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Exploring structure, agency and performance variability in everyday safety: An ethnographic study of practices around infusion devices using distributed cognition

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ABSTRACT

Objectives: Infusion safety is a recognised concern internationally. While few observational studies explore the causes of the errors that occur, even fewer describe how safety is maintained in routine practice. We sought to understand safety around infusion devices.
Methods: An ethnographic study of infusion device use was conducted on a haematology ward. This included observations of 51 infusions, plus their preparation where possible, during 120 h of ward observation over 11 days. Field notes were transcribed and analysed using deductive coding informed by distributed cognition. A further inductive thematic analysis highlighted new themes for making sense of the data.
Results: The distributed cognition analysis highlighted how infusion treatment was affected by interactions distributed across artefacts, tasks, social networks, physical space and time. These interactions occurred close to and away from the infusion: at micro, meso and macro levels according to distance from the actual process. The inductive analysis highlighted three new interdependent themes that account for how safety is constructed and compromised: structure, agency and performance variability.
Discussion and conclusion: Safety is constructed through the co-evolution of sociotechnical structure and agency whereby structure shapes and influences people's behaviour and people reproduce and create structures. Everyday performance variability emerges from these interactions, including deviations in processes and outcomes (e.g. incidents, near misses and opportunities). Studies of everyday safety can explore interactions between four points of a sociotechnical structuration model: structure, agency, and satisfactory and unsatisfactory performance.

1. Introduction

Infusion administration has been recognised as a potential safety risk by regulators, manufacturers and healthcare providers alike (AAMI, 2010; NPSA, 2007; Blandford et al., 2016). Understanding work system design, which includes the way people, tasks, tools and technology, and the environment are organised, is essential for insights into safety (Carayon et al., 2006). Observation is recognised as an appropriate method for investigating how nurses interact with infusion devices in practice (Carayon et al., 2005). However, relatively few ethnographic studies have been conducted on the situated interactions that cause infusion error and fewer still on how safety is usually maintained.

Taxis and Barber (2003a, b) used a theory of human error to explore the causes of intravenous infusion medication errors. They observed a high rate of error across ten different wards (including intensive care, paediatrics, surgery, cardiology and nephrology). The most common errors were injecting bolus doses too fast and errors in preparing drugs requiring multiple preparation steps. Error producing conditions included the design and use of technology, communication, workload, patient-related factors and lack of supervision. Furniss et al. (2011b) investigated 'unremarkable' errors and low-level disturbances in infusion pump use on an oncology day care unit. These included nurses self-correcting their own errors before they reached the patient, which resonates with research that questions what should be classed as an error

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(Baker, 1997), and how one should respond to these low-level disturbances.

Moving away from causes of error, Furniss et al. (2011a) analysed behaviour that contributes to safety on an oncology day care unit. This involved nurses anticipating and proactively organising work to reduce risk. Rajkomar and Blandford (2012) studied infusion pump practice using distributed cognition on an intensive care unit, without a particular focus on error. This approach is aligned with a Safety II approach that advocates understanding how a system 'normally' creates safety and not just how it goes wrong (Hollnagel et al., 2015).

Safety II builds on studies of situated actions in the work place and seeks to understand the 'dynamic events' that create everyday safety (Haavik et al., 2016). However, advice on how to study performance variability related to these dynamic events is still maturing (e.g. Hollnagel et al., 2018). Distributed cognition has a long tradition of being used for work place studies (e.g. Hutchins, 1995a). It is a cognitive theory that focuses on how information is transformed and propagated between tools, artefacts and people in sociotechnical systems. Its central tenets are that cognition should be considered to extend beyond the brain and that a broader range of mechanisms should be included when accounting for cognitive activity (Hollan et al., 2000). Distributed cognition has been used in various studies to understand sociotechnical systems related to safety (e.g. Hazlehurst et al., 2007; Tariq et al., 2012; Sarcevic and Ferraro, 2017). However, to our knowledge, it has not played a major role in safety science discourse per se; instead, it has focused on understanding everyday work which resonates well with Safety II. Distributed cognition could help account for the dynamic events that create and compromise safety, i.e. how performance variability emerges from the interactions of people, tools, and artefacts in context.

Distributed Cognition for Teamwork (DiCoT) has been proposed as a framework to facilitate distributed cognition analyses and was used to shape our data gathering and preliminary analysis (Blandford and Furniss, 2005; Furniss and Blandford 2006). This is composed of themes and principles that help the analyst explore contextual interactions in complex sociotechnical systems (Berndt et al., 2015). The themes are listed below, and the associated principles are included as the supplementary material to this paper:

- The **information flow theme** focuses on how information is transformed and moves around the system, often through task steps, between people, artefacts and tools.
- The **artefact theme** focuses on what external tools and representations are used, and how their design impacts the computational properties of the system.
- The **physical theme** focuses on the physical arrangement of the space, whether it is papers on a desk, people in a room or signs in a building.
- The **social theme** focuses on the roles, responsibilities and expertise of people in the system and how they do or do not work together.
- The **evolutionary theme** focuses on how the system has evolved over time, to include both where it has been and where it might be going, and how information is organised and distributed over time.

DiCoT has been extended to DiCoT-CL, which adds concentric layers to the DiCoT themes (Furniss et al., 2015) (Fig. 1). This highlights sociotechnical interactions close to and further away from the action (from the 'sharp end' to the 'blunt end' (Catchpole and Wiegmann, 2012)). Using different layers in sociotechnical system representations is not novel (e.g. Rasmussen, 1997), and micro, meso and macro layers commonly feature in discussing sociotechnical interactions (e.g. Greenhalgh and Stones, 2010). Classically, the meso layer would be at the organisational level and the macro layer at the national/societal level; however, due to our focus on individuals and teams we define them at a lower level of granularity:

- The **micro layer** includes sociotechnical interactions close to the medical procedure or interactions with the device itself, e.g. interacting with the pump interface and preparing infusions;
- The **meso layer** includes sociotechnical interactions at the ward level, e.g. nurses might intervene to help when colleagues' pumps are alarming or they might not hand over information from a shift, increasing the chance of omissions in patient care;
- The **macro layer** includes sociotechnical interactions at the hospital level and higher, e.g. hospital management setting the configuration of pumps and the design of the pumps by the manufacturer.

In a subsequent inductive analysis (informed by that first analysis), the interplay between structure, agency and performance deviations emerged as being important for understanding safety. We briefly outline some of the main sociological literature to give theoretical depth to these concepts – a full review of the literature is beyond the scope of this paper.

Structuration theory (Giddens, 1984) posits that social structures and individual agency are mutually dependent and co-evolve, each constraining and enabling the other. The creation and reproduction of social systems is dependent on both structure and agency. For example, Giddens was interested in bridging between objective social theories that perceived hard external social structures independent of the individual and subjective social theories that assumed social structures are only housed in the perceptions and interpretations of individuals (Greenhalgh and Stones, 2010). This resonates with anti-dualist theorising in more recent safety science discourse that tries to encapsulate ideas that bridge hard and soft sciences, material and social interactions, decentralised and centralised control, and participant and observer involvement in safety systems (Le Coze, 2013). One of the disadvantages levelled at a structuration theory is the idea of "central conflation" (Archer 1982, 1988) that warns that if structure and agency are entwined then it may be impossible to consider the detail and contribution of each separately (Emirbayer and Mische, 1998), which could also be a point of reflection for anti-dualist theorising in safety science.

Agency is associated with free will and the ability of individuals to decide their own course of action. In theorising about agency, Emirbayer and Mische (1998) identify component elements of agency and explain how these 'agentic dimensions interpenetrate with forms of structure'. They define human agency as "the temporally constructed engagement by actors of different structural environments - the temporal-relational contexts of action - which, through the interplay of habit, imagination, and judgment, both reproduces and transforms those structures in interactive response to the problems posed by changing historical situations. This definition encompasses what we shall analytically distinguish below as the different constitutive elements of human agency: iteration, projectivity, and practical evaluation" (Emirbayer and Mische, 1998, p.970). The iterative element emphasizes how actors react to past patterns of thought to help sustain identities, interactions and institutions over time. The projective element encompasses the imaginative faculties of actors in projecting trajectories of possible future states that relate to their hopes, fears and desires. The practical-evaluative element captures the practical and normative judgements of actors and their response to 'the emerging demands, dilemmas, and ambiguities of presently evolving situations' (Emirbayer and Mische, 1998, p.971). As far as we are aware this depth of sociological theory has not been directly applied to safety studies but these issues of agency resonate with safety science themes such as rules, necessary violations, and production and protection pressures (Le Coze, 2013; Hollnagel, 2009).

