John Kinnear

Report Series
No 20

The Interface between People and Equipment

August 1980

The Butler Cox Foundation

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Abstract

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The Interface between People and Equipment

by Tom Stewart

August 1980

Ergonomics is the scientific study of the inter-relation between people and their occupations. It deals with the equipment they use, the environment in which they work and the working system as a whole.

In military and certain other specialised equipment where it is essential to minimise the chance of human error, the importance of ergonomics has long been recognised. More recently, however, the widespread introduction of computer-based equipment into business environments, has led to an increasing awareness of the importance of applying ergonomics in the design and installation of non-specialised equipment. The need to apply ergonomics with that equipment has been brought about by two factors. Firstly, although the cost of poor interfaces between people and equipment has up till now been largely hidden, there is a growing realisation that substantial productivity benefits can be gained by improving the interfaces. Secondly, staff are increasingly unwilling to tolerate, in the working environment, many of the conditions that they have accepted over the years. For example, they are increasingly refusing to work with equipment that is (at least in their view) too difficult to use, or that is potentially dangerous.

This report considers the ergonomics of the interface between people and equipment, and it is therefore concerned with people, tasks, equipment, workplaces and the working environments. It identifies the various components of the interface between people and equipment, and it shows how the problems that each component causes can be either overcome or prevented. In many situations there are obvious benefits to be gained from improving the interface, such as improved safety, improved comfort and working conditions for staff and increased efficiency. Moreover, the increasing large-scale growth of computer-based office systems, and the emergence, in many countries, of regulations that are specifically concerned with ergonomics, make it important for organisations to be aware of the contents of this report.

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by Tom Stewart

August 1980

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Chapter 1

INTRODUCTION

BACKGROUND

People use equipment to perform tasks, and these tasks are organised into procedures to form a work system. In the office, the work system typically includes a variety of self-contained equipment such as typewriters, photocopiers and telephones. Increasingly, the work system itself is computer-based, and the equipment in the system includes a visual display terminal. However, if the work system is to be a success, all those involved must use the equipment correctly and effectively, and they can do this only if there is a well-designed interface between each user and the equipment.

The purpose of this report is to show how many of the problems that bedevil work systems can be eliminated by the appropriate design of the interface between people and equipment.

In order to succeed, systems have to be technically correct, of course. This means that the equipment actually has to work, and with computer-based equipment this applies also to the software. The success (or the productivity) of a business system should be considered throughout its complete life cycle. This point was examined in some detail in Foundation Report No. 11 "Improving Systems Productivity", where it was shown that most of the cost of a computer-based system was incurred in areas other than in the initial development of the system.

The system can be technically correct, but it may still fail to be a successful business system if those who use it find it either difficult or boring to use, or if they feel alienated or threatened by it. It must also create, and be part of, an acceptable working environment for those who will spend much (if not all) of their working lives using the system.

Systems productivity therefore, is not only about developing and installing technically correct systems. It is also about the inter-relationships between people, procedures and equipment throughout the complete life cycle of the system. In the past, the emphasis has been on making the equipment work (and that means both hardware and software for computer-based systems), and on creating the correct procedures. But today, the increasing proliferation of computer-based equipment, and the increasing tendency to disperse equipment throughout the organisation mean that the systems designer now has to pay far more attention to the needs of those individuals who will be using the system.

In this report, we consider the relationship between two of the elements of a system — people and their interface with the equipment they use as part of a business system. However, the three elements of a system (people, procedures and equipment) are interdependent, and the interface cannot be considered in isolation from the procedures and tasks that the system performs.

The productivity of a working business system is concerned both with its effectiveness and its efficiency. An effective system ensures that the right tasks are performed, and it may also ensure that some tasks are performed that could not be performed if the system did not exist. An efficient system ensures that more tasks can be performed with existing staff members, or else that the same number of tasks can be performed by fewer people. Both the effectiveness and the efficiency of a system are influenced by the way in which people actually use the system.

A system that does not take account of people factors at both the design stage and the implementation stage is likely to fail to meet its business objectives throughout the remainder of its life cycle. It will be prone to errors and slower to use, and these two deficiencies will have corresponding adverse effects on the quality of the product or service that the system is supporting. The staff who use the system will receive little (or no) job satisfaction, and their morale will suffer as a result. Their reduced morale may manifest itself in the form of high absenteeism and staff turnover, and in extreme situations it could even lead to industrial vandalism.

