Methodological approaches to anaesthetists’ workload in the operating theatre

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This review examines the basic concepts of workload and methods of measuring them. The components of anaesthetists’ operating room activities, and the factors contributing to workload, are analysed using an ergonomic-based model for technological environments. The available evidence on the relationship between workload and training and supervision is presented and the effect of workload on the quality and safety of anaesthetic care is reviewed. There is, as yet, only a small body of work examining workload and its effects in anaesthesia. While studies have identified the general pattern of workload in relation to the different stages of the perioperative period, measurement, particularly of overlapping tasks, is still evolving. It is clear, however, that induction and emergence are the most intense periods of both practical and ‘non-technical’ aspects of work. Allocation of attention to a range of tasks simultaneously is a key characteristic of anaesthetic practice. Experienced staff appear to show ‘spare capacity’ in performance during routine cases, which, we suggest, allows them an attentional ‘safety margin’ should adverse events occur. The effects of production pressure and mental ‘overload’ remain speculative and so practical recommendations for anaesthetic staffing, both in terms of numbers and matching skills to surgical demand, cannot be made. The potential for delegation of tasks, for instance to non-physician anaesthetists, can also not be made on evidence-based grounds. Strategies for active management of workload may be useful in practice.

Keywords: anaesthesia, workload; anaesthetists, ergonomics

The work of anaesthetists includes many different duties. Their clinical work may be in the operating theatre, where, depending on country and context of practice, they may be providing anaesthesia themselves or supervising others, or in the intensive care unit, labour ward, or pain clinic. In addition, most anaesthetists have significant other responsibilities in administration, teaching, and research. However, the work of providing anaesthesia for surgery has specific characteristics, which has been described as ‘managing a single highly interactive system composed of the patient, clinical equipment, surgeons, and other operating room (OR) personnel, and the broader OR environment’.34 Given these characteristics, the practice of anaesthesia presents many challenges in the field of ergonomics and it is this aspect of anaesthetists’ work that this review will focus on, bringing together basic ergonomic concepts and published work applied to the practice of anaesthesia. We collected material from standard textbooks, from searches of the electronic databases Medline and Embase and from reference lists of cited papers. While we have concentrated on presenting the methodological aspects of the subject, we have also attempted to address the following questions: What does the intra-operative work of the anaesthetist consist of? How does workload change with experience, supervision, teaching or delegation? Is there a relationship between workload and safety or quality of anaesthetic care?

Basic definitions and concepts
Definitions of workload are rarely short and simple. Workload may be described best as a dynamic balance between the challenge of a task and an individual’s response to that task. Annett has proposed a model reflecting this interaction (Fig. 1), which we will adopt in this review.2 A similar, but more inclusive definition comes from Hart and Staveland:18 ‘Workload is not an inherent property, but rather emerges from the interaction between the requirements of a task, the circumstances under which it is performed, and the skills, behaviours, and perceptions of the operator’.

Components of workload
Farmer and Brownson10 identify three key aspects of workload.
**Task demands.** Although objective and replicable for study purposes, task demands do not necessarily equate with workload because of varying skills and experience among those performing the task.

**Effort.** This is described as ‘the conscious allocation of mental processing resources’. Effort may not reflect workload, for example, where workload increases but there is resistance on the part of the subject to increase effort.

**Performance.** Workload is particularly concerned with meeting set demands: performance is the way this is achieved and the effectiveness with which it is achieved. Performance is also important in evaluating effort needed, as a measure of primary and secondary task achievement and can indicate spare capacity.

A further component of workload is **attention.** This is regarded as a key demand of the anaesthetist’s work, especially during the maintenance stage of anaesthesia. A useful concept here is the *multichannel theory of attention,* which is based on the notion that humans process information in different modes. Through practice, certain tasks can be carried out with less direct attention, which allows their performance while maintaining spare capacity for other tasks.

**Methods of measuring workload**

Workload is, in part, influenced by the nature of the task in question. This section briefly discusses task analysis and task, or action, density before reviewing what are specifically regarded as workload measures. The methods reviewed are illustrated by applications to anaesthesia where these exist. Weiniger and Slage suggest that ‘Because workload is a multidimensional construct, different measures of clinical workload may reveal different aspects of clinical care’. Studies often make use of multiple methods and while this allows investigation of different perspectives, it is important to bear in mind the levels of agreement between different types of measurement.