Structure is associated with a persistent pattern of social rules and/or arrangements that could manifest themselves in situations as diverse as a general election, a court case, joining the scouts, workplace procedures, religions, habits, routines and rituals. In theorising about structures, Sewell (1992) says that there is a multiplicity of types and

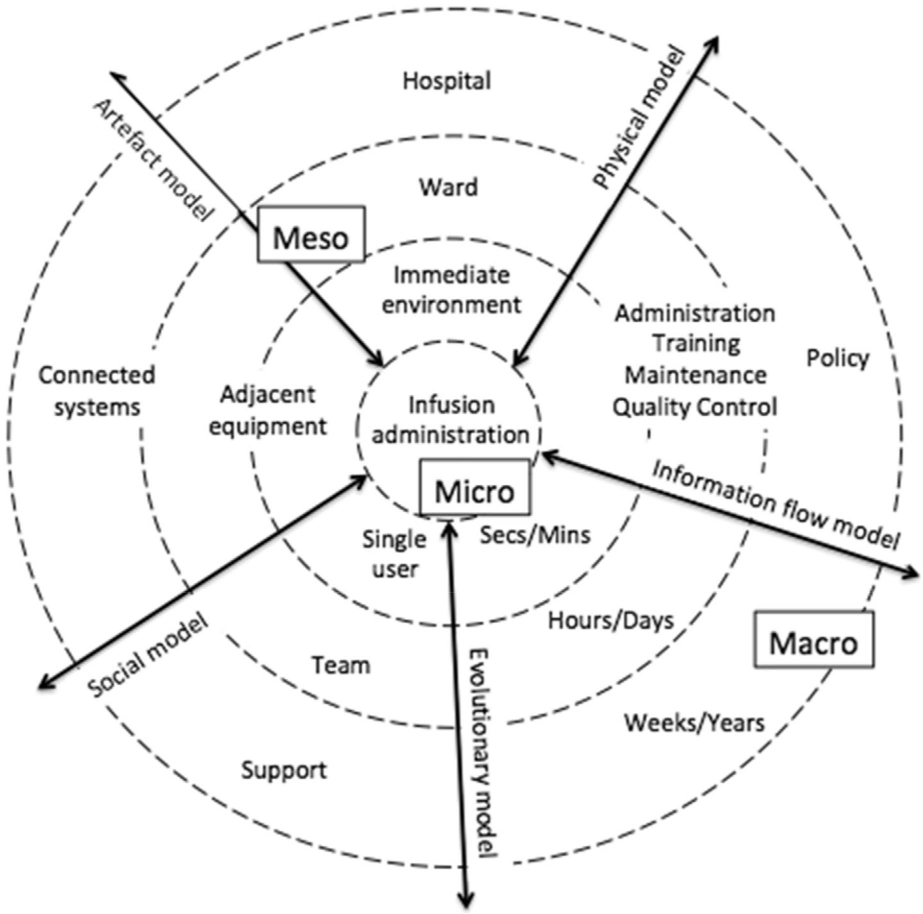

Fig. 1. The DiCoT concentric layers (DiCoT-CL) framework (adapted from Furniss et al., 2015). Each layer of the sociotehcnical system is divided into five areas to reflect the themes of the different DiCoT models, i.e. information flow, artefact, physical, social and evolutionary models.

levels of structures that act concurrently on actors and might even be contradictory, that resources are related to structures and may have multiple meanings for actors, that there is unpredictability in what structures to follow and invest in because effects on resources are not know, and that the internal structures of knowledge and schemas can be creatively transferred to new situations. This provides a complex and structured space for actors to operate in; this structure greatly influences actors but it also gives them some degree of agency in terms of how to navigate this space. Lopez and Scott (2000) highlight the roles of three different types of structure: institutional structure that provides cultural and normative patterns of behaviour that define expectations of agents, relational structure that emphasizes patterns of interconnections and interdependence between agents and the positions they occupy, and embodied structure that refers to the habits and skills possessed by agents. Structural themes are strong in the safety science field, and might be traced back to historical moves away from human error as a cause of accidents to focus on latent conditions and sociotechnical system structures that contribute to poor performance (Le Coze, 2013).

Structuration theory has advanced theorising about nursing research and patient safety (Hardcastle et al., 2005; Groves et al., 2011; Aveling et al., 2016). Researchers have also expanded the approach to theorise about technology adoption and use by considering how technological structure enables and constrains individual agency, and how individual agency and social structure shape technology use (DeSanctis and Poole, 1994; Greenhalgh and Stones, 2010).

If we take the idea of co-evolution of structure and agency, central to structuration theory, to be over generations then we get closer to the original view of distributed cognition presented by Hutchins (1995a). Hutchins uses Simon's (1981) parable of the ant to emphasize the environment's role in shaping cognition. Briefly, we may attribute the complicated movements of an ant on the beach to its knowledge, learning and decision-making; especially as it seems to move less randomly and find sources of food more efficiently over time. However, the ant's trajectory tells us more about the beach than the ant. The argument is that it is the same simple ant but the pheromones laid on the beach by the rest of the colony allow it to engage with the environment more efficiently. Simon (1981) uses the parable to emphasize the role of the external artificial environment on cognitive processes. Hutchins (1995a) extends this message but emphasizes how cognition is structured, e.g. by the evolution of tools and artefacts, by preceding generations through a process of sociocultural heritage. Both of these emphasise environmental structure in cognitive activity.

Within haematology, infusion pumps play a vital role in treating patients by delivering drugs and fluids intravenously, and delivering enteral and parenteral feed. We aimed to investigate how safety is constructed and compromised around infusions on a haematology ward, and to describe the sociotechnical system in which infusion practice is organised and embedded. Different clinical contexts have different infusion arrangements and issues; infusion safety in haematology has not been focused on previously. This work also contributes to situated accounts of how Safety II may be studied and how safety is usually maintained around infusions more generally.

Table 1
Structural elements observed that shape infusion practices. Sociotechnical features related to structures that show how information processing is distributed across themes and layers. Case numbers progress in chronological order through Tables 1, 2 and 3 so they each have a unique identifier. DiCoT principles have been *italicised* – descriptions of DiCoT principles can be found in the supplementary material.