Thus, there is a clear case for taking proper account of people factors when designing and installing systems, and particularly for paying attention to the way in which people actually use the equipment. This is true for all the types of equipment that are used in offices and factories. The general principles put forward in this report apply to all types of factory and office equipment, and not just to computer-based equipment that we use as examples in the report.

PEOPLE AND SYSTEMS

Before we discuss the interface between people and systems in detail, we need to review some of the main charactertistics that typify man as a component in a work system that also includes procedures and equipment. Trite though it may be to say it here, man is a complex being, and any attempt to subdivide his nature must of necessity be artificial. Nevertheless, it is usual to consider man's nature under three headings:

— Physical characteristics.

— Psychological characteristics.

— Psycho-social characteristics.

Each of these three characteristics has to be taken into account when discussing the interface between people and equipment. Man's physical characteristics determine the optimum size and shape of the equipment, and also the forces required to operate it. Man's psychological characteristics not only determine the way man thinks, solves problems and communicates, they also determine his motivation to perform a specific task, and the attitudes and values he holds. These psychological considerations are particularly relevant to the way in which tasks are designed and organised into jobs. However, people do not exist in isolation, and man's psycho-social characteristics determine the way in which people inter-react with one another.

People vary considerably in their characteristics, and the designers of equipment need to take these variances into account. When designing equipment, it is normal to consider the percentile values for a particular characteristic (that is the percentage of people below, or at a particular value of a range). Thus, a workstation may be designed for the range 5th percentile to 95th percentile for the physical characteristics of people. This represents a considerable range, but even so it means that one-tenth of the population may not be able to use the workstation effectively.

Designing the best compromise for a percentile range is quite a different matter from designing the best equipment for the average user. The reason for this is that the effects of a mismatch may not be balanced equally at both ends of the range. For example, it would be inconvenient for tall users if an emergency stop button was positioned too low, but, even worse, it could be disastrous for short users if it was positioned too high.

When considering the interface between people and equipment it is convenient to consider man's physical and psychological characteristics as forming an information processing system in its own right. Viewed in this way, it is possible to identify four main human sub-systems:

1. A sensing sub-system that detects and encodes signals from the physical environment, and that consists of receptors (eyes, ears, touch, etc.), which respond to different types and ranges of energy. The sensing sub-system has a finite, but remarkable range of sensitivity (for hearing, the ratio of the minimum detectable energy to the maximum tolerable is $1:10^{14}$). Also, the sub-system is better at making relative judgements of magnitude rather than absolute judgements. This constraint has considerable implications for the designers of equipment, and figure 1 shows some of the sensing parameters that designers have to take into account.

Figure 1 Relative and absolute discrimination for sight and sound

	Sight		Sound	
	Brightness	Colour	Loudness	Tones
Relative discrimination	570 levels of intensity	128 different colours	320 levels of intensity	1600 different tones
Absolute discrimination	5 levels of intensity	12 different colours	5 levels of intensity	6 different tones

(Source: H P Van Cott and R G Kincade)

2. A memorising sub-system that provides the short-term and long-term storage of information and has a powerful coding and cross-referencing ability. The short-term memory has a very limited capacity (typically of about seven digits), and it is retained for a few seconds or minutes. It is also susceptible to interference and distortion. Information stored in the long-term memory of the brain is re-coded into a shorthand form (known as chunking) so that a single idea or concept can be used to memorise a complex set of information, and can also be used to cross reference other ideas or concepts. The speed or accuracy of recall increases when the information that is input to the brain can readily be re-coded into convenient pieces of information.

3. An information processing sub-system that acts on the sensed or stored information, filters unnecessary information, recognises patterns, makes decisions, and selects responses. It also controls the physical functions of the body such as breathing and digestion.

4. A responding sub-system that translates the processed information into such actions as postural adjustments of the body and limbs, search and scan movements of the eyes, and speech production. It contains finely balanced feedback mechanisms that make it capable of precise and delicate outputs such as speech or piano playing. It is also capable of powerful outputs such as weight lifting and pedalling.

Well-designed equipment exploits both the strengths and the weaknesses of the characteristics of people and the four human sub-systems identified above. A consideration of these strengths and weaknesses will help to establish the optimum allocation of tasks and functions between the equipment and the person using the equipment.