**Task analysis and action density**

Task analysis involves ‘an ordered sequence of tasks and subtasks, which identifies the performer or user; the action, activities or operations; the environment; the starting state, the goal state; the requirements to complete the task such as hardware, software or information’. Task analysis and measurement of workload are not necessarily carried out together or for the same purpose but task analysis may facilitate workload measurement by identifying the individual work components or subtasks to be measured. Identifying tasks refines the measurement of workload associated with those tasks and facilitates consistent study design and comparison. Similarly, task analysis facilitates time and motion studies by identifying tasks and subtasks for time measurement. Manser and Wehner have addressed this through the development of a method, which measures ‘action density’. This involves a trained observer observing in the anaesthetic room and operating theatre using a computer-based recording method called ‘Flexible Interface Technique’ (FIT-System).

**Measurement of workload**

**Performance**

Annett notes that although objective measurement of performance in ergonomics is generally preferable, subjective evaluation by experts has become common practice. Typically, studies designed to measure performance often include a secondary task, which subjects are asked to complete as and when they have the time while giving priority to a primary task. Performance on the secondary task is used as an indicator of spare capacity, from which workload is inferred. Measurement of performance on the main task aims to give an indication of workload, but it is not possible to assume that as workload increases, performance deteriorates. Variables for a proposed index of task difficulty include familiarity of stimuli, number of concurrent tasks, task difficulty (as a component measure), and competition for limited mental resources. The component task difficulty measure is based on the number of items to be remembered for the task including possible demands on short-term memory.
We identified a number of examples of performance measurement in anaesthesia. Byrne and Jones\(^6\) asked trainee anaesthetists to keep ‘an accurate, contemporaneous anaesthetic record’ during simulated critical incidents. This record-keeping was used as a secondary task but, for the purposes of the study, the trainees were not made aware of this. As expected, competence in carrying out the secondary task was impaired as workload in the primary task increased. Gaba and Lee\(^{14}\) introduced mental arithmetic questions as a secondary task in real anaesthesia cases. They observed ‘skipped problems’ and a high response time in carrying out the secondary task, particularly while undertaking manual tasks and, less predictably, while there was conversation between staff. Weinger and colleagues have used the response time to a so-called ‘vigilance light’ illuminated intermittently during anaesthesia cases.\(^{32} 33\)

The advantage of performance-based measurement lies in giving a measure of ability for the main task of interest and, where a secondary task is introduced, as a measure of spare capacity. This latter aspect is useful in the case of unexpected events in the workplace. The disadvantage of performance measures is that they may not be sensitive to an increase or decrease in workload if the subject compensates through increased, or reduced, effort respectively. The recording of concurrent or overlapping tasks is also subject to variation in observer interpretation.\(^{21} 26\) Other possible limitations relate to the multi-channel theory of attention. The secondary task, if included in the study, may interfere with the primary task or may not depend on the performance of the primary task.\(^4 10\) Overall performance is difficult to measure in anaesthesia because of the range of factors affecting outcome and the low proportion of adverse outcomes.\(^{13}\)

**Subjective or psychological workload**

Subjective or psychological workload is a well-established but much-debated measure. Typically, study subjects are asked to complete questionnaires. A range of factors can contribute to subjective workload and be used for rating. ‘Usability’ is typically an audit of workplace features using checklists and report forms but may be used in subjective ratings, for example the Software Usability Measurement Inventory or System Usability Scale and questionnaires/ interviews. Other scales include: presence or ‘being there’ (applied to the design of simulators and other virtual environments), comfort/annoyance, and perceived urgency of auditory warning signals.\(^2\) A key factor is the degree of shared meaning or ‘inter-subjectivity’ among raters.\(^2\) O’Donnell and Eggemeier,\(^{24}\) Wickens,\(^{35}\) Annett\(^2\) and Farmer and Brownson\(^{10}\) review a number of scales. These include the Cooper–Harper Scale, which was originally developed as a checklist for use by pilots to assess handling characteristics of aircraft. The questionnaire is in the form of a decision tree. Two scales that concern the response of the user specifically to the demands of the task are the Subjective Workload Assessment Technique (SWAT) and the NASA Task Load Index (NASA-TLX). SWAT includes scales for time load, mental effort load, and psychological stress load each with three levels. NASA-TLX includes six workload categories presented as questions with visual analogue scales to which subjects respond (Table 1).

