Integrating human factors with infection prevention and control

Julie Storr, Dr Neil Wigglesworth, Claire Kilpatrick

In this thought paper, the authors discuss the application of human factors principles within infection prevention and control activities. They argue that the time has come to strengthen infection prevention and control capacity and capability by embedding human factors principles, methods, expertise and tools. They suggest that a root and branch review, through a human factors lens, of infection prevention measures could help develop interventions that work safely within the complex sociotechnical system that is healthcare.

Thought paper
May 2013

About the authors

Julie Storr is President of the Infection Prevention Society of the UK and Ireland and works in a consultancy capacity for the World Health Organization's Patient Safety Programme. A graduate nurse from the University of Manchester, she has worked on national and international patient safety and infection prevention programmes including the award-winning clean**your**hands™ campaign – independent research concluded that the campaign contributed to the recent reductions in MRSA in England. In addition to training and lecturing extensively on infection prevention and patient safety, Julie regularly writes on the subject and was a contributing author to the *WHO guidelines on hand hygiene in health care*. She is currently studying for a doctorate in public health (Healthcare Leadership and Management) at Johns Hopkins Bloomberg School of Public Health.

Dr Neil Wigglesworth is the Editor of the *Journal of Infection Prevention*, the scientific journal of the Infection Prevention Society, and sits on the IPS board of directors. In addition, Neil is the Nurse Consultant to the Healthcare Associated Infection Programme of Public Health Wales as well as holding honorary positions with Leeds and Cardiff Universities. Neil has published and presented internationally on a range of aspects of healthcare-associated infection and patient safety, with a particular interest in quality improvement approaches and systems thinking as applied to infection prevention.

As a researcher, Neil is interested in the impact of the healthcare environment and human behaviours on the adherence to evidence-based infection prevention practice.

Claire Kilpatrick is Head of Communications at the Infection Prevention Society, on its board of directors and works in a consultancy capacity for the World Health Organization's Patient Safety Programme. A nurse by background, Claire started working at a national level in public health in 2001, introducing new healthcare-associated infection surveillance programmes. Claire then led on the issue of evidence-based national infection control policies and care bundles, and a high profile public and healthcare social marketing campaign focused on changing behaviours towards hand hygiene in Scotland. In addition to training and lecturing on infection prevention and patient safety, Claire promotes the subject through Twitter, as well as more traditional publications. She was a contributing author to the *WHO guidelines on hand hygiene in health care*, after joining WHO as a programme manager in 2008. Claire has also recently led on a patient experience programme as part of her role as Interim Director of Quality in an English hospital, winning a national award for this work.

Summary

This paper discusses the application of human factors principles within infection prevention and control activities – up until now a largely unexploited area. The necessity to prevent harm and death from avoidable infections has received significant attention during the last decade and many of the conventional weapons in the patient safety armoury have been used with good effect, for example root cause analysis (RCA) for investigating Meticillin-resistant *Staphylococcus aureus* (MRSA) bacteraemia.

Human factors approaches per se have been addressed in a piecemeal manner within infection prevention and control, with some interesting examples, mainly centred on checklists. However, this has tended to take place in a vacuum and has not been as transparent as it might have been in order to inspire others to consider such an approach. The engagement of leading human factors and ergonomics experts and the piecing together of the science of human factors alongside conventional infection prevention thinking has not been systematically addressed for healthcare.

This paper argues that the time has come to strengthen infection prevention and control capacity and capability by embedding human factors principles, methods, expertise and tools. To address how we can better develop interventions that work safely within the complex sociotechnical system that is healthcare, a root and branch review of infection prevention measures through a human factors lens is suggested as a way forward. This is essential if the requisite behaviour change is to be achieved in healthcare at this critical juncture, if the gains of recent years are to be maintained and if the defects in processes and adherence to protocols are to be successfully overcome.