Ideally, the allocation of functions is based on a comparison of the relative strengths and weaknesses of people and equipment, and this comparison is specific to each application. However, a general statement of the relative advantages of man and machines can be made by using the Fitts list (named after its originator) shown in figure 2. The entries in the "machine" column of the list are not static. As technology continues to advance, the entries will change to show a greater relative advantage for machines, and new entries, not hitherto considered within the domain of machines, may appear in the list.

Figure 2 The Fitts list: the relative advantages of man and machines

Characteristic	Machine	Man
Speed	Much superior	Lag 1 second
Power	Consistent at any level. Large, constant, standard forces	2.0hp for about 10 seconds 0.5hp for a few minutes 0.2hp for continuous work over a day
Consistency	Ideal for: routine; repetition; precision	Not reliable: should be monitored by machine
Complex activities	Multi-channel	Single-channel
Memory	Best for literal reproduction and short term storage	Large store, multiple access. Better for principles and strategies
Reasoning	Good deductive	Good inductive
Computation	Fast, accurate. Poor at error correction	Slow, subject to error. Good at error correction
Input sensitivity	Some outside human senses, eg radioactivity	Wide energy range (10^{12}) and variety of stimuli dealt with by one unit; eg eye deals with relative location, movement and colour. Good at pattern detection. Can detect signals in high noise levels
	Can be designed to be insensitive to extraneous stimuli	Affected by heat, cold, noise and vibration (exceeding known limits)
Overload reliability	Sudden break-down	Graceful degradation
Intelligence	None	Can deal with unpredicted and unpredictable; can anticipate
Manipulative abilities	Specific	Great versatility

However, the adaptability of people is a major human strength, especially by comparison with the adaptability of machines. In practice, this often means that a person is left to carry out the functions that a machine is not able to perform. But if too much is expected of the person (perhaps, for example, by asking him to exert excessive force in order to operate a control), then he may fail to perform the task, and the equipment will not then be used effectively. On the other hand if too little is expected of him (perhaps, for example, by not allowing him to use any intelligence) he may find the task boring and tedious. This may result in an lack of vigilance that may cause errors to be made or, even, equipment to be abused.

Also, if the tasks performed by the equipment do not match the task needs of the user, the equipment may not be used at all. Many of the future applications of computers in the office will, in practice, provide an additional way of carrying out a task. For example, electronic mail will, for the most part, supplement the telephone, telex and physical mail. Often, therefore, the use of these new systems will be at the discretion of the user, and, to encourage him to use them, they clearly need to be attractive — or at least not unattractive — to use.

THE SCOPE OF THE REPORT

The interface between a user and his equipment is concerned not only with the controls and displays used and the functions and facilities they access, but also with the workplace and the environment in which the equipment is used.

In practice, these factors interact, and this information is the focus of the discipline called ergonomics (or human factors engineering in the USA). In the United Kingdom, the Ergonomics Society defines ergonomics as "the scientific study of the inter-relations between people and their occupations. It deals with the equipment they use, the environments in which they work and the working system as a whole".

In military and certain other specialised equipment where it is essential to minimise the chance of human error, the importance of ergonomics has long been recognised. More recently, however, the widespread introduction of computer-based equipment into business environments, has led to an increasing awareness of the importance of applying ergonomics in the design and installation of non-specialised equipment. The need to apply ergonomics with that equipment has been brought about by two factors. Firstly, although the cost of poor interfaces between people and equipment has up till now been largely hidden, there is a growing realisation that substantial productivity benefits can be gained by improving the interfaces. Secondly, staff are increasingly unwilling to tolerate, in the working environment, many of the conditions that they have accepted over the years. For example, they are increasingly refusing to work with equipment that is (at least in their view) too difficult to use or even potentially dangerous.

People's concern about the quality of their working conditions has given rise to a growing body of legislation, regulations and standards governing the working environment, and we discuss the most important of these in chapter 2. In the remainder of this report, we emphasise the ergonomic requirements of computer-based systems and equipment. However, the same requirements apply to all other types of equipment. In chapter 3 we examine the ergonomic requirements of the physical interface between users and equipment (the hardware interface), and we consider, in chapter 4, the way in which the facilities and functions are accessed (the software interface).

Chapter 5 examines the ergonomic requirements of both the workplace and the working environment, with particular reference to computer-based equipment, and it discusses the way in which the physiological requirements of the users of such equipment make an impact on the way in which the equipment is used. The report concludes in chapter 6 with a review of the most important reasons that make it necessary for organisations to take action to improve the equipment interface, and then provides guidelines for the action that can be taken.