Subjective measures of effort and fatigue include the Rating of Perceived Exertion (RPE and CR10 scales) produced by Borg and the Swedish Occupational Fatigue Inventory (Table 2).\(^3\) The scale of 6 to 20 corresponds to a heart rate of 60–200 beats min\(^{-1}\). Subjects’ ratings on the scale usually correlate closely with actual heart rates.\(^4\) This was used by Weinger and colleagues to measure subjective workload as part of a broader range of measurements of task analysis and workload in anaesthesia.\(^{32} 33\)

| **Table 1** The NASA Task Load Index rating scales\(^{35}\) |
|-----------------|-----------------|---------------------------------|
| **Title**       | **Endpoints**   | **Descriptions**                |
| Mental demand   | Low/high        | How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving? |
| Physical demand | Low/high        | How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious? |
| Temporal demand | Low/high        | How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic? |
| Effort          | Low/high        | How hard did you have to work (mentally and physically) to accomplish your level of performance? |
| Performance     | Good/poor       | How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? |
| Frustration level | Low/high        | How insecure, discouraged, irritated, stressed and annoyed vs secure, gratified, content, relaxed, and complacent did you feel during the task? |

| **Table 2** Borg’s RPE scale\(^3\) |
|-----------------|--------|
| **Rating**      | **Description of rating** |
| 6:              | No exertion at all |
| 7:              | Extremely light |
| 8:              | Very light |
| 9:              | Light |
| 10:             | Somewhat hard |
| 11:             | Hard |
| 12:             | Very hard |
| 13:             | Extremely hard |
| 14:             | Maximal exertion |
The advantages of subjective workload measurement are its high ‘face’ validity and the apparent ease with which operators apply the ratings. It is particularly appropriate for complex workload situations with multiple demands. The Borg scale has the advantage of being a global measure, unlike some subjective scales which do not take account of all demands. There are also a number of disadvantages of subjective measures: the difficulty of comparing qualitatively different tasks; the lack of agreement on components of workload and therefore the scales to be used; and some evidence to suggest that the more experience the subjects have, the more likely they are to under-estimate workload in demanding, experimental tasks.

Physiological

Although included in some subjective evaluations of workload as seen above, physiological measures are usually regarded as a distinct category of workload measures. Their relevance is based on the premise that changes in workload cause changes to the body. Although there are a number of possible physiological measures of effort, heart rate has been most commonly used in studies of workload in anaesthesia. The advantages are that objective measurement is possible and it can be carried out unobtrusively. The disadvantages are that physiological effects do not necessarily correlate with performance and a large quantity of data is produced requiring analysis and time-matching with tasks. Use of heart rate as a measure of physiological workload can be refined by taking account of varying levels of oxygen consumption between individuals but this has not so far been applied to studies in anaesthesia.

Heart rate and heart rate variability have been used among a number of measures of workload of anaesthetists. One recent study used multiple measures to evaluate workload through the period from arrival of the patient for anaesthesia to departure of the patient from the theatre. The mean heart rate for all subject groups was highest at intubation, and displayed a secondary peak at extubation. Heart rate was positively correlated with workload density, observer workload rating, and subjective workload rating for non-teaching cases but not for teaching cases.

What does the intra-operative work of the anaesthetist consist of?

This question can be addressed on three levels. First, what factors contribute to workload and work intensity in general? Secondly, what are the mental and physical tasks, which the anaesthetist must perform? Thirdly, how are these tasks distributed—that is, how do anaesthetists spend their intra-operative time?

Factors contributing to workload

Edwards’ ergonomic-based model for technological environments identifies four components, which we have drawn on to classify the human and physical factors involved in anaesthesia (Table 3). ‘Software’ is not restricted to the definition used in computing but includes aspects such as regulations and operating procedures. The ‘liveware’ element is the most complex, concerning as it does the actions of humans, as individuals and in teams. One specific aspect, noted by Galea and colleagues, is that mental ‘underload’ can be as stressful as mental overload and is potentially harder to detect.

Edwards’ classification is useful but the categories are not mutually exclusive. Thus, liveware and hardware elements may interact as in Weinger and colleagues’ study, where the use of transoesophageal echocardiography increased workload and decreased vigilance. A further finding was that electronic record-keeping allowed only a small reduction in the charting time but did not adversely affect workload or vigilance. Loeb found that vigilance levels were similar for anaesthesia residents undertaking manual record-keeping and anaesthesia residents who had assistants to keep records.