Case No. and title	Day	DiCoT themes	Layer	Description	Impact on infusions
1) Infusion pump pressure indicator	1	Artefact	Micro	After setting up the infusion and programming the pump the nurse pointed to a small bar on the pump's interface that indicated the pressure in the giving set. She explained that if this continued to rise the pump would stop and the alarm would go off. None of the other nurses had shown me this feature of the pump before and I didn't notice them looking at it.	This small indicator gave the nurse more feedback about what the pump was doing and why.
2) 'Phosphate 43'	1	Information flow	Micro	The experienced nurses have done the regular calculations so many times that they remember the figures they need by rote. For example, 500 ml phosphate was often prescribed over 12 h, which means the rate is about 43 ml/hr. The nurses call this 'Phosphate 43,' which suggests that the rate is embedded in their language. Nurses experience patterns of drugs, doses, rates and volumes for patients with certain conditions over and over again. These patterns form schemas, so common infusion administration is less about random number entry and more about meaningful schemas. This indicated a certain degree of *expert coupling* between experienced nurses and infusion administration orders.	Regular calculations are memorised rather than performed and in some instances information is ingrained in the language nurses use.
3) Familiar medications	1	Social Artefact	Micro	A nurse was making up an infusion in the treatment room and said she knew this drug was mixed with sodium chloride 0.9% due to her experience. If it was something she was unfamiliar with she would consult the infusion guide book they have in the treatment room which would give instructions of how to make up and administer the different drugs.	This is a form of distributed memory and knowledge, some internal and external, to administer infusions safely.
4) Infusion input: volume, duration and rate	11	Artefact	Micro	The pump needs two of these three values to work out the third: volume, duration and rate. Nurses would often input the volume and duration and let the pump work out the rate, especially if it was a difficult calculation.	Infusion calculations are offloaded to the pump.
5) Accessible calculator	8	Artefact	Micro	The pharmacist has a small calculator hanging from her key chain across her waist, meaning that this aid was always close to hand.	Calculations could be externalised and checked.
6) Chemo trolley	1	Artefact	Micro	There is a dedicated chemotherapy trolley that is set up with the equipment needed for those types of infusions (see Fig. 4).	This *arrangement of equipment* simplifies the cognitive task because everything should be close to hand.
7) Flag labelling	5	Artefact	Micro	Information about the infusion and the syringe markings both need to be read. A nurse filled out a yellow sticker to put on the giving set line rather than the syringe otherwise it would be difficult to read on the syringe and would cover the syringe's markings that also need to be read.	Sticking a label directly on to the syringe could make information difficult to access. However, there is a risk that if the syringe is changed but not the giving set the information would be incorrect.
8) Student supervision	1	Social	Micro	A student nurse is trained on how to give infusions under close supervision of a qualified nurse. The student nurse had written figures on a piece of paper to help her. This is an example of *creating external scaffolding* to simplify cognitive tasks.	Training the next users who will perform this task.
9) Paper prescription chart sections	2	Artefact	Micro Macro	The prescription chart had many different sections: 1. Once only, surgical, antibiotic, prophylactic, or premedication; 2. Regular prescriptions; 3. Oral anticoagulants e.g. warfarin; 4. As required; and 5. Single and continuous intravenous infusions. Infusions can be prescribed in any of sections 1–4. A nurse interacting with a prescription chart is at the micro layer, but the design of the prescription chart is at the macro layer.	Information spread across a series of subsections can be hard to find and easier to omit. However, it also means staff know where to look for different types of information.
10) The daily ward routine	2	Evolutionary	Meso	There is an ebb and flow to the ward and administering infusions. The main time for administering infusions are 6am, 12noon and 6 pm. Prescription charts will generally be reviewed by nurses at 8am, 12noon, 6 pm and 10 pm. Nurses do 12hr shifts from 7 to 7, so they will hopefully have their 6o'clock doses done before the next shift starts.	This routine helps nurses organise their day.
11) Start of shift handover and safety briefing	1	Information flow	Meso	At the start of the shift there is a handover by each nurse to the new shift coming in. This includes significant information about the patients and what medications they have had. This is immediately followed by a safety briefing that includes raising awareness of safety issues, e.g. patients with similar names on the ward.	The handover to the new shift raised situational awareness about all the patients on the ward, and pertinent safety issues. This helps reduce the likelihood of infusion errors.
12) Riskier patients are not out of sight, out of mind	11	Physical	Meso	If patients need to be closely attended to for whatever reason they are moved to a room in front of the active reception area, near the treatment room. There is a lot of activity and so these rooms more readily fall within the clinicians' *horizon of observation* (see Fig. 3).	This means the patient and their treatment can receive higher levels of implicit and explicit attention.
13) Distributed memory	5	Social	Meso		Distributed memory and problem solving between the nursing team.

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Table 1 (*continued*)

Case No. and title	Day	DiCoT themes	Layer	Description	Impact on infusions
				In the treatment room a nurse was preparing a drug and asked the other nurses about its preparation. One of the other nurses in the room had the answer because she had done the same thing recently, which showed *shared memory and problem solving* at the ward level.	
14) Distributed expertise	5	Social	Macro	One of the nurses had two patients on patient controlled analgesia pumps and wanted to speak to a pharmacist who was off the ward to check whether the syringes needed to be changed every 24 h or every 72 h, which showed the *socially distributed properties of cognition* at the hospital level.	Nurses could call others for specialist advice.

2. Methods

2.1. Study design

Ethnographic observations and interviews were used to investigate infusion administration and the wider system in which it was embedded. Ethnography was considered an important methodological approach for exploring how frontline staff worked, identifying tacit knowledge, unremarkable routines and issues in-situ. Essentially this allowed us to engage with how safety is constructed and compromised in context, while paying attention to the local rationality of staff, i.e. how they understood things from their perspective. DiCoT-CL (Furniss et al., 2015) guided the data collection and analysis. The study was approved by an NHS Research Ethics Committee [10/H0715/13].

2.2. Setting

The haematology ward was in a busy London teaching hospital. It had 19 beds in separate side rooms with en suite facilities so that each patient could be kept in isolation. Each side room had positive or negative air pressure to keep airborne bacteria out if the patient was immunocompromised, or in if they had an infectious disease. Infection control procedures included barrier nursing, which meant nurses typically washed their hands; put on a disposable apron and gloves, and sometimes a mask, before entering a side room; and washed their hands and threw away the disposable protective clothing after leaving the side room. Between each patient side room and the main ward corridor was a small anteroom that had a sink, stocks of protective clothing and bins so that barrier nursing could be performed.

During the daytime, nursing staff typically comprised a nurse manager, four nurses and two healthcare assistants. However, staffing levels varied from shift to shift and sometimes included student nurses and temporary staff. Paper prescription charts were used, with standard infusion pumps that did not include drug libraries or dose error reduction software.

2.3. Data collection

Observations focused on infusion administration, plus preparation where possible. Infusions via pumps were observed, including intravenous and subcutaneous infusions and nasogastric feeds. Bolus doses of medication were excluded. Staff were asked for written consent to observe their work at the start of a shift. Patients were not asked for consent because their data was not the focus of the study, but they were verbally asked for permission to observe their treatment. Data collection mechanisms included:

(1) Observations of infusion administrations, plus their preparation where possible;
(2) nterviewing staff (between infusions and other tasks);
(3) Observing the general ebb and flow of ward life;
(4) Talking to patients informally as part of observing their care.
(5) Photos were taken of artefacts but not people or patient data.

The number of observed infusions was counted. The interviews with staff (which took place between infusions and other tasks) were not counted. In practice these interviews were formed from partial conversations spread across and between shifts when nurses found the time, and some nurses were much more engaged than others.

DiCoT-CL themes and principles informed the data collection (Blandford and Furniss, 2005; Furniss and Blandford 2006). Other areas of interest were also attended to if they were relevant to the context of infusion administration, e.g., patient care and experience. The first author, who has expertise in fieldwork and distributed cognition, collected all data and kept extensive field notes of the context, observations and interviews.

Table 2
Adaptations and workarounds observed in infusion practices. Sociotechnical features related to agency that show how information processing is distributed across themes and layers. Case numbers progress in chronological order through Tables 1, 2 and 3 so they each have a unique identifier. DiCoT principles have been *italicised* – descriptions of DiCoT principles can be found in the supplementary material.

