Clinical review

Ergonomics in medicine and surgery

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This review outlines some of the issues surrounding ergonomics that are relevant to medical and surgical practice and to health care in general

In just a few years, the roles of medical and surgical practitioners have undergone a major transformation, owing to developments in a new generation of advanced technologies such as surgical robotics, in-theatre interactive three dimensional displays, speech recognition for the control of critical theatre systems, virtual reality simulators, telemedicine, telecare, and e-learning. Yet despite the research and development community's enthusiasm for innovation, the end users—practitioners and specialists—are often ignored during the design and development processes, sometimes with serious consequences. We describe the growing relevance of ergonomics or human factors principles and methodologies to medical and surgical practice, emphasising the importance of moving away from "technology push" (the assumption that a high tech approach to the design of information technology systems will always provide a robust, reliable solution) to one that is more focused on the needs of the human in the design of medical equipment, systems, and processes.

Summary points

Understanding human limitations early in the development of medical devices can reduce errors and avoid performance problems exacerbated by stress and fatigue

Using ergonomics in a design process can reduce the costs of procuring and maintaining products

Ergonomics can minimise the incidence of injury or longer term malaise from poor working environments

An ergonomics task analysis can help identify key components of surgical skill, ensuring that students have affordable, appropriate, valid, and reliable training

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Sources and selection criteria

The discipline of ergonomics has attempted to make important changes over half a century by introducing human centred processes to the design of equipment, systems, and working practices in many domains of activity, including health care. This review is based on our experience in introducing ergonomics into medical research and development programmes, together with data taken from sources bridging medical, industrial, and defence communities, including information obtained through key texts, the UK Ergonomics Information Analysis Centre, the US Human Systems Information Analysis Center, and international ergonomics and medical websites.

Ergonomics

Ergonomics is the study (or science) of the interaction between humans and their working environment (box 1). Also known as human factors (a term originating from the United States, but gaining popularity in Europe), it has had a long and successful history of influencing the uptake of human centred design processes in different domains, such as the automotive industry and defence, and, to a lesser extent, medicine and surgery. Ergonomics can also be looked on as a bridge between human behaviour and technology, striving to guarantee the usability of future devices.

Overview of medical ergonomics

A report in 1999 suggested that at least 44 000 (and up to 98 000) people die in the United States each year from medical errors in hospitals (a figure greater than that recorded for road traffic fatalities, breast cancer, or AIDS).[1] The US Food and Drug Administration has stated that although many of these fatalities cannot be attributed to human errors involving medical equipment or systems, some certainly can be.[2] Other researchers have suggested that the incidence and outcome of errors arising from such interactions far exceed those resulting from electromechanical failures of those devices.[3 4] These findings point to an absence of attention on the part of designers and developers to the ergonomic qualities of their products.

Ergonomics guidelines focusing on the design of medical devices and risk management have resulted from these efforts but are still not in widespread use.[5 6]

P+ *Additional information is on bmj.com*

Box 1: Components of ergonomics

- To optimise system performance while maximising human wellbeing and operational effectiveness, ergonomics embraces a range of human centred issues relevant to equipment or systems design and training, including:
- Body size (anthropometry), motion, and strength capabilities (biomechanics)
- Sensory-motor capabilities—vision, hearing, haptics (force and touch), dexterity
- Cognitive processes and memory (including situational awareness)
- Training and current knowledge relating to equipment, systems, and practices
- Training and current knowledge of medical conditions (including emergency conditions)
- Expectations and cultural stereotypes relating to the operation of equipment
- General health, age, motivation, stress levels, mental fatigue, performance under drug treatment or the effects of alcohol

Nor have they been updated to reflect current ergonomics issues and the new generation of computerised systems. Furthermore, and despite their publication on the internet, the guidelines still remain unknown to many staff involved in the development of medical equipment throughout Europe.