Mental and physical tasks of anaesthesia

The practical procedures of anaesthesia are common and visible but competent anaesthesia requires that appropriate mental tasks are carried out at the same time, in order to ensure patient safety. Weinger and colleagues noted that the practice of anaesthesia requires ‘many skills, including sustained vigilance, parallel decision-making, and fine motor

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Table 3 Factors contributing to workload based on Edwards’ typology

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<th>Software</th>
<th>Hardware</th>
<th>Environment</th>
<th>Liveware</th>
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<td>List scheduling</td>
<td>Clarity and intelligibility of monitors</td>
<td>Lighting</td>
<td>Individual:</td>
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<td>Production pressure</td>
<td>Range and accuracy of alarms</td>
<td>Noise</td>
<td>Fatigue</td>
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<td>Matching workload and work intensity to the availability and capabilities of anaesthetic staff</td>
<td>Availability and reliability of equipment</td>
<td>Temperature and humidity</td>
<td>Sleep deprivation</td>
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<td>Degree of automation</td>
<td>Layout of theatres and anaesthetic rooms</td>
<td>Boredom</td>
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<td>Attitudes to risk, stress and unanticipated events, Familiarity with equipment</td>
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skills’.32 Such skills are a product of sustained practice and experience and are guided in their use by a body of specialized knowledge. While the intra-operative period may have a lower physical task density than the induction and emergence periods, it involves ‘… querying many sources, which include the patient, the various electronic and manual devices, and other operating room personnel’, verification of the validity of the information, formulating ‘a hierarchy of data in terms of immediate importance’, forming a hypothesis of the patient’s condition in relation to the desired condition and preparing interventions accordingly.30 This complexity makes the study of workload in anaesthesia difficult, and this is compounded by the difficulty of finding universal standards for measuring technical and behavioural performance.

The ‘non-technical’ skills of anaesthesia have received more attention in recent years. Fletcher and colleagues have highlighted the importance of communication, team-working, planning, resource management, and decision-making.11 Similarly, Gaba has developed a cognitive process model to describe the complex decision-making environment of the anaesthetist.13 There is, as yet, little empirical work in this area though our own group has used an observational approach to study knowledge in action in anaesthesia.27

Task distribution during anaesthesia

The different stages of the anaesthesia process produce different types of requirements. Generally, studies of workload indicate that induction and, to a lesser degree, emergence are the most intensive. However, many of the tasks performed are part of a routine, which tends to reduce the effort required. Maintenance, in contrast, is typically less physically ‘action dense’ but mental activity continues as a wide range of information is used and processed.27 28

In the late 1980s, McDonald and Dzwonczyk used a time-and-motion approach to classify the anaesthetist’s intra-operative activities23 and calculated the average proportion of time spent on each activity (Table 4). Those with the longest duration were: observation of the circle system (25% of total time), direct patient care activities (17%), and completion of anaesthesia records (12.5%). Those with the shortest duration were performing peripheral nerve stimulation (2.5%), adjusting the surgical table (2%), and observing the ECG (1.2%). Assumptions cannot easily be made as to whether duration of these tasks is correlated with effort as some of the shorter tasks require specific skills while some of the longer tasks require mainly vigilance.

They also explored the relationship between sequence and concurrence of tasks by performing link analysis (the frequency of occurrence of paired activities). They found that 48% of the total number of linkages involved only 10 pairs of activities and suggested that the ability to perform tasks or level of vigilance could be affected both by (1) density/ frequency of occurrence of tasks and (2) changing from one type of focus to another, for example from a non-patient task to a direct patient activity.

It should be noted that this pioneering work is now over 15 yr old. McDonald and Dzwonczyk repeated their work a couple of years later, when more automatic monitors were available, and gained the impression that most of the time given previously to checking the circle system and carrying out ventilation was now given to patient monitoring tasks.22 Current anaesthetic practice is likely to be different again.

How does workload change with experience, delegation/supervision, and teaching?

Experience

Common sense would suggest that experience of undertaking certain tasks reduces the workload required to perform them. This is borne out by empirical work. In one study,32 novice trainee anaesthetists were found to take longer over tasks, show longer latency of response and greater task workload than third-year trainees and experienced nurse

| Table 4 McDonald and Dzwonczyk’s typology of anaesthesia activities23 |
|-----------------|-----------------|-----------------|
| **Patient activities** | **Indirect** | **Non-patient activities** |
| **Direct** | **Indirect** | **Non-patient activities** |
| Observe skin colour and capillary refill | Observe arterial pressure | Complete patient records |
| Palpate pulse and skin temperature | Observe ECG | Adjust surgical table |
| Listen to breath and heart sounds | Observe or adjust anaesthesia machine | Activity at drug trolley |
| | Observe, adjust or change i.v. infusions | Communication, non-patient related |
| | Perform peripheral nerve stimulation | Idle time |
| | Observe circle system | Unclassified time |
Clinicians were recorded. However, the mean heart rate of anaesthetists was found to vary inversely with length of experience. Statistically significant differences between junior residents, senior residents, and experienced anaesthetists were recorded.33

Delegation/supervision

Experience suggests that the effect of delegation on workload varies depending on the nature of the task and how confident the delegating anaesthetist feels about the capability of the person to whom the task is assigned. In many countries, although not in the UK, it is common practice for a physician anaesthetist to supervise one or more non-medical anaesthetic practitioners (usually nurses) at the same time. Although this is a common model of practice worldwide, it does not appear to have been studied from the workload point of view.

