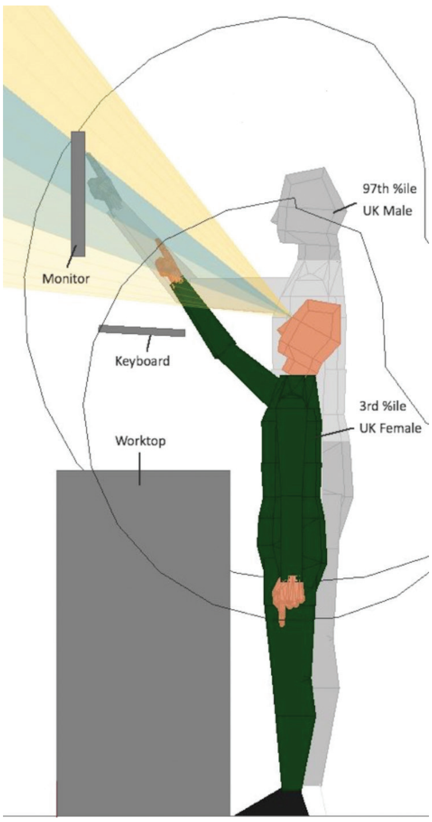

Figure 6 SAMMIE model showing the reach distances for the 3rd percentile female and 97th percentile male manikins in relation to the anaesthetic room computer monitor and keyboard

These were modelled in SAMMIE to demonstrate the current layout of equipment for shorter stature anaesthetic room users. Figure 6 compares the reach distance and vision field (foveal region for reading tasks; Pheasant & Haslegrave 2005) for a 3rd percentile UK female (stature = 1,521mm) for the computer, with a 97th percentile UK male (stature = 1,879mm). The 3rd percentile user is not able to comfortably reach the computer touchscreen monitor, or use the keyboard positioned at eye height without assuming an awkward working posture that affects comfort and task performance.

Data triangulation

Data were combined, compared and triangulated to review the key themes relating to the design of the anaesthetic rooms:

- Lack of space in anaesthetic room during complex cases
- Arrangement of equipment on the worktop area for drug preparation tasks
- Patient safety concerns leading to preferences in use of anaesthetic room or OR for preoperative tasks
- Poor accessibility of equipment for shorter users
- Negative affect of the anaesthetic machine design on tasks.

Discussion

The analysis highlights the need to consider drug preparation and patient preparation as two separate tasks.

The drug preparation LAs were found to be similar within, but different between, anaesthetic rooms, so it seems that the layout of equipment has an effect on task activity. This suggests that standardising the layout of drug preparation equipment and techniques could improve efficiency and safety. An improved worktop area could minimise movements and improve task efficiency, reduce anaesthetic room user discomfort, accommodate a larger proportion of anaesthetic room users and improve patient safety.

For patient preparation tasks, the variance in task activity was found to be very wide both within and between each anaesthetic room, possibly due to the diversity of tasks required for each patient (as presented in the HTA, Figure 5). Other factors affecting activity were the number of people in the anaesthetic room team and individual technique. The results suggest that modifications to anaesthetic room design alone may not be the most effective way to improve the safety and efficiency of patient preparation tasks, so system level changes were explored including changes to procedures, working practices and training.

An HFE investigation should always analyse the task activity within both micro and macro systems. Wilson (2014) described the 'systems of systems' in healthcare as nested and overlapping (parent/sibling) systems. The 'bed in a hospital is a system, the patient monitoring equipment is a sibling system, the two together plus the patient's room comprise another system, ...; whereas the radiology or scanning equipment, the drugs dispensary, the beds, the ambulances are all systems, but together can be seen as a system of systems when looking at maintenance and replacement regimes'.

It is suggested that difficulties with the existing anaesthetic room layout are the result of a lack of awareness (and/or consideration) of anaesthetic room users and their task requirements. Working procedures allowed new equipment to be placed on the worktop wherever there was space, irrespective of relationships to other equipment and task activities. As with any other organisational change, the practicalities of implementing a new system would require support from senior management and cooperation across departments and professions (Hignett 2001).

A system level change to address concerns with patient preparation tasks could be to move preoperative tasks from the anaesthetic room to the OR, as discussed by five participants. This service evaluation did not collect data about the use of the OR for preoperative tasks, so further research into the use of the OR for preoperative tasks is needed. Sandberg et al (2005) provided support for the use of anaesthetic room in operating departments, by suggesting that incorporating anaesthetic rooms into the operating suite design can increase system efficiency.

Anaesthetic rooms are diverse working environments in which anaesthetic room teams perform a wide range of safety critical and complex procedures

Although a wide range of procedures, patients and task variations was observed, it was not possible to see every variation of anaesthetic room use. Therefore the results may not be generalizable to all anaesthetic room users and anaesthetic rooms. The sample size was small with only three anaesthetic rooms being analysed at one hospital.

Design recommendations

Design recommendations (Figure 7) include standardising the anaesthetic room worktop to group equipment for (1) anaesthetists and (2) ODPs to optimise the performance of different task activities.