Nevertheless, the term ergonomics continues to appear in marketing literature relating to products. On closer inspection it becomes evident that a formal, documented ergonomic approach to the design of, for example, an advanced operating theatre or surgical robot, has not been conducted and that evaluations involving end users are far from adequate. By offering operating rooms of the future, complete with multiple colour TVs, voice operated systems, support robots, ceiling mounted articulated arms, teleconferencing facilities, interactive three dimensional displays, and preoperative planning simulators in no way guarantees that these facilities are fit for human use.[7] It is often impossible to find any evidence of qualified ergonomists on the development panels for these projects, a situation that is probably commonplace throughout the medical community. This is ironic considering the message issued by David Rattner, the director of the minimally invasive surgery programme for the US Center for Integration of Medicine and Innovative Technology:

> Designing an operating room of the future, which will optimise the newest developments in surgery, requires much more than plugging in the new technologies. We are approaching the re-design at a systems level: how will different disciplines and different technologies work together to provide the best patient care environment?[8]

The only effective method of ensuring that medical technologies are fit for use and will not result in costly training or maintenance regimens is for practitioners to question the policy of companies to ascertain if ergonomics is a formal part of their development process and, specifically, if they can demonstrate the human centred rationale underpinning their products.

Accessing and exploiting knowledge of ergonomics

To become involved in the exploitation of knowledge and techniques of ergonomics, medical practitioners have two options. The first is to have access to, or be able to commission the services of, experienced and fully accredited ergonomists. These can be found in databases held by nationally and internationally recognised professional bodies, including the UK's Ergonomics Society and the Centre for Registration of European Ergonomists (an organisation responsible for awarding the title of Eur.Erg. to practitioners).

The second option is for medical practitioners to take on a personal responsibility to be aware of key issues and to maintain a working knowledge of the main sources of ergonomics data and standards. This option is not as onerous as it might seem. By registering with certain websites and downloading reference texts, it is possible to keep abreast of the current state of thinking in such human centred topics as usability, workspace design, specifications for human-computer interfaces, and evaluation and assessment of new technologies.

Application of ergonomics

One example of the application of ergonomics techniques is a tool using computer graphics developed for the Institute of Naval Medicine by Virtalis to assist in the design of surgical environments on board ships (fig 1). The end users for this tool were not computer specialists and could not afford the time for in-depth training. They required an uncomplicated, low cost, and simplified method of accessing and manipulating ergonomics databases for the purpose of rapidly designing layouts for general triage and surgical compartments. They also required a means of implementing instant changes to those layouts during review meetings to meet the changing needs of their customers. This ergonomics tool is generic so it could be applied to a range of civilian medical and surgical applications, such as equipment design and the layout of hospital spaces or facilities within general medical practices.

The definition of end user requirements is not always as straightforward. In many instances, especially for those applications demanding innovative approaches to equipment and systems design or, increasingly, training programmes, it is necessary to

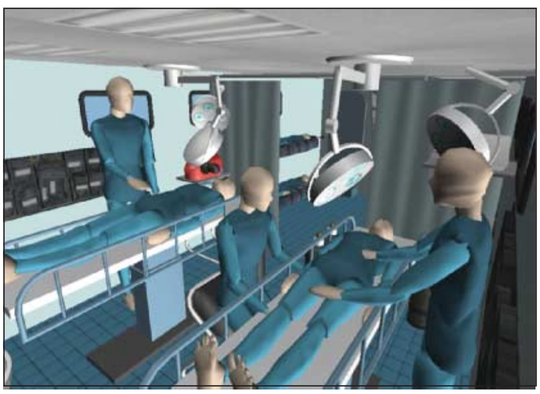

Fig 1 Simple three dimensional computer graphics, or virtual reality tool, used to produce a basic ergonomic design for mini operating theatres on board Royal Navy vessels