Delegation must be guided by the supervisor’s situation awareness and overall ability to process information on the patients’ condition. The speculations of McDonald and Dzwonczyk are relevant, however. They considered that only four of thirteen different tasks performed in their study ‘made use of [the anaesthetist’s] training as a specialist physician’ and that relatively little use is made of acquired medical knowledge compared with the relatively high use of manual skills. They suggested that ‘para-professional personnel’ could be used to carry out many tasks, which are not related to direct patient management to allow physician anaesthetists to concentrate on observation of the patient.23

In any case, if practitioners are familiar with working together, this is likely to make for a more cohesive team. ‘Cross-training’, whereby each team member develops an understanding of the roles and responsibilities of each other member, has also been suggested as beneficial to team-working under conditions of high workload by facilitating implicit co-operation.7 Fletcher and colleagues also note that communication skills have not been emphasized as much as technical skills in training11 and the role of communication in safety—both as a distraction from vigilance14 and in the inadequacy of its use19—has been explored in anaesthesia studies.

Teaching

Weinger and colleagues33 found that teaching teams, involving one-to-one supervision of fourth year medical students or first month anaesthesia residents by a teacher and trainee, of average of 6 yr experience, had significantly slower response times to a warning light than non-teaching teams of doctors of similar experience. This vigilance test was also a procedural (performance) workload assessment measure indicating increased workload and reduced spare capacity. They also found that workload density was significantly increased for teaching as opposed to non-teaching teams, although, contrary to expectations, there was no significant difference in doctors’ heart rates between teaching and non-teaching teams. Greaves17 suggested, with reference to the findings of Byrne and Jones9 regarding capacity to carry out a secondary task as described above, that the teaching of trainees in theatre should be tailored to the workload of the trainees.

The ability to accomplish tasks, including two or more tasks simultaneously or in alternation, may depend not only on inherent task demands and the level of experience but also on methods of training and practice. The theory on the role of practice in task performance is reviewed and developed by Schneider and Detweiler who suggest that dual task training has advantages over single task training25 and this may be a promising approach in the future.

The relationship between workload and quality or safety

There is little published work examining the relationship between workload and either quality or safety of anaesthetic care. A survey by Gaba and colleagues12 elicited information from anaesthesiologists on internal pressures that is those that were self-imposed, and external pressures, which could come from within the hospital or beyond. Respondents placed the highest pressure on themselves to avoid delays to surgery, to avoid litigation, and to get along with surgeons. Relatively high external pressure was experienced by surgeons to proceed with a case rather than cancel and from administrators to reduce turnover time. Sixty-three per cent of respondents suggested that they had made errors because of workload. Another study8 addressed attentional overload as a cause of human error in anaesthesia monitoring through observation of, and interviews with, 12 anaesthetists. The authors conjectured that some subjects might have experienced cognitive loading with reasoning tasks, which reduced attention for monitoring tasks.

Conclusion

There is, as yet, only a small body of work examining workload and its effects in anaesthesia. It is clear that the work of the anaesthetist involves both practical and non-technical skills and also that, in the perioperative period, induction and emergence are the most intense periods of both types of work. A key characteristic of anaesthesia practice is the allocation of attention to a range of tasks. Our knowledge of how anaesthetists’ time is divided during the maintenance phase of anaesthesia is derived from studies that may not
reflect current anaesthetic practice. It might be supposed that automation of monitoring and record-keeping would reduce the workload associated with these tasks but this has not been borne out by the few studies that have examined this issue.

Experienced staff appear to show 'spare capacity' in performance during routine cases, which we suggest allows them an attentional 'safety margin' should adverse events occur. The effects of production pressure and mental 'overload' remain speculative and so practical recommendations for anaesthetic staffing (both in terms of numbers and matching skills to surgical demand) cannot be made. The potential for delegation of tasks, for instance to non-physician anaesthetists, can also not be made on evidence-based grounds.

Future research in this emerging area could usefully examine the relationship between production pressure and work intensity. Current work on communication, teamwork and decision-making and their effects on workload should be extended.

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