Case No. and title	Day	DiCoT themes	Layer	Description	Impact on infusions
15) Alcohol gel application to the giving sets	1	Artefact	Micro	There was a problem with a batch of giving sets that were not recognised by the infusion pump. The nurses spread alcohol gel on the line as a workaround that sometimes helped the pump register the giving set. If this did not work nurses might infuse the drug or fluid via gravity (i.e. not using the pump) and set the rate by counting the drip rate because they would not want to disconnect the line, deal with a potential spillage and waste the dose that remained in it.	This could increase pump alarms, increase workload, and increase likelihood of gravity infusions that were less controlled.
16) Tactics to prevent and deal with air in the line	10	Artefact	Micro	Nurses had various tricks for priming the line with fluid and reducing air in the line. They sometimes primed the line manually into a sink, and at other times primed the line with the pump but hold the line up high so the pump's mechanism acted against gravity which reduced the chance of air bubbles. Bubbles in the line could be better inspected against a light background, e.g. a wall. The line could be flicked to dislodge bubbles that would hopefully go up the line and into the drip chamber where they would no longer be a problem.	Air in the line was a frequent source of repeat alarms and so actions to reduce these small bubbles had large consequences on staff workload and patient comfort.
17) Note to self	3	Artefact	Micro	A bank nurse (i.e. a nurse used to working on a different ward in the trust but doing an extra shift on this ward) stopped by the treatment room to read the code for the door that they had noted on their handover sheet. This is an example of *creating external scaffolding* to simplify cognitive tasks.	Staff not used to working on the ward could externalise extra information on their handover sheet so they were not hindered later.
18) Distributed teamwork	1	Information flow Artefact	Micro Meso	A nurse attended to another nurse's patient because their pump alarm was going off. The alarm indicated that the infusion was almost complete. The nurse reduced the rate to 4 ml/hr so it kept the cannula patent, and gave the other nurse more time to attend to the infusion later. This shows the *socially distributed properties of cognition*.	This dealt with the immediate problem of the pump alarming, but increased the likelihood that the infusion might be forgotten about.
19) Millimetre measurement	5	Artefact	Micro	A nurse borrowed another nurse's ruler so that she could measure millimetres on a syringe (see Fig. 5). The syringe driver operated in millimetres per hour. This allowed for *representation-goal parity* as the representation is brought into coordination with the goal state, i.e. the nurse wanted X millimetres of drug in the syringe and could measure this using the ruler.	The ruler transformed a complicated conversion of millimetres to millilitres into a simple visual task.
20) Using the thermometer as a timer	5	Artefact	Micro	A nurse was adjusting the drip rate of an infusion using the roller clamp to increase and release pressure on the line. She needed to count the drips to work out the rate and used her thermometer as a timer because it beeped every 15 s (*a mediating artefact*). The audio signal from the thermometer did not interfere with the nurse's visual counting task.	The appropriation of the thermometer as a timer facilitated the calculation of the drip rate.
21) Managing infusion access: delayed infusion	2	Information flow	Micro	A patient was prescribed more than one drug but only had one access device. They were already having problems with this connection, and so the nurse made the decision to delay one of the drugs for 2 h rather than change the connection or put in a second access device.	Delaying one of the drugs made sense in terms of patient comfort.
22) Not running out of paper forms/templates	1	Artefact	Meso	Nurses sometimes had to use supplementary sheets of paper for certain procedures, e.g. for recording the administration progress of titrating rituximab. They would photocopy sheets and forms if they were running low. However, sometimes nurses would use the last remaining sheet meaning there was nothing to work from. The ward clerk had designed some sheets that could be printed from her computer if the last sheet was used, which is an example of managing *mediating artefacts* that would otherwise become unavailable.	Sheets and forms can help shape cognitive tasks. Without these sheets and forms the likelihood of error could increase. The ward clerk created a supply of these templates.
23) Keeping nurses close to the action	1	Physical	Meso	The ward clerk reported that a computer was removed from the reception area at the front of the ward. This was to prevent some nurses sitting in this quieter area and ignoring alarms that were not theirs.	This could impact promptly responding to infusion alarms, and the division of labour amongst the nurses.
24) Patient comfort: Slowing the infusion	6	Information flow	Meso	A nurse requested a doctor to adjust a prescription so potassium could be infused over 12 h instead of 8 h. The patient had complained of soreness and the nurse thought a slower infusion might be more comfortable.	Prescription adjusted for patient comfort.

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Table 2 (*continued*)

Case No. and title	Day	DiCoT themes	Layer	Description	Impact on infusions
25) Adjusting routine practice	7	Information flow	Meso	A doctor was speaking to the nurses because they wanted rituximab given late in the day, which deviated from their normal practices. Rituximab is generally not given late in the day because patients can react to it; giving it early means they can take remedial actions during the day when the patient is more alert and the ward is better staffed.	Adjusting routine practice because of clinical need.
26) Patient comfort: Paused infusion	5	Social	Meso	A nurse needed to change a syringe in a syringe driver. The patient also wanted a shower so the nurse disconnected it and returned in half an hour so the patient had time to shower without the pump attached.	Some delay in managing the infusion so other activities can be performed.
27) Patient comfort: Delayed infusion	8	Social	Meso	A nurse delayed an infusion as the patient went outside to smoke.	Some delay in managing the infusion so other activities can be performed.
28) Removing stock removing risk	5	Artefact	Macro	The hospital previously used two types of small syringe drivers (capable of subcutaneous or intravenous infusions): the MS16a that infused over an hour and the MS26 that infused over 24 h. Only the MS16a is stocked now.	Only stocking one removed the risk of confusing them.

2.4. Analysis

Field notes were transcribed and coded by the first author. The data were explored through deductive and inductive coding, which were done in parallel. NVivo 11 qualitative data analysis software was used to aid this process.

Deductive coding used DiCoT-CL (Furniss et al., 2015). Observations were coded by theme (i.e. information flow, artefact, physical, social and evolutionary), by layer (i.e. micro, meso and macro layers), and associated DiCoT-CL principles such as situation awareness, arrangement of equipment, expert coupling, and horizon of observation where relevant (see supplementary material). All co-authors checked and refined the categorisation and description of the resultant thirty-seven distributed cognition features (see Tables 1–3).

Inductive coding included features of the context and activities that described infusion practice and the context of work. New themes emerged during the analysis and their relationships were captured in a model of safety structuration. Narratives were developed to illustrate the relationships: three major issues for managing infusion practices on the ward were described, emphasizing how the new themes in the model played out in practice. Narratives were chosen because these issues traversed a number of themes and they could not readily be captured in short descriptions. All co-authors checked and refined the narratives and their thematic classifications (see Tables 4–6).

3. Results

Observations were conducted on 11 days over a 9 month period (August 2012 – March 2013), totalling about 120 h of fieldwork. The researcher observed nurses administering 51 infusions.

3.1. A Distributed cognition view of the sociotechnical system

Thirty-seven distributed cognition features were identified in the data; each one has a unique case number across Tables 1–3.

Infusion practice is part of a complex sociotechnical system that involves different tools and technologies, distributed over different people and physical space, over different periods and patterns of time (Tables 1–3). The specific configuration of each element of the system can affect safety and performance. Fig. 2 relates to the social theme and shows overlapping areas of responsibility and goals in staff structure: patients were typically allocated evenly among the nurses but higher dependency patients could affect the division of labour. Fig. 3 relates to the physical theme and shows a schematic diagram of the ward. Beds 11, 12 and 13 had healthcare professionals passing by more frequently because they were next to the treatment room and reception, so high risk patients were generally positioned here so that they could be monitored more easily.

Artefacts were brought into coordination to set up and administer infusions, such as paper prescription charts, infusion pumps, additive labels, and trays and trolleys to organise the work. Fig. 4 shows a separate trolley for chemotherapy administration, which physically and cognitively organised equipment for that task and helped to ensure separation of equipment from that used for other types of medication. Fig. 5 shows a nurse using a small ruler for measuring millimetres on a syringe that was marked in millilitres. What could have been a complicated calculation to convert millimetres into millilitres was transformed into a simple perceptual task thanks to the ruler. However, operating in millimetres per hour conflicted with national guidance, which warned that many users did not find this intuitive (Case No. 37 in Table 3).

Different layers of the sociotechnical system influence safety and infusion devices. For example, the micro layer generally refers to a single nurse with the patient at the bedside focused directly on the infusion task (e.g., specific details in the prescription chart were sometimes incomplete or incorrect (Case No. 29 in Table 3); the meso

Table 3

Performance variability outcomes related to infusion practices. Sociotechnical features related to performance variability that show how information processing is distributed across themes and layers. Case numbers progress in chronological order through Tables 1, 2 and 3 so they each have a unique identifier. DiCoT principles have been *italicised* – descriptions of DiCoT principles can be found in the supplementary material.