Introduction

Infections present a very real risk of harm and sometimes death within and outside healthcare; the risk is part of the natural balance of this complex planet that we live on. Once inside the world of healthcare, itself a complex system created by humans to provide necessary treatment and life support, the risks most definitely increase. The more vulnerable the person, the greater the risk to them from what we do – no matter how necessary. Infection acquired as a result of healthcare is an adverse outcome, often a culmination of a series of lapses, errors and omissions arising in that complicated healthcare system. Its consequences can be devastating. For example, a patient with an indwelling device, such as a central venous catheter, who develops an infection may be up to three times more likely to die than a patient without a device.[1]

Infection prevention and control – a facet of patient safety – is the science concerned with stopping patient harm and death. Where this is not possible it contributes to the achievement of what has been described as an irreducible minimum, attempting to minimise the impact of infection on patient outcomes.

Historically, our default as a discipline is to talk a technical language, largely to ourselves, and to develop protocols and guidelines that are intended to influence behaviour, informed largely by technical experts in the field. Gurses *et al*[2] suggest that many patient safety improvement efforts involve interventions that were developed with a myopic view, without adequately considering how and whether an intervention would fit with other elements of the care system or lead to unintended consequences. This is a truth in infection prevention and control and has stimulated the development of this paper.

The central question of this paper, therefore, is whether the time is right to redefine infection prevention and control for the 21st century by reaching out to and working with other disciplines, ones that the wider safety community have been embracing now for a number of years. Such an approach has the potential to enhance the development and implementation of interventions that will take that irreducible minimum as low as it can be. This paper looks at the prevention of infection through a human factors lens and asks, what does the discipline of human factors have to offer and how can we harness its expertise and momentum to the benefit of patient safety?

Background and context

In recent years there have undoubtedly been high profile successes in infection prevention and control, such as the dramatic reductions in MRSA bloodstream infections (which is viewed as one proxy indicator of harm overall) and *Clostridium difficile* in the UK.[3–6] However, healthcare-associated infections (HCAI) continue to occur and continue to present a risk to users of healthcare; a risk that should not and will not be tolerated, particularly given recent high profile events and the increasing consumer culture. Today's healthcare is complex, with many variables, including:

- the number of actors involved
- the explosion in available processes, procedures and technologies
- the throughput of patients
- the ratio of nurses to patients
- the dependency of patients
- the layout of clinical areas.

This presents a 'perfect storm' in an environment that could not be better designed to facilitate spread of microbes to those most vulnerable. There is no doubt that every day, in healthcare facilities in the UK and around the world, people continue to suffer from the effects of surgical site infections, urinary tract infections related to catheters, infections related to vascular catheters and more. The human, organisational and financial burden of these infections is high and therefore not only unacceptable to patients, but also to healthcare providers – as well as being a matter of national concern.

Traditional 'weapons' in the infection prevention 'armoury' that have been deployed in the name of reducing, or where possible eliminating, the risk of HCAI, include: education, audit, surveillance with feedback and the production of guidance, including reference to where evidence exists. More recently, sometimes in combination with targets, central directives and even legislation, approaches derived from industrial quality control have been used increasingly under the broad heading of 'quality improvement'. In particular, and with some reported success, the following have been used by infection prevention and control specialists to varying degrees.

- Root cause analysis (RCA) for MRSA bloodstream infections and *C. difficile* toxin cases.
- The application of process measurement and feedback using 'run charts' and statistical process control (SPC) charts.
- Change methodologies and tools, such as the Plan Do Study Act (PDSA) cycles.

Despite this, and the achievement of some successes, the ongoing occurrences of HCAI must be addressed now. Patients are being harmed and a significant proportion of this harm can be prevented – how we respond is not a matter of choice but of being open to doing things differently.

Infection prevention or, where possible, the elimination of HCAI sits, quite rightly, squarely in the wider domain of patient safety. It is, as has been quoted many times, everyone's responsibility. Improving patient safety is predicated on an understanding of the interactions within healthcare between humans, including the practices and procedures they perform, the work environment, the organisation itself, teamwork, technology, and the value systems and culture behind these, commonly referred to as its safety climate or culture.[7,8] An urgent need to understand and address these interactions has seen the relatively recent arrival of the approach to improvement known as 'human factors' into the broader domain of patient safety. This fits nicely with the current need to progress the infection prevention agenda – moving it to a new level to ensure meaningful, sustainable interventions are adopted rapidly and reliably with greatest impact.