INTENDED READERSHIP

This report is intended for management services directors and their managers who are responsible for evaluating equipment design and also for purchasing and installing equipment. It is particularly relevant to the managers of the information systems function who have a responsibility for developing systems that can be used in the most productive way. As we explained earlier, good or poor ergonomics will have an effect on the total cost of a system over its life cycle, and indeed may dictate for how long the system is of use to the organisation. Last, but certainly not least, the subject is of concern to those who will use the systems and equipment that are provided, and in particular it is of concern to those line managers who are responsible for approving (or, alternatively rejecting) the proposed equipment or software.

CHAPTER 2

THE LEGISLATIVE AND REGULATORY BACKGROUND

Several types of legislation and regulation have an impact on the design of equipment and the working environment in which it is used. The most obvious and direct legislation concerns the health and safety of the workers, and many countries have laws to protect production workers from identifiable hazards. In recent years, the scope of health and safety legislation has been extended to all sectors of the workforce, and even to the general public. Many countries have introduced laws that cover employment protection, industrial training and worker participation, and these laws limit the freedom of employers to introduce new equipment and to change working conditions without taking due account of their employees. In addition to direct legislation, there has been a growth in national and international standards governing the design and use of industrial and office equipment. Also, trade unions are now continuously active in negotiating standards and codes of practice that govern the introduction of new technology.

The implications of these laws and regulations can be considerable, and in some countries, such as Sweden, they can be ignored only at the risk of imprisonment. In this chapter, we discuss the implications of health and safety legislation, the implications of other employment legislation, and the implications of national and international standards.

HEALTH AND SAFETY LEGISLATION

The first recorded report of an occupational disease was in the fourth century B.C. when Hippocrates described a disease of miners, now thought to be hookworm. By the sixteenth century, enough was known for Paracelsus to compile a textbook which listed metals and minerals responsible for various occupational symptoms and suggested remedies.

The creation of factories using steam-driven machinery during the industrial revolution led to new problems. Long hours, unguarded machinery, poor lighting and inadequate ventilation contributed to accidents, diseases and an increase in worker mortality. By 1802, conditions in the United Kingdom were so bad that the Health and Morals of Apprentices Act was passed to regulate the working conditions of cotton mill apprentices. Since then, legislation concerned with working conditions and the safety of equipment has grown considerably. Virtually all technologically advanced countries now have some kind of legislation, although some of it is concerned solely with disease and accidents attributable to easily identified physical or chemical agents. Nonetheless, such health and safety legislation has established the principle that society has a duty to protect workers against hazards that they themselves might not recognise, and over which they often have little control.

Within recent years that principle has been extended significantly in four directions:

— new legislation now explicitly includes psychological and ergonomic factors, and so increases greatly the range of hazards against which workers must be protected.

— More and more legal responsibility for badly designed products is being placed directly on the designer, the manufacturer, and the supplier.

- The responsibility to protect workers against the hidden hazards of modern technology and its products is being extended to include all citizens, whether they are users, customers or bystanders.

- Laws against discrimination by race, sex and age have opened up occupations to people who were previously excluded from them.

These extensions of the duty of society to protect workers mean that the recognised range of occupational hazards and potential victims of the hazards have been expanded.

An expanded range of occupational hazards

One of the first countries to expand its legislation to include psychological and ergonomic considerations was the USA. The Occupational Safety and Health Act (OSHA), enacted in 1970, took a broad view of the health and welfare of the worker. In many ways, OSHA was ahead of its time, and it has proved difficult to enforce. The ergonomic knowledge necessary to establish standards was often not available, and there were, and indeed still are, not enough trained inspectors. The ratio of inspectors to businesses means that, on average, an employer in the USA can expect a visit from an inspector only once in sixty years.

In other countries, the emphasis has been placed on the role of the employees and the trade unions in monitoring the effectiveness of the legislation. For example, the 1974 Health and Safety at Work Act in the United Kingdom followed the Swedish example of establishing union safety representatives. The Swedish Joint Regulation of Working Life Act (also known as the Democracy at Work Act), which came into effect in 1977, provided workers with even more influence over their conditions of work. The Work Environment Act of 1978 stipulates that working conditions must be adapted to human physical and mental attitudes. The Act makes provision for changing standards by stipulating that the work environment shall be kept in a satisfactory state having regard to the nature of the work involved, and also to the social and technological progress occurring in the community at large.