Case No. and title	Day	DiCoT themes	Layer	Description	Type and severity of deviation
29) Incomplete and incorrect prescription charts	1	Artefact Social	Micro	The details for some infusions were incomplete on the prescription chart. Furthermore, the doctors had written the rate in the duration column. The nurses were used to this, and knew what was meant so they did not feel it was a significant issue. One actually expressed her preference that doctors did not specify everything because they often did not know that level of detail.	Procedural discrepancy
30) Incorrect rate	11	Information flow	Micro	The nurse was administering a 260 ml infusion that was prescribed to be given over 4 h. She set up the infusion and programmed the pump with a volume of 260 ml and then a rate of 260 ml/hr. Before she pressed start the observer intervened and the nurse corrected the rate to 65 ml/hr. The nurse was at the end of a shift and said she was exhausted.	Medication administration near miss
31) Omission	5	Information flow Artefact	Micro Meso	One of the nurses omitted some medication that was prescribed for a patient, which was on the back sheet of the prescription chart. The nurse was adamant that this was not handed over to her. The ward manager said that nurses should check the whole prescription form and the patient's notes carefully. They should not rely on handover information as a *behavioural trigger*. One reason is that doctors can prescribe things without telling the nurses.	Medication administration incident
32) Wrong patient	9	Information flow Artefact	Micro Meso	Two patients were on the same drug that was made up by pharmacy and kept in the fridge. The nurse picked up a bag from the fridge and administered it to the wrong patient – the doses were different. The ward manager said this had not happened before and should have been picked up by a second nurse double checking that it was the right bag before it was administered to the patient.	Medication administration incident
33) Oral/Intravenous change	10	Information flow Social	Meso	The doctor prescribed something to be given orally and the nurse wanted to give it intravenously. However, the doctor was too busy during the night shift to come to the ward to change it so it had to be given orally.	Failed adaptation
34) Severely short staffed	11	Social	Meso	A senior nurse manager reported that the night before on a different ward an agency nurse cancelled at short notice and so they were left with only two qualified nurses for the whole ward, which included two patients who required one to one care. The coordination of resources meant this workload is unmanageable.	Procedural incident
35) Borrowing staff from a different ward	1	Social	Macro	A nurse from a neighbouring ward requested that they could borrow a nurse because they were short staffed. However, the nurses on the ward said they had no one to spare. Being short staffed will impact workload and potentially increase likelihood of error.	Failed adaptation Staffing issue
36) Problematic giving sets	1	Artefact	Macro	There was a problem with a batch of giving sets that came from the manufacturer. When inserted into the pump, the device reported that they were invalid giving sets or that there was air in the line when there was not. This led to the workaround noted in Table 2: Case No. 15.	Equipment issue
37) Millimetres should not be used	5	Artefact	Macro	The National Patient Safety Association (NPSA) released Rapid Response Report NPSA/2010/RRR019 warning that many users do not find older ambulatory syringe drivers that operate in millimetres per hour intuitive. This trust was still using a pump that worked in millimetres per hour some years after this national guidance (e.g. see Fig. 5).	National guidance discrepancy

Table 4
Narrative 1 – Downstream consequences of the infusion pump's 10 min pre-completion alarm, and commentary on the interplay between structure, agency and performance variability This narrative has been formed by synthesizing field notes from the first author's first person perspective.

Narrative 1 – Downstream consequences of the infusion pump's 10 min pre-completion alarm	Commentary on the interplay between structure, agency and performance variability
The infusion pump's 10 min pre-completion alarm was a source of frustration for staff and patients. One of the patients described the issue: "The nurse sets up the pump and leaves, 10 min before it ends it goes off which could be at any time e.g. 2 am, the patient then calls the nurse, they come and ask why you called them, then they turn off the alarm and leave. Then the pump really alarms as it is finishing, the patient tings the bell again and then the nurse comes once they're free. […] When you have been lying here for three weeks you notice things you might not normally… pointless alarms… you need to rethink what the alarm is for, for who, for when and for what action. Is it to alarm me as the patient?" The nurse supported this account and said the alarm disturbs the patients, wastes staff time and seems needless. She also referred to some patients who refused treatment via pumps "because the noises it made drove them mad".	The process of barrier nursing (which is supported by the physical structure of the ward) conflicts with interactive structure of the device.
The patient suggested that nurses carry some form of technology that could receive alerts from pumps remotely, so they could be notified directly rather than disturbing patients.	Suggested change in structure to address issue.
Later I found out that the infusion pump had a standard configuration across the hospital (apart from in critical care and paediatrics). This meant that 10 min before an infusion was due to finish a pre-completion alarm would sound. This was intended to alert the nurse to prepare for a follow on infusion or prepare to disconnect the device. However, due to the physical layout of the haematology ward this pre-alarm frustrated staff and patients. A nurse said that they raised the issue about the pre-completion alarms with management a long time ago but they were told that this was how the pumps were designed and nothing could be done about it. However, this was not a design issue for the manufacturer but a configurable option set by the hospital. There was clear friction between the practice of barrier nursing and the interactive structure of the device's pre-alarm configuration.	Configuration of the device is done at the macro level. However, ward staff did not know who was responsible for this.
A downstream consequence of this issue is that nurses would sometimes break with protocol and tell the patients how to silence the pre-completion alarm directly or indirectly. An 'indirect' example was a nurse explaining how to silence the pre-completion alarm to me; however, she seemed more concerned that the patient indirectly understood what she was saying as the pump was facing them as she went through the process step by step. The patient made it clear that they were not 'brave enough' to interact with the device themselves. A 'direct' example was a patient who said, "If that goes off I just press the OK button; she [the nurse] has taught me well." The nurse was a little embarrassed as it was not something she should have done. The nurse said, "You know some patients you can tell but others you can't." Other nurses that did this also said that they do not allow all patients to do this. Indeed, one patient who was prone to confusion had worked out what to do by himself, but was reprimanded for interacting with his pump, and the nurse tried to warn him that he could potentially give himself a bolus dose and cause himself an injury. I later heard that on occasion patients had been found in side rooms with unfinished infusions and pumps with flat batteries, and it may have been because patients had silenced their pump's alarm when it was warning of a low battery rather than a pre-completion alarm. This example shows adaptations by staff and patients, and the potential deviations that can follow.	Staff and patients adapted to the problems they faced in coping with this structure, which sometimes led to deviations.
A different patient told me how she didn't like to be a nuisance and so she would sit there for 10 min whilst the pre-completion alarm went off next to her. She would only call the nurse when it was time to turn off the pump.	Again, patients would adapt to the structure they perceived. This could also be considered in a deviation in patient experience.

layer generally refers to interactions at the ward level (e.g. between two different professionals) or other activities that are beyond the infusion task itself (e.g., two patients might be confused on the ward and there might be severe staff shortages (Case Nos. 32 & 34 in Table 3); and the macro layer refers to interactions at the hospital level or higher (e.g., problems with the manufacture of giving sets and national guidance to follow (Case Nos. 36 & 37 in Table 3). The boundaries between layers were not always found to be clear.

At the micro level, nurses experienced repeated patterns of the same drugs, doses, infusion rates and volumes for patients with certain conditions. Common infusion administration appeared to become less about unfamiliar number entry and more about meaningful schemas. This indicates a degree of *expert coupling* between experienced nurses and infusion administration orders. Nurses reported that they have done some calculations so many times that they remember the figures they need by rote: "Some people have to do the calculation but for us who have been doing it for so long we just know the numbers". In one case the nurses embedded rate information in their name for an infusion, i.e. 'phosphate 43' was used to refer to a 500 ml phosphate infusion prescribed over 12 h, which requires an infusion rate of about 43 ml/hr. This suggests that these patterns can be reified in language.

3.2. A view of the system in terms of structure, agency and performance variability

Three new themes emerged from the inductive analysis that are important for understanding infusion practice: structure, agency and performance variability. The structural elements of the sociotechnical system provide it with shape, constraints, expectations and plans. These are realised in the design and configuration of technologies such as infusion pumps, the design of artefacts such as prescription charts, and the organisation of equipment, people and processes (Table 1). The agency theme captures people's resourcefulness, inventiveness and volition. This is observed in adaptations and workarounds (Table 2). People do not always operate mechanistically as they need to cope with surprises, system degradations and opportunities to improve performance. The performance variability theme captures positive and negative deviations from norms established at the individual, ward, hospital or national level. These are observed in incidents, near misses and discrepancies such as incorrect and missing information (Table 3).

Structure and agency are co-dependent while performance variability emerges from their interaction; however, the developing situation is monitored, and anticipated potential outcomes can feed back into the emerging situation (Fig. 6). This adaptive control could lead to attempted structural changes or influence how agents choose to act. Positive and negative deviations are highlighted in Fig. 6 as instances of

Table 5
Narrative 2 – Issues with national guidance for nasogastric tube placement for infusions of artificial nutrition, and commentary on the interplay between structure, agency and performance variability This narrative has been formed by synthesizing field notes from the first author's first person perspective.