Explaining human factors

Even those with specific expertise in the field find it difficult to arrive at a concise and usable definition for human factors when applied to the field of healthcare.[9] As the synonym for human factors is ergonomics, Professor Peter Buckle of the Clinical Human Factors Group (www. chfg.org) and the Institute of Ergonomics and Human Factors (UK) has proposed adopting the definition of the International Ergonomics Association Council:

'Ergonomics (or human factors) is the scientific discipline concerned with understanding of interactions among humans and other elements of a system and the profession that applies theory, principles, data and methods to design in order to optimise human well-being and overall system performance.'

The description by Russ *et al*[10] helps to flesh out this definition by describing '...*a science at the intersection of psychology and engineering ... dedicated to designing all aspects of a work system to support human performance and safety ... improve system performance and prevent accidental harm'.* What is clear is that human factors or ergonomics is a broad field with many sub-specialities or focuses including, broadly, physical, cognitive and organisational. These can be broken down further with examples such as product design, communication, perception and performance and usability.[11]
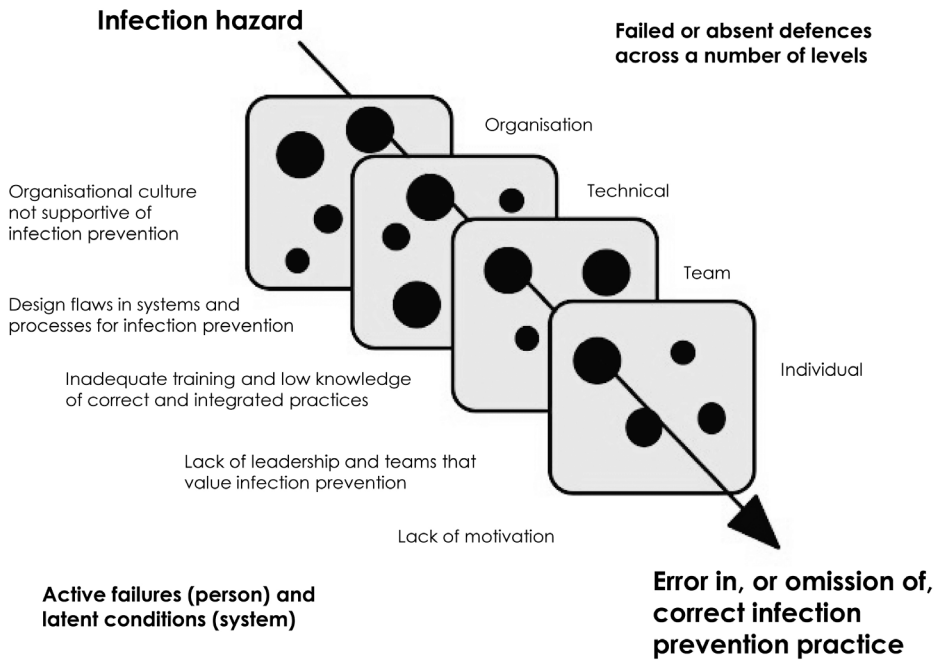
This very complexity and range of what constitutes human factors is perhaps a major contributor to what has been described by human factors practitioners and experts as the adoption, in some areas

of healthcare, of a somewhat narrow and perhaps one-dimensional view of human factors work derived from examples in the airline industry.[12] In a recent editorial Catchpole[13] describes this adoption of the 'airline model' as a 'double-edged sword' which has undoubtedly improved patient safety and healthcare quality in a number of areas, in particular through the use of crew resource management (CRM) training approaches, but which has at the same time given the community of healthcare professionals a limited perspective on what human factors-based approaches can offer in terms of quality and safety.