Box 2: Benefits of task analysis: the MIST system

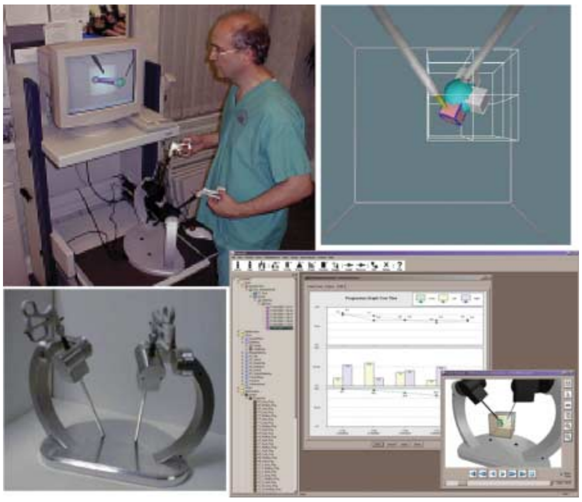

Fig 2 Minimally invasive surgical trainer, MIST, fosters laparoscopic skills by training on carefully selected task primitives (top right), designed after a psychological breakdown of perceptual and motor behaviours of observed surgeons

One example of the benefits to be gained from a task analysis in a surgical setting is the minimally invasive surgical training system, MIST. The system, originally developed by the present authors, has been available as a technology based training product for laparoscopic surgery since 1997 (www.mentice.com).[9] The simulator has also been the subject of a well documented range of experimental clinical and applied psychology studies during the late 1990s.[10 11–13] The main reason for its success is that the early task analyses led to the development not of a highly detailed simulation of a virtual human body (requiring an expensive graphics supercomputer) but of a simplified skills trainer, presenting trainees with simple but relevant tasks ("task primitives") using a low cost, off the shelf personal computer, capable of generating objective records for students' performance (fig 2). Variations on the system are now appearing, such as the LapSim trainer (www.surgical-science.com). Despite the availability of increasingly sophisticated graphics, however, the use of task primitives for objective measures of training is still evident, showing the power of ergonomics and task analysis techniques in delivering meaningful and cost effective solutions to virtual reality training.

analyse how the end users perform their tasks and exercise their experience and skills in real operational settings (see bmj.com). This task analysis is a key human centred process by which interactions between humans and their working environment can be formally described at a level appropriate to a predefined end goal (box 2). Without a properly executed task analysis, there is a risk of specifying or designing a system or piece of equipment that does not take account of the most relevant components of human skill (this is especially true for training regimens exploiting simulation technologies). In a medical or surgical setting, such an omission can lead to human error and, potentially, patient fatalities.

A task analysis can be carried out in many ways, yet there is no single, guaranteed formula.[14] The type of analysis often depends on the human factors specialist involved, whether or not the task exists in reality or has yet to be designed, the goal of the analysis (new system design or new training procedures), the support of the end users, and any constraints imposed by the analysis environment. When there is a need for rapid results from analyses, the more popular techniques involve observation and interviews, often supplemented with video and audio records.[10] Other techniques use quite sophisticated computer based solutions, from recording of data using mixed media (for example, video, computer keystrokes, physiological parameters, voice) to simulations based on models of human physical and psychological performance.

A successful example of a task analysis occurred in a project partly funded by the European Union. Project IERAPSI (integrated environment for the rehearsal and planning of surgical intervention) was designed to address advanced visualisation and training technologies for surgery of the temporal bone area of the skull—a common surgical site with complex anatomy.[15] In collaboration with the ear, nose, and throat surgical teams at Manchester's Royal Infirmary, the Institute of Laryngology and Otology (University College London), and the University of Pisa, task analyses were undertaken on several surgical interventions, including cochlear implant, middle fossa, and translabyrinthine acoustic neuroma resection, each lasting an average of six hours and carried out by consultants. Detailed