Narrative 2 – Issues with national guidance for nasogastric tube placement for infusions of artificial nutrition	Commentary on the interplay between structure, agency and performance variability
The husband of a patient was concerned that the continuing delay to his wife's nasogastric feed was contributing to her poor health. National policy had recently changed in response to an incident where feed was accidentally pumped into a patient's lungs, which caused them to drown. Now, at the trust, an X-ray needed to be taken to check the position of the tube before the feed could be started. The husband complained that the policy had changed but the practices to manage this policy had not. The patient had her nasogastric tube in place since 4am, she still needed an X-ray to confirm its placement, but it was getting close to 5 pm now and that is when the radiologists go home, so she would have to wait another day before getting any feed.	New structural guidance had filtered down from the national level, to the trust and to the ward. This was in response to serious deviations. These structural changes were contributing to other deviations as patient's feed was delayed.
When the pump was eventually started the husband came to fetch me. He was aware that I was interested in infusion practices and pumps. He wanted to know whether the pump was working or not. When I looked at it there were no moving parts and it did not appear to be doing anything. We fetched the nurse who was also unsure. She disconnected the line and reconnected it. The pump whirred and moved and pushed a shot of feed down the line. There was a light bulb moment as we realised that the pump was not continuous but the patient would get a shot of feed every so often. There was not enough feedback from the pump to let us know it was working and we had the wrong mental model of how we thought it should work.	The design of the device did not provide suitable feedback to indicate whether it was working or not, which relates to its structure. Consequently we were not sure if a deviation had occurred.
Later I observed another issue relating to verification of nasogastric tube placement: a doctor asked where their patient was as they were met with an empty room on the ward. The nurse informed him that the patient had gone down to X-ray. This was not good news. The doctor had anticipated delays in getting an X-ray for the nasogastric placement so he had booked the patient in early, but now the patient had gone down to have an X-ray before the nasogastric tube had been put in place. So the X-ray was pointless, the patient was exposed to an unnecessary radiation dose, and the whole procedure further delayed. An example of the doctor adapting to the structure they are met with, but ultimately this time it being a failed adaptation.	Staff adapted to the problems they faced in coping with this structure, which sometimes led to deviations.

performance variability that tend towards satisfactory and unsatisfactory outcomes. These could be extreme as in the case of an accident or an example of excellence, or ordinarily they may be more mundane. From a Safety II perspective there is always some performance variability to be attended to as different trade-offs and complexities are negotiated to maintain safety.

Three narratives developed from the data illustrate how these themes play out in practice (see Tables 4–6). In Narrative 1 (Table 4), the physical structure of the ward appeared to conflict with the interactive configuration of the infusion pumps. The pumps were configured to alarm ten minutes before the end of an infusion, which meant patients had to summon a nurse to silence the alarm, only for the nurse to

Table 6
Narrative 3 – Issues with caring for patients receiving infusions away from the ward, and commentary on the interplay between structure, agency and performance variability This narrative has been formed by synthesizing field notes from the first author's first person perspective.

Narrative 3 – Issues with caring for patients receiving infusions away from the ward	Commentary on the interplay between structure, agency and performance variability
Ambulatory patients were being treated off-site. Here patients would receive infusions through a special pump that could be locked with a pin code. The pump would be programmed on the ward and then the patient would go home or to a nearby hotel while the infusion finished. The ward manager explained that this was cheaper than the patients occupying a hospital bed and probably more comfortable for them too. A 'spare' bed was kept on the haematology ward just in case an ambulatory patient needed to come back into the ward for extra care. However, this 'spare' bed had a special status that could not be recorded on the hospital's bed management system, consequently they would get many calls about their 'free' bed as people tried to find beds for patients in the hospital.	The ward was reconfiguring and expanding its capacity by treating inpatients away from the physical confines of the ward. This was an adaptation leading to new structure. However, some structures like the design of the hospital's bed management system could not be changed, which caused issues.
Managing hospital beds is a complex task involving different risks and uncertainties. For example, one patient had gone down to surgery and given she would go to a post-op ward after the manager re-assigned her bed when she left as he needed it for another patient. To their surprise the patient came back from surgery – it was not going ahead today for some reason. The returning patient was given the 'spare' bed because there was no other room on the ward.At the same time an ambulatory patient had come in for extra care and needed a bed, but there was now no 'spare' bed. The ambulatory patient waited in the waiting area but hour after hour went by. The ward manager was in a predicament because there was no room on the ward. The evening was drawing in and the patient still did not have a bed after seven hours of waiting. Another patient was deteriorating and was receiving special care from a member of critical care on the ward. The manager asked if he could be transferred to critical care. This would free up a space for the ambulatory patient. However, critical care was full and had higher priority cases.	The ward manager has to use the resources and structure of the ward as best they can, which sometimes means adapting to surprises and deviations. Here the structure, 'spare bed,' had been forsaken for another priority need, i.e. the patient returning from theatre. This led to a deviation in that an ambulatory patient needed to be admitted but there was no space. The ward manager tried to use critical care as a solution to their capacity issues but that did not work.
On a different day an ambulatory patient phoned in because their pump was beeping and the nurse had to try to problem solve and give them instructions over the phone. This new way of working brought with it new problems as nurses on the ward were not used to giving remote support over the phone.	The operating structure of the ward meant that staff needed to adapt to new ways of working and providing support.

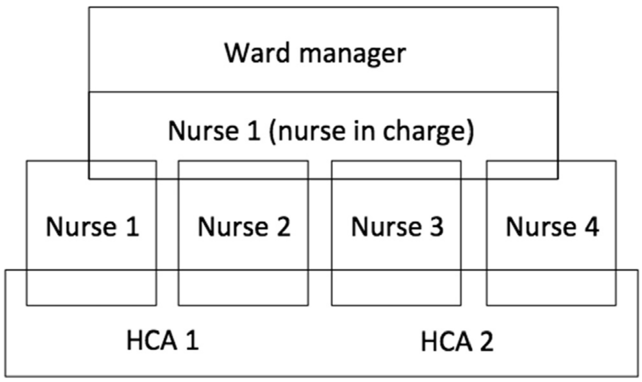

Fig. 2. Staff structure with overlapping areas of responsibility and goals. The ward manager has overall responsibility and shares day to day running of ward with one of the four nurses, who is designated the nurse in charge for the day. These four nurses may be regular qualified nurses on the ward. Other variants include students, and temporary staff from a different ward (i.e. bank staff) or from outside of the hospital (i.e. agency staff). The two health care assistants (HCA) assist the nurses in their duties, e.g. take blood glucose meter readings.

have to come back ten minutes later. Downstream consequences of this included frustration for the nurse and patient, wasted nursing time, patients lying next to pumps with alarms sounding for 10 min because they did not want to add to the nurse's workload, and patients directly interacting with their pumps against hospital rules. It was suggested by one nurse that this learned patient behaviour could have contributed to cases of pumps running out of battery power and stopping early, i.e. patients may have silenced their pump's alarm when it was warning of a low battery rather than a pre-completion alarm. Adapting to these frustrations, some nurses coached patients to silence these alarms themselves, which was also against hospital rules. Further, this suggests a failure of adaptive control: ward staff believed this to be a device design issue that could not be changed, but the device's instruction manual suggested that this was a configuration that could be changed

Fig. 4. Photo of chemotherapy trolley; each drawer has equipment needed for this task.

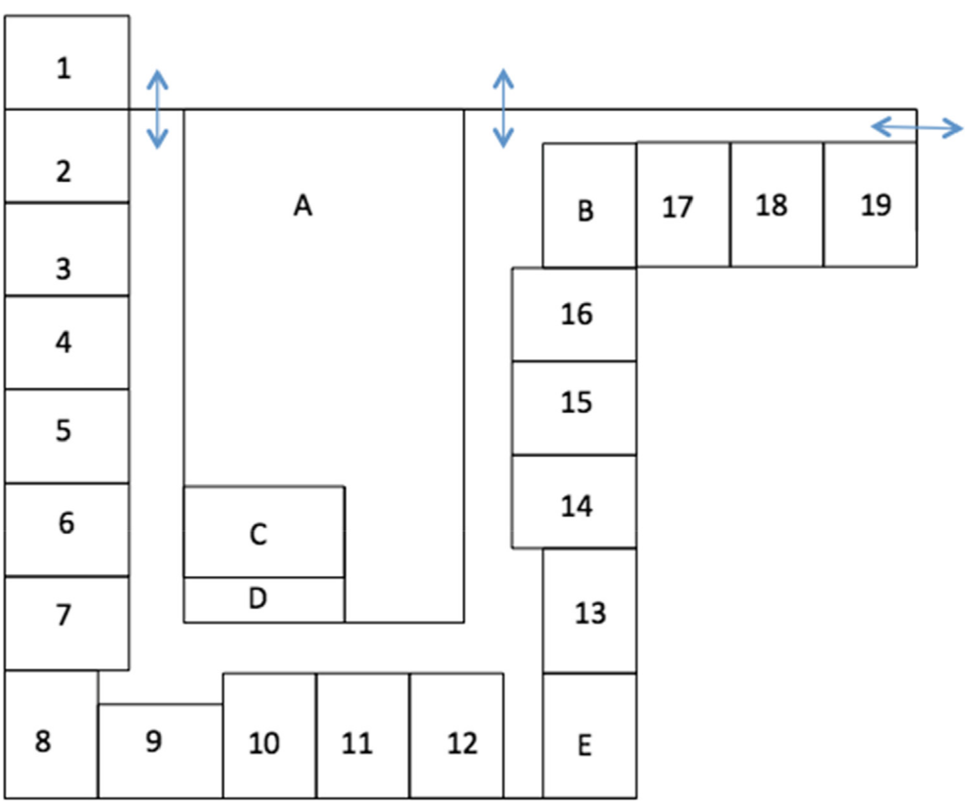

Fig. 3. Physical layout of the haematology ward. Beds are labelled 1–19. A = multiple rooms comprising office area, toilets, kitchen, staff areas, etc; B = empty reception area and waiting area; C = treatment room where drugs are prepared; D = active reception area with receptionist; and E = ward manager's office. Arrows indicate entrances and exits to ward.