A fundamental tenet of human factors thinking is that human error is not absolutely preventable and systems need to be designed that are resilient when human errors occur. Systems in healthcare must be designed with the capability to prevent errors occurring, mitigate the harm of any error that cannot be prevented, and recognise the occurrence of errors such that actual harm to patients can be prevented – so error does not lead to catastrophe.[14]

Perhaps one of the most well known illustrations of this thinking to people in the field of healthcare is the 'Swiss cheese' model of error causation by James Reason. Figure 1 illustrates the model with an infection prevention example and shows how system factors that are inherently error provoking (latent conditions) combine with inevitable human lapses (active failures) to create potentially catastrophic harm. An example, often quoted, of the incorrect injection of cancer medication into the spine instead of the bloodstream, leading to

Figure 1: Reason's 'Swiss cheese' model of error causation related to infection prevention and control[15]

Infection hazard

Failed or absent defences across a number of levels

Organisation

Organisational culture not supportive of infection prevention

Technical

Design flaws in systems and processes for infection prevention

Team

Inadequate training and low knowledge of correct and integrated practices

Individual

Lack of leadership and teams that value infection prevention

Lack of motivation

Active failures (person) and latent conditions (system)

Error in, or omission of, correct infection prevention practice

death, shows that the system in which the different types of injection port were intra-compatible was just waiting for the human error to happen.

Culture, in particular the term 'safety culture' or 'safety climate', is a feature of many papers on human factors. In the World Health Organization (WHO) review of human factors,[16] a large part of the review is dedicated to the concept of safety culture and its influence on the normal behaviour of workers in relation to risk taking, rule observation and speaking up about safety. One important aspect of human factors is appreciating the current safety culture and the review describes the array of tools currently available for measuring safety culture prior to designing or implementing any interventions. The WHO review[17] summarises state-of-the-art thinking on human factors and patient safety. It centres, not exclusively, around Moray's[18] model of the organisational, human and technical components of sociotechnical systems, with the patient firmly at the centre and layers of influencing factors surrounding the patient (work environment or equipment; individual; team; organisation and management and societal, cultural and regulatory influencers). Interestingly, this review failed to address patient factors.

Translating the body of knowledge on human factors into patient safety action at the frontline remains a challenge. The behaviour change wheel recently introduced by Michie and colleagues[19] is an attempt to improve such a translation. Michie talks about the need to develop the science and technology of behaviour change and make this useful to those designing interventions and planning policy. She emphasises that insufficient attention has been paid to analysing the nature of behaviour as the starting point of behaviour change interventions. The model Michie frames the behaviour change wheel around is the COM-B (capability, opportunity, motivation – behaviour) system, a framework for understanding behaviour.

- **Capability** is the individual's psychological and physical capacity to engage in the activity concerned, that is their knowledge and skills.
- **Opportunity** is all of the factors beyond the individual that make behaviour possible or prompt it. For example, the design of healthcare facilities that affect the workflow and care delivery on a day-to-day basis by busy individuals, including how and when they perform infection prevention practices.
- **Motivation** is defined as the entirety of brain processes that energise and direct behaviour – not just goals and conscious decision making. With relevance to infection prevention and control it includes habits and analytic decision making.

Capability and opportunity both influence motivation and all contribute to the requisite (or not) behaviour. When applying this to the design of interventions aimed at behaviour change we should be considering what the behavioural target is (adherence with an infection prevention practice as part of a broader sequence or process of care) and consider what components of the behaviour system (opportunity, capability, motivation) would need to be changed to achieve this.

Michie[20] emphasises the importance of context, and this is incorporated within the behaviour change wheel: *'behaviour in context is thus the starting point of intervention design'*.

Use of human factors approaches in infection prevention to date

To fully address the utility of human factors within an infection prevention context it is necessary to articulate precisely what we mean by infection prevention and control. A conventional 'elevator pitch' for infection prevention and control might be something like:

'Every day in my infection prevention and control job I influence others to do the right thing, to take a number of different steps which will ultimately protect patients from infections as far as possible.'

This demonstrates that this specialty focuses on very technical expertise, risk management overall, and sharing this intelligence with many different people to try to ensure that they are aware of the risks and important mitigating steps. However, it is clear that the focus is not on behaviour change (though this is subtly embedded) and the skillset of infection preventionists tends not to be grounded in the science

of this aspect of influencing and changing attitudes and actions.