Fig 3 Procedures requiring the use of microscopes (top left) can lead to back pain, fibromyalgia, or tension headache in up to 80% of microscopists. Three dimensional graphic simulation of temporal bone area with virtual drill (bottom left). Trainee surgeons view the graphics with special binoculars (top right). They can sense the simulated drill effects using a pair of PHANToM haptic (force and touch) feedback hand controllers (bottom right) (www.sensable.com)

records of surgical performance were made under task headings, including bone exposure and drill site mark-up and superficial and deep bone drilling or burring procedures. Assessments were also conducted of contemporary training techniques, including the drilling of cadaveric bones (increasingly rare, due to limitations in availability), plastic temporal bone models (www.temporal-bone.com), and a *Temporal Bone Dissector* CD Rom.[16]

The results from the integrated environment for the rehearsal and planning of surgical intervention studies indicated that a simulator based on a realistic reproduction of the surgeon's interface (for example, microscope, drill, irrigator) was essential. The analysis also emphasised the importance of finding an appropriate interface device that would convey to trainee surgeons the difference in forces, vibrations, and tactile and sound effects as the virtual drill penetrated through various densities of bone (fig 3).

Conclusions

Despite the success of ergonomics in many areas, why has it yet to make a major contribution to health care? Evidence of a growing number of international websites outside Europe shows a growing commitment to introducing ergonomics in the workplace. One or two European organisations, such as Germany's Kommission Arbeitsschutz und Normung, have been proactive in the generation of ergonomics guidelines to make some of the emerging international standards more useful to those attempting to address hazards, risks, and usability in medical systems.[17] However, many of the recommendations contained within the Kommission's reports have yet to be implemented on a continent wide basis and most do not yet deal with the ergonomic issues surrounding the more high tech systems. As Ramon Berguer, professor of surgery at the University of California-Davis and one of the pioneers in the application of ergonomics principles to surgical practice, stated:

> A scientific and ergonomic approach to the analysis of the operating room environment and the performance and workload characteristics of members of the modern surgical team can provide a rational basis for maximizing the efficiency and safety of our increasingly technology-dependent surgical procedures[18]

The successful application or adoption of ergonomics demands commitment and participation from all levels of a healthcare organisation. The formation of an active ergonomics or human centred design programme within a hospital, health centre, or general practice is neither an onerous nor a costly task.[19] However, the benefits of early adoption far outweigh the potential costs and consequences of ignoring the human factor for health service staff and patients alike.

Additional educational resources

Useful books

Boff KR, Lincoln JE. *Engineering data compendium: human perception and performance*. Ohio: Armstrong Aerospace Medical Research Laboratory (AARML) Wright-Patterson Air Force Base, 1988 (available from the Human Systems Information Analysis Center, HSIAC).

Bridger R. *Introduction to ergonomics*. London: Taylor and Francis, 2003

Karwowski W, ed. *International encyclopaedia of ergonomics and human factors*. London: Taylor and Francis, 2001

Useful websites

Ergonomics Society (UK) (www.ergonomics.org.uk/)—Home of the UK's principal source of information on ergonomics and related disciplines

California Division of Occupational Safety and Health (www.dir.ca.gov/dosh/puborder.asp)—A US website containing a substantial list of freely downloadable ergonomics guidelines and publications, including the popular *Easy Ergonomics* workplace design document

Ergonomics Information Analysis Centre (UK) (www.eee.bham.ac.uk/eiac/index.htm)—An international ergonomics information service based at the University of Birmingham

Human-Systems Information Analysis Center (US) (iac.dtic.mil/hsiac/)—A good resource for general human factors information, hosted at the US Air Force's Wright-Patterson base in Dayton

US Food and Drug Administration Human Factors Program (www.fda.gov/cdrh/humanfactors/index.html)—A relevant website containing useful information, publications, and links on human factors issues relating to usage of medical devices

rmis.com Resource Library (ergonomics and medicine) (www.rmlibrary.com/sites/ergmedic.htm)—A web resource containing ergonomics information predominantly relating to occupational health and trauma

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