Fig. 5. Photo of nurse using a ruler to measure millimetres on a syringe that is marked in millilitres. This was for a syringe driver that was configured to deliver in millimetres over an hour.

locally. One patient suggested changing the structure of the system to resolve these issues, such that the nurse would carry a device to alert them of the pump alarms directly rather than alerting the patient who then needed to summon the nurse.

In Narrative 2 (Table 5), hospital systems struggled to effectively accommodate new national guidance, which added new structural demands to nasogastric tube placements: positioning had to be confirmed by X-ray before the infusion was started. One patient suffered continued delays to her X-ray which left her without nutrition overnight, which caused distress to both her and her husband. To avoid such issues, individuals adopted workarounds, e.g. doctors booked X-rays before the nasogastric tube had been placed in anticipation of delays. However, this could lead to deviations, e.g. one patient had an X-ray before their nasogastric tube was in place, so the X-ray had to be redone, adding to the patient's radiation burden and increasing workload for the radiology department.

In Narrative 3 (Table 6), the ward had expanded its services to care for inpatients with infusion pumps away from the hospital. For example, some patients could now receive infusion treatment in a nearby hotel. This innovation was driven by the ward's space constraints and reduced treatment costs, i.e. the nightly cost of a hotel room is a lot cheaper than a hospital bed. A 'spare' bed was reserved for these ambulatory patients in case someone was unwell and needed to come back on to the ward. However, the structure of the hospital bed management system could not be adapted to effectively show the status of the 'spare' bed for ambulatory patients. This meant the ward was under pressure to fill the bed reserved for ambulatory patients from other areas of the hospital who saw it as 'available' on the system. These wider changes also meant that nurses had to provide remote support to patients over the phone, e.g. for infusion pump alarms. Again, this shows the changing structures with new deviations and need for adaptations left in its wake. Fig. 6 captures these relationships.

4. Discussion

Our findings highlight how safety in infusion practices depends on the unfolding interactions of a complex sociotechnical system. Factors across the system, both close to and far from infusion practice, and involving the interplay between structure, agency and performance variability within the system, can all affect safety.

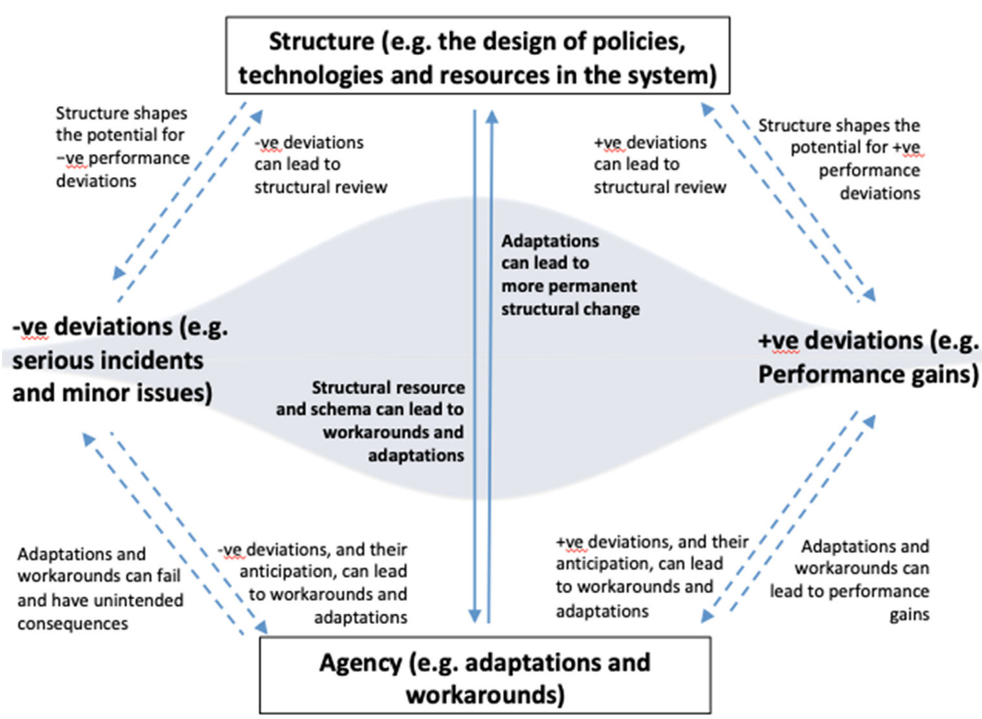

Fig. 6. A sociotechnical structuration model for studying safety, showing the interplay between structure, agency and performance variability. There are three main parts to reading this model: (1) the relationship between structure and agency is capture by the central vertical arrows; (2) performance variability emerges from the interaction between structure and agency and is distributed across the grey area horizontally; (3) structure and agency can influence positive and negative outcomes while deviations from the norm, and their anticipation, can feed back to influence structure and agency denoted by the dashed arrows.

4.1. Infusion safety across sociotechnical themes and layers

Infusion practice is affected by sociotechnical system design, which validates previous findings (Carayon et al., 2005; Rajkomar and Blandford, 2012). Also, Lyons and Blandford (2018) highlight the challenges of troubleshooting infusion pumps at a distance, which corroborates observations about nurses trying to provide remote support to patients over the phone. The deductive coding highlighted how information is transformed and propagated across system structures involving different technologies, artefacts, people and processes, organised over different spaces and patterns of time. However, micro, meso and macro layers of distributed cognition have not previously been considered for infusion practice. This has only been previously applied to interactions around an inpatient blood glucose meter (Furniss et al., 2015). The present paper provides evidence of their relevance for infusion practice, as interactions at all levels can affect safety: from new national protocols to infusion device interfaces. This resonates with previous safety models that examine different layers close to and far from the action (e.g. Rasmussen, 1997), sometimes conveyed as active errors and latent conditions (e.g. Reason, 1990), or 'sharp end' and 'blunt end' factors (e.g. Cook and Woods, 1994; Catchpole and Wiegmann, 2012).

4.2. Sociotechnical structuration model for safety

The structure, agency and performance variability framework that has emerged from this empirical work is novel. The role of agency is often neglected in distributed cognition literature and sociotechnical systems research, which tends to focus on system structures rather than the agency of individuals within it (Rochlin, 1999). Even though cognition can be recognised as a largely individual activity, the unit of analysis has been larger sociotechnical structures, e.g. a bridge of a ship (Hutchins, 1995a), a cockpit (Hutchins, 1995b) or a control room (Furniss and Blandford, 2006). To return to the parable described in the introductory section, distributed cognition studies tend to focus on the beach rather than the ant. Indeed, there is little or no account of agency in infusion administration for critical care in the account developed by Rajkomar and Blandford (2012); this is something new the current study has highlighted. However, strategies patients adopt to cope with the complexities of home haemodialysis were identified in a distributed cognition study by Rajkomar et al. (2014). Hutchins (1995a, p.288) made it clear that the adaptive capacity of humans plays a critical role in producing and exploiting a rich world of cultural structure. Fig. 6 emphasises the idea of human agency and adaptive capacity for distributed cognition analyses, which would typically focus on system structures.