There has been a tendency in healthcare to position infection control as something separate to the mainstream activities of healthcare workers; that it is comprised of stand-alone actions, not part of the everyday flow of work which healthcare workers tend to be focused on. This is exemplified perfectly in a recent study from 2012 reporting the findings of a series of interviews exploring the attitudes of student nurses and their mentors towards infection control.[21] In this report, students are exposed to a constant theme of negative attitudes, in which infection prevention is largely seen as *an additional workload burden rather than an integral aspect of patient safety and quality of care*. One comment jumps out of the report that reinforces the urgency of moving forward with greater integration of human factors into infection prevention and control. A student described a conversation between a ward sister and a consultant: *I can either practice infection control or I can treat the patients, you choose*.

This raises the important issue of situation awareness as a facet of human factors that emerges from the 2009 WHO review.[22] Its relevance to infection prevention and control is that: *on most jobs the worker needs to have a good mental model representing the status of their current task and the risks within the surrounding work environment*. This example highlights a mental model that sees the clinical task or treatment as separate to the prevention and control of infection; the clinician is blind

to the possibility that infection control is an integral part of the process of treatment that they are performing. Anderson *et al*[23] offer some interesting insights behind these common perceptions using human factors engineering principles. These include:

- the inevitable delayed feedback between omission and consequence
- the lack of connection in the mind of the healthcare worker with a positive result
- time pressure and high cognitive workload
- the lack of consistent, inbuilt infection control cues
- a historic failure to take sufficient account of design.

It is clear from Anderson's paper that the invisibility of microbes has a strong impact on the cognitive aspect of performing infection control activities:

As humans, we perceive what we can see, what we smell, what we can touch and what we can hear – and we act on those perceptions. If we perceive nothing, as in the case of the microbes, we must rely on our mental resources or other artificial interventions to remember to act.[24]

Assessing the uptake and impact of human factors thinking and approaches in infection prevention so far is no easy task. As has already been discussed, 'human factors' as a description covers a wide range of topics and sub-specialties, albeit with a focus on systems and human-system interactions at the core of them. The notion of human factors has been described previously by others as less specific and a less well defined construct than many subjects in the healthcare literature.[25]

Searching the literature reveals no shortage of engagement among the infection prevention community with the broader 'quality improvement' movement. The literature is replete with descriptions of the use of tools and techniques that form part of the quality improvement lexicon. It is hard to open a relevant journal without finding reports of the use of 'care bundles', improvement collaboratives and, a little more rarely, PDSA cycles, Lean and Six Sigma and SPC charts. We might question how many of these interventions have been considered and implemented with due regard to the underlying principles that should underpin them. For example, how many 'care bundles' can we find that meet the requirements that they be based on high quality evidence and are then implemented with due regard to the contextual requirements of the facility and clinical setting?

What, if any, evidence is there that human factors theory and practice has been used or has influenced interventions to reduce HCAI? On one level it could be argued that human factors have permeated a long way into the infection prevention mindset – if by human factors you simply think 'checklists'. There is no doubt that the use of a checklist can constitute an intervention based on a human factors approach: checklists can address the issue of 'high cognitive workload' and can contribute to process standardisation.[26] However, in the (many) published reports of the use of checklists to address an infection prevention issue, commonly central venous catheter-related bloodstream infections and other medical device associated HCAI, there is little if any evidence of human factors expertise or input to the design of the said checklists; nevertheless many of these show significant reductions in infection rates.

Another group of infection prevention literature that has been influenced by ergonomics is the 'multi-modal' behaviour change strategy typified and exemplified by the World Health Organization's approach to hand hygiene improvement.[27] Although human factors or ergonomics as a theory or a body of expertise may often only be tacitly acknowledged at most, these approaches clearly take account of the interactions between healthcare workers, patients and the care environment and equipment rather than relying on only one level of intervention such as training. The design of the healthcare facility's environment to optimise the availability of alcohol-based hand rub is the simplest and most direct example in this category. Though rare, explicit descriptions of human factors in healthcare facility design (both system wide and in individual clinical areas or processes) for reduced infection do exist, both in principle[28] and in practice,[29–31] and this emphasis on overt ergonomic thinking is welcome.