1. Anaesthetists

- Modified syringe dispenser to sit on the worktop, ideally removable for restocking.
- Wall-mounted refrigerator for emergency (and other) drugs.
- Drugs cupboard lowered and widened with interior arrangement of drugs standardised - most frequently used drugs on lower shelves.
- Sharps bin moved to the space under the worktop, so sharps do not need to be handled near eye height during disposal.

2. ODPs

- Computer monitor and keyboard lowered to include height adjustable option and monitor as a portable tablet device.
- Paperwork stored away from the sink to reduce risk of water damage.
- Trolleys containing equipment for additional procedures not blocked by the airway trolley.

Conclusions

Anaesthetic rooms are diverse working environments in which anaesthetic room teams perform a wide range of safety critical and complex procedures. The way the anaesthetic room is used varies depending on patient requirements, the layout of the anaesthetic room and the nature of anaesthetic room team performing the preoperative tasks.

Using HFE methods to analyse use of anaesthetic rooms for drug and patient preparation tasks identified several aspects of the environment which contributed to problems and safety concerns. The spatial separation of these two tasks should be explored as this might allow a smaller anaesthetic room to be provided for drug preparation tasks, with patient preparation tasks being transferred to the OR.

It is suggested that making simple design modifications to the layout could eliminate many of the issues for drug preparation tasks. For example, there should be a standard arrangement of equipment along the worktop, a standard arrangement for drugs in the drugs cupboard, and a standard design of patient trolley.

However, design changes alone are unlikely to be sufficient to maximise safety and efficiency and minimise errors during preoperative tasks, so changes at a system level are recommended. Implementing system changes will be more challenging than implementing design modifications, as this may require financial investments to facilitate changes in working practices.

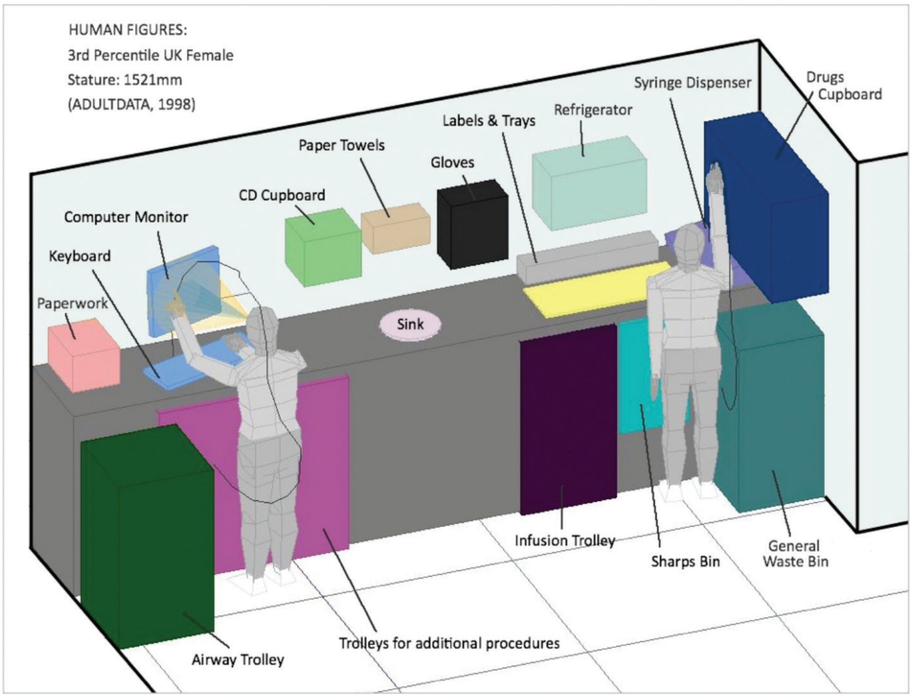

Figure 7 SAMMIE model of recommended anaesthetic room worktop for DP tasks with ODP workspace (left) and anaesthetist workspace (right)

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About the authors

Marie Davis
BSc Ergonomics (Human Factors Design)

Loughborough Design School, Loughborough University

Sue Hignett
PhD

Professor of Healthcare Ergonomics and Patient Safety, Loughborough Design School, Loughborough University

Steve Hillier
MBChB, BMedSci, FRCA

Clinical Fellow in Simulation and Human Factors, Anaesthesiology, Northampton General Hospital NHS Trust, Cliftonville, Northampton

Nicky Hames
MBChB, FRCA

Consultant Anaesthetist, Northampton General Hospital NHS Trust, Cliftonville, Northampton

Simon Hodder
PhD, BSc

Lecturer (Ergonomics/Human Factors), Loughborough Design School, Loughborough University, Loughborough

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The Association for Perioperative Practice
Daisy Ayris House
42 Freemans Way
Harrogate
HG3 1DH
United Kingdom

Email: hq@afpp.org.uk
Telephone: 01423 881300
Fax: 01423 880997
www.afpp.org.uk