Our results suggest that structural sources go beyond social and technological structures to include other sociotechnical structures like paper artefacts, information flows and the arrangement of the physical space. We use four elements from strong structuration theory (SST) (Greenhalgh and Stones, 2010) to frame important insights from our results: (i) external structures (context shaping factors), (ii) internal structures (the psychology of individuals), (iii) agency (how agents choose to act), and (iv) outcomes (where internal and external structures are reproduced or changed).

4.2.1. External structures

One of the most striking findings was the friction caused between two external structures: the infusion pump's pre-completion alarm and the barrier nursing that was supported by the physical structure of the ward. This had downstream consequences for social structures, individual agency and deviations, e.g. how nurses and patients interacted together, whether nurses chose to follow hospital rules and issues created by patients silencing alarms. In other areas of the hospital with different structures, e.g. where barrier nursing is not performed and they have a more open physical space, the pre-alarm may help with managing work.

4.2.2. Internal structures

At the 'sharp end', experienced nurses develop cognitive schemas that organise patterns of thought around conditions, drugs, doses, volumes, and rates. For one infusion the nurses had even adapted their language to offload cognitive effort into the environment (Table1: Case No.2). The ideas of cognitive schemas and using language in this way are absent from previous accounts of health numeracy that have used distributed cognition (Ancker and Kaufman, 2007). Experienced nurses are likely to have an intuition about whether or not numerical values and other infusion details fit their cognitive schemas (Klein, 1999). The idea of cognitive schemas in this context could affect how researchers understand interactions with infusion pumps. For example, Back et al. (2012) asked participants without clinical knowledge to programme volumes and rates into simulated infusion pumps in a lab. They found that when information was close to hand, participants were more likely to programme values into two pumps at the same time (e.g., programming rates on pump A and pump B, then volumes on pump A and pump B, and then starting pumps A and B). Here, they showed that by manipulating the external structure, i.e. the distance of the prescription chart, they affected interleaving within programming cycles, which increased the chance of omitting to release the roller clamp. They remark that it is therefore not necessarily better to have task relevant information close to hand in safety critical contexts. However, the current study suggests that for real infusion administration contexts, cognitive schemas (i.e. internal structures) reduce the likelihood of interleaving within programming cycles because they are programming based on their schema rather than on individual numbers with little or no meaning. The drug, volume, rate and duration form a coherent whole for experts, just as this sentence is more than individual words. We observed only one case in which two infusion pumps were set up at the same time; there, the two pumps were programmed separately and then started at the same time. This corroborates observations that nurses can interleave between programming cycles (Furniss et al., 2011a; Gant, 2011), but we have found no evidence of interleaving within programming cycles as the experiment suggests. Internal structures play an important role in safety.

4.2.3. Active agency

How agents choose to act can be influenced by the spirit of the structures that shape the system (i.e., how the system ought to behave like the spirit of the law); where there is an incoherent spirit there will be a weaker exertion on behaviour (DeSanctis and Poole, 1994). This might be observed where staff resources do not match the demands of the task, and staff have to make trade-off decisions between being efficient and thorough (Hollnagel, 2009). Staffing issues were observed in our results that could have led to such trade-offs (Table 3: Case Nos. 34 and 35). Incoherence might also surface where structures do not suit each other (Table 4: Narrative 1) and where there are innovations in the system (Tables 5 and 6: Narratives 2 and 3).

4.2.4. Outcomes

Changes in internal and external structures seem most obvious in the face of system innovations (e.g. national guidance and accommodating patients off-site), which lead to adaptations and deviations as the system tries to reorganise itself to cope with these new demands. Multiple dependencies and feedback loops affect emergent performance as agents adapt their behaviour to new structures and learn about new issues (e.g. Table 5: Narrative 2). Outcomes depend on the dynamic and unfolding interactions between structure, agency, and performance variability.

Greenhalgh and Stones (2010) suggest a triadic relationship between social structure, agency and technology. However, the model we propose groups sociotechnical structures together and introduces performance variability as the third element in the framework.

Performance deviations from the norm are critical for safety, which is why they are salient in our study. We suggest that the potential for performance deviations co-evolves with structure and agency through feedback mechanisms, e.g. monitoring current performance and anticipating future performance.

4.3. From distributed cognition to structuration theory

Revealing the complexities of the sociotechnical system that influence the safety of infusion administration has demonstrated distributed cognition's utility. Following Halverson's (2002) four categories for assessing the utility of theory: it has provided *descriptive power* (i.e. a conceptual structure to make sense of and describe the activity); *rhetorical power* (by helping us name and highlight important features of the cognitive system); *inferential power* (e.g. we have inferred that nurses have cognitive schemas for infusion administration rather than observing this phenomenon directly); and *application power* (e.g. changing the configuration of the pre-completion alarm on the infusion pump would benefit staff and patients in this context). However, the deductive application of DiCoT-CL (Furniss et al., 2015) was limited in light of the emergent inductive themes. Distributed cognition mainly focused on sociotechnical structures that could be internally or externally represented in the cognitive system. Applications of distributed cognition typically say little about notions of agency. This encouraged us to go beyond current analytical support for distributed cognition to create a new model and to draw on structuration theory as a 'lens' to add theoretical insight.

Distributed cognition helps develop the notion of structural sources. Coming from sociology, structures have been predominantly social, as applied in safety contexts (e.g., Aveling et al., 2016; Groves et al., 2011). Technical structures have been important for safety science (e.g. Perrow, 1984) and included in studies by researchers looking at technology use (DeSanctis and Poole, 1994; Greenhalgh and Stones, 2010). Following sociotechnical traditions, our analysis suggests that system safety is not only dependent on broad social and technical structures, but also other situated DiCoT-CL related structures, e.g. in the form of technology-in-use, information flows, artefacts and physical spaces.

Structuration theory helps emphasise and develop the notion of agency and how it is coupled to structural sources for sociotechnical system research. This can be at the level of individual adaptations and workarounds as we have focused on here. However, we have not explored wider aspects of agency such as beliefs, rituals and non-functional displays, which are championed by authors like Rochlin (1999). For example, a broader analysis might lead to a deeper account of why the patient in Narrative 1 decided to sit next to an alarming infusion pump for ten minutes rather than call the nurse to turn it off, and the role of visitors in safety, such as the concerned husband in Narrative 2. Exploring wider aspects of agency is part of future work.

4.4. Strengths and limitations

The generalizability of our findings needs to be investigated as insights about infusion practices in this context cannot simply be transferred to contexts with a different configuration because complex adaptive systems cannot easily be decomposed into component parts (Sittig and Singh, 2010). For example, ICU typically has one nurse per patient, stacks of pumps per patient, and infusion administration recording practices that would be unfamiliar in haematology (Rajkomar and Blandford, 2012). However, a strength of this study is that it has explored the interactions important in this haematology context.

One person, the first author, performed the data gathering and analysis; however, the resulting distributed cognition features were checked and refined by the co-authors. Extra checks on the deductive coding (as we have done) are appropriate, whereas it is inappropriate to do similar validation steps on the inductive coding because of its more complex and emergent nature (Blandford et al., 2016) so we rely here on the account of the analysis process and the inspectability and credibility of the inferences.

The safety structuration model has emerged from this analysis at the same time as helping us to make sense of the data. Therefore it needs to be tested in future studies where it can be used from the start. Further theorising between the elements in the model are needed. For example, some structures are easier to change than others, which can affect adaptive actions; e.g., coaching patients to silence their own pre-alarms was within the nurses' scope of control whereas reconfiguring the design of the infusion pumps was not. This is for future work.

5. Conclusion

This study has revealed interactions influencing safety around infusion devices in hospitals that have not been previously documented. These insights include intricacies close to the infusion administration such as how the cognitive schemas of staff develop around conditions, doses, volumes and rates of infusions, and the manner in which some of this information is encoded in language. Influences away from the infusion administration include, for example, national guidance about nasogastric tube placement, the design of hospital bed management systems, staffing levels and configuration of device alarms. Distributed cognition lent itself to exploring these complex situated interactions across multiple themes and different layers. Three new themes also emerged showing the role of structure, agency and performance variability in safety. We propose a sociotechnical structuration model for safety whereby safety is constructed through the co-evolution of structural sources (e.g. procedures, technologies, artefacts, social structure and space); the agency of people who appropriate, work around and adapt structures in the face of contextual demands; and performance variability in processes and outcomes (e.g. incidents, near misses and opportunities).

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Declaration of Competing Interest

None.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssci.2019.06.006.

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