There are a number of reports published in the infection prevention literature that appear to be based on human factors approaches, in that they may use the term 'human factors' or other terms that lead to a suggestion of human factors content such as 'process design' or 'system intervention'. However, on close inspection the majority of these are essentially traditional approaches to interventions that have

'adopted' the terminology, perhaps with one eye on the perceived originality of the manuscript for publication.

Finally, there are numerous examples of published reports that relate to the areas of teamwork, leadership and communication as it pertains to an organisation or department's ability to reduce the incidence of one or more types of HCAI. Generally these make no overt reference to systems ergonomics as the study of cross level and whole system factors that influence the performance of teams and individuals within them. Rather, they focus on the qualities of successful leaders, on 'champions', on individual behaviours and on team interactions and tools to influence them, without reference to the interaction with other aspects of the system.

Gurses and colleagues[32] emphasise the need to build capacity among current and future healthcare providers and administrators to increase understanding of human factors and the potential this has to transform patient safety – largely through training. While training per se, and not as part of a multimodal approach, has its weaknesses, teamwork and learning together is known to be one of the success factors in enhancing human factors and building a cohesiveness and coalition that will make sure all key steps are taken during everyday workflow, including critical infection prevention measures. Such steps should enhance not only reliability of departments but also, over time, organisational reliability, leading to the positive and harm-free environmental culture that everyone wants to see.

The cultural milieu into which patient safety and infection prevention interventions are introduced has already been stated to be critical. There is, however, a limited amount of literature on attempts to determine safety culture prior to implementing infection prevention interventions. Although this is the fifth component of the WHO multimodal strategy on hand hygiene improvement, how to do it has been largely ignored.

In summary, although the efforts of infection prevention teams and practitioners have been laudable and not without success, the potential value of the application of human factors principles and methods remains largely unexploited in a coherent manner within the field of infection prevention and control. What evidence there is of human factors approaches being used actively in healthcare is limited both in scope, being derived largely from the airline 'checklist' model, and also in the apparent lack of human factors/ ergonomic expertise routinely involved in tool development. Considering just some of the elements of human factors and the published literature, the impact of multi-professional teamwork, design of workflow processes and environments, safety culture, decision-making strategies and leadership in the prevention of infections is increasing, but at a slow rate. The engagement of leading human factors and ergonomics experts and the piecing together of the science of human factors alongside conventional infection prevention thinking has not

been systematically addressed within the NHS or elsewhere. Furthermore, the very recent emergence of the safety case concept in healthcare[33] as one method for systematically identifying and managing risks to patient safety, offers much to infection prevention and control.

Creating a safer future

Drawing on the more general field of human factors and patient safety, the integration of human factors thinking into infection prevention and control would involve both looking back and looking forwards to analyse the structural and process-related factors that contribute to unsafe care and then designing these so that they improve, and the performance and outcomes of healthcare workers improves.[34]

It could be argued that the, albeit limited, attempts by infection prevention practitioners, their teams and their colleagues, to understand and incorporate human factors approaches into their programmes of work and drives to reduce avoidable infection and harm constitute both an appetite 'out there' and a great opportunity for a sea change in thinking about preventing infection.

As infection prevention matures and reaches out beyond its current narrow, technical view of the world, there will be greater exploration and integration of disciplines that have huge potential to enhance the translation of research and evidence into practice. Human factors could be an exciting place to start and one that has significant potential to contribute to even greater reduction in patient harm.

In order to progress the integration of human factors into infection prevention and control it is crucial that policy makers, national organisations with a remit for quality and patient safety, professional infection prevention and control bodies, academics, as well as leaders within healthcare organisations, explore and facilitate the following.

- The need to engage the infection prevention community, and work as part of a broader coalition with the human factors, patient safety and quality improvement scientific communities – where the embedding of such expertise into healthcare is already at a more mature stage.
- The infection prevention community, working in collaboration, needs to recognise its strengths as technical subject matter experts and change agents, but also its limitations in the field of human factors – again reaching out to identify the areas within infection prevention and control most amenable to human factors approaches.
- There is a need to consider how best to integrate human factors engineering within infection prevention and control training.
- Working in partnership, the patient safety and infection prevention communities must determine the most effective way to progress this agenda by exploring the research gaps, and the organisations and academic communities that might be best placed to work on this – for example, professional organisations such as

the Infection Prevention Society and Healthcare Infection Society could lead on or contribute to such work.

- In the same vein, how to effectively partner with relevant academics and secure research funding should be addressed; funding bodies need to be encouraged to fund this kind of work.
- Greater consideration should be given to the utility of safety culture assessments prior to implementation of infection prevention interventions.
- Finally, as a matter of urgency, infection preventionists need to become evangelists on this topic and proceed, through collaboration, with this integration of human factors into infection prevention and control.

This paper sets out a call to action to those working in patient safety and infection prevention and, more importantly, introduces a burning imperative associated with the call. Patient safety can be enhanced now and so actions must be intensified in this critical area.

The WHO review of human factors highlights the many recommendations arising from safety investigations that have called for organisations to change their safety culture to 'make it easy to do the right thing, and hard to do the wrong thing' for patient care. The WHO review uses the seminal Institute of Medicine report[35] to reinforce this:

'*The health care organization must develop a culture of safety such that an organization's design processes and workforce are focused on a clear goal – dramatic improvement in the reliability and safety of the care process*.'

Infection preventionists need to work with human factors experts when designing, implementing and evaluating infection prevention interventions. Refocusing on the prevention and control of infection through a human factors lens offers us a new way of looking at an old problem. It affords the opportunity to fundamentally assess whether the problems we think exist are the real problems and furthermore explore whether we are focusing energy on the right approaches to tackle these problems. It would involve a transformation in our thinking, where we stop talking a technical language only to ourselves and start listening to, reaching out to and learning from other disciplines. Human factors would be an excellent starting point. Such an approach could inject a new energy and sense of urgency and importance to the infection prevention agenda, increasing efficiency and removing unhelpful redundancy, overuse, underuse and misuse of current interventions for the benefit of patients.

References

1 Siempos II, Kopterides P, Tsangaris I, Dimopoulou I, Armaganidis AE. Impact of catheter-related bloodstream infections on the mortality of critically ill patients: a meta-analysis. *Critical Care Medicine* 2009;37(7): 2283-9.

2 Gurses AP, Ant Ozok A, Pronovost PJ. Time to accelerate integration of human factors and ergonomics in patient safety. *BMJ Qual Saf* 2012;21:347-51.

3 Health Protection Agency (now Public Health England) (2013) *Quarterly Epidemiological Commentary: Mandatory MRSA, MSSA and E. Coli bacteraemia, and C. difficile infection data (up to October–December 2012).* (www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1284473407318)

4 Public Health Wales (2012) *Clostridium difficile mandatory surveillance report 01/10/11 – 30/09/12 all Wales.* (http://howis.wales.nhs.uk/sites3/page.cfm?orgid=379&pid=18707#cdiff)

5 Health Protection Scotland (2012) *Quarterly report on the surveillance of Clostridium difficile infection (CDI) in Scotland, October–December 2012.* (www.hps.scot.nhs.uk/haiic/sshaip/wrdetail.aspx?id=54514&wrtype=9)

6 HSC Northern Ireland, Public Health Agency (2012) *C. difficile surveillance quarterly report October–December 2012 (Qtr 4).* (www.publichealthagency.org/directorate-public-health/health-protection/healthcare-associated-infections)

7 Vincent C. Understanding and responding to adverse events. *New England Journal of Medicine* 2003;348;11:1051-1056.

8 Firth Cozens J. Evaluating the culture of safety. *Qual Saf Health Care* 2003;12:401.

9 Clinical Human Factors Group (2011) *Towards a working definition of human factors in healthcare* (www.chfg.org/news-blog/towards-a-working-definition-of-human-factors-in-healthcare)

10 Russ AL, Fairbanks RJ, Karsh B-T, Militello LG, Saleem JL, Wears RL. The science of human factors: separating fact from fiction. *Quality and Safety in Healthcare* 2013;00:1-7. doi:10.1136/bmjqs-2012-001450.

11 Russ *et al* (2013) and www.chfg.org

12 Catchpole K. Spreading human factors expertise in healthcare: untangling the knots in people and systems. *Quality and Safety in Healthcare* 2013;0:1-5. doi:10.1136/bmjqs-2013-002036.

13 Catchpole (2013).

14 Reason J. Human Error: models and management. *BMJ* 2000;320:768.

15 Reason (2000).

16 Flin R, Winter J, Sarac C, Raduma M. *Human Factors in Patient Safety Review of Topics and Tools: Report for Methods and Measures Working Group of WHO Patient Safety.* World Health Organization, 2009. (www.who.int/patientsafety/research/methods_measures/human_factors/human_factors_review.pdf)

17 Flin *et al* (2009).

18 Moray N. Culture, politics and ergonomics. *Ergonomics* 2000;43:858-868.

19 Michie S, van Stralen MM, West R. The behaviour change wheel: a new method for characterising and designing behaviour change interventions. *Implement Sci* 2011; Apr 23;6:42.

20 Michie *et al* (2011).

21 Ward DJ. Attitudes towards infection prevention and control: an interview study with nursing students and nurse mentors. *BMJ Qual Saf* 2012;21:301-306.

22 Flin *et al* (2009).

23 Anderson J, Gosbee LL, Bessesen M, Williams L. Using human factors engineering to improve the effectiveness of infection prevention and control. *Critical Care Medicine* 2010; Aug;38(8 Suppl):S269-81.

24 Anderson *et al* (2010).

25 Watterson P. A critical review of the systems approach within patient safety research. *Ergonomics* 2009;52(10):1185-1195.

26 Patterson JE, Malani PN, Maragakis LL (2010) Infection control in the intensive care unit: Progress and challenges in systems and accountability. *Critical Care Medicine* 2010; Aug;38(8 Suppl):S265-8.

27 World Health Organization (2009) *Save Lives: Clean Your Hands. A Guide to the Implementation of the WHO Multimodal Hand Hygiene Improvement Strategy.* (http://whqlibdoc.who.int/hq/2009/WHO_IER_PSP_2009.02_eng.pdf)

28 Storr J, Kilpatrick C. Hand hygiene improvement in the community: a systems approach. *Wound Care* 2012;March: S24-9.

29 de Korne DF, van Wijngaarden JDH, van Rooij J, Wauben LSGL, Hiddema UF, Klazinga NS. Safety by design: effects of operating room floor marking on the position of surgical devices to promote clean air flow compliance and minimise infection risks. *BMJ Qual Saf* 2012;21:746-52.

30 Birnbach DJ, Nevo I, Scheinman SR, Fitzpatrick M, Shekhter I, Lombard JL. Patient safety begins with proper planning: a quantitative method to improve hospital design. *Qual Saf Health Care* 2013;19:462-5.

31 Kho AN, Dexter PR, Warvel JS, Belsito AW, Commiskey M, Wilson SJ, McDonald CJ. An effective computerized reminder for contact isolation of patients colonised or infected with resistant organisms. *International Journal of Medical Informatics* 2008;77:194-8.

32 Gurses *et al* (2012).

33 Sujan MA, Cleland G, Habli I, Medhurst J. *Using safety cases in industry and healthcare.* London: The Health Foundation, 2012.

34 Gurses *et al* (2012).

35 Kohn LT, Corrigan JM, Donaldson MS. *To err is human: building a safer health system.* Institute of Medicine Washington, DC: National Academy Press, 2000.

The Health Foundation is an independent charity working to improve the quality of healthcare in the UK.

We want the UK to have a healthcare system of the highest possible quality – safe, effective, person-centred, timely, efficient and equitable. We believe that in order to achieve this, health services need to continually improve the way they work.

We are here to inspire and create the space for people to make lasting improvements to health services.

We conduct research and evaluation, put ideas into practice through a range of improvement programmes, support and develop leaders and share evidence to drive wider change.