Health and safety standards vary in different countries and attempts to harmonise them (as for example in the EEC Commission's 1978 Action Programme on Safety and Health at Work) usually result in tighter standards. The recent EEC framework Directive on hazardous agents in the workplace represents the first systematic EEC attack on serious hazards in the workplace. Some of the discussion generated by the Directive has highlighted the differences of opinion within the EEC on where the emphasis should lie. Those countries that already have extensive health and safety legislation would prefer the emphasis to be on national action. Those countries that do not have such legislation would prefer to abdicate their responsiblity to Brussels. Even so, there is increasing pressure on member countries to match those EEC countries that have higher standards.

In addition to pressure for legislation that protects workers from injury, there is also pressure to actively promote workers' health and well-being. In the past, health and safety legislation has specified the minimum standards required to protect workers, but increasingly the legislation is being supported by additional and advisory material that specifies the recommended working conditions. This applies particularly to the use of visual display terminals in offices.

The first example of legislation in this area was the Swedish National Directive on Reading Display Screens that became effective on 1st January 1979. It contained six points about conditions for the safe and comfortable reading of visual display terminals. Also, in the Federal Republic of Germany, the standards of the Deutsche Institut für Normung (DIN) for visual display terminals and their workplaces were published in 1977, but they are not always obligatory. However, the Central Office for the Prevention of Accidents and for Work Medicine of the Hauptverband der gewerblichen Berufsgenossenschaften has recently published safety regulations for visual display workstations in the office. These regulations incorporate the various DIN standards and specify the characteristics that visual display terminals and workplaces must have before they are considered suitable for continuous use throughout the working day. The regulations will become effective on 1st January 1982, although some of the detailed design requirements such as keyboard thickness, image quality, etc., will not be effective until 1985.

Other European countries are also producing regulations covering visual display terminals. For example, the Social Affairs Department in the Netherlands are soon to publish guidelines for equipment and workplaces, although it is not yet clear whether these will be compulsory or advisory, and, in Finland, advisory regulations have been published. In the United Kingdom, the Health and Safety Executive is expected to prepare a discussion paper in the near future that is likely to be regarded as authoritative, even though it may have no formal status.

An expanded range of potential victims

Many countries have introduced a variety of legislation that is designed to protect the general public from the hazards of modern technology. The majority of the regulations are concerned with the release of toxic substances and other environmental pollution. However, legislation concerning product safety extends the scope of the legislation on safety to any user, and increases the responsibility (and the liability) of the supplier. In the United Kingdom, the public can claim some protection under the Trades Description Act, and the worker is protected also under the Health and Safety at Work Act. In other countries, there is specific legislation concerning product safety, examples being the Consumer Product Safety Act in the USA and the LOV om Productkontroll in Norway.

Anti-discrimination legislation has had a major impact on the design of equipment and workplaces. For example, the Equal Employment Opportunity Act in the USA and the Sex Discrimination Act in the UK have opened a number of jobs to women for the first time. This has changed dramatically the range of anthropometric and biomechanical characteristics of workers that protective clothing, tools, vehicles and equipment must match. Other legislation concerning racial, religious and age discrimination has had a similar effect.

OTHER EMPLOYMENT LEGISLATION

A variety of other types of employment legislation may have an impact on the design of equipment and workplaces. For example, the Swedish Data Act protects the data about an individual to such a degree that Volvo were unable to install a computerised telephone exchange, because it had facilities for monitoring the use of telephones by individuals. Legislation covering privacy and security exists in a number of other European countries, although it is a little less stringent than the Swedish legislation.

There are a number of laws and regulations that make it attractive for employers to consider schemes that use existing staff. Employment protection laws restrict employers' freedom to dismiss or redeploy employees, either by controlling the actions that management can take, or by imposing financial penalties in the form of redundancy payments. Also, in some countries there are financial incentives for re-training existing staff. Although such legislation may not make a direct impact on the design of specific equipment, it does put more emphasis on designing equipment that existing employees, after re-training, can use.

Industrial democracy legislation has a major impact not only on the design of equipment and the workplace, but also on the way new equipment is installed or implemented. The Scandinavian countries have the most advanced industrial democracy legislation, and they also have considerable experience of the impact that increased industrial democracy has on the systems development process. For example, in Norway, in their attempts to persuade the unions to accept new equipment and new systems, companies now tend to put more effort into feasibility studies and system specifications. This tendency has improved the quality of systems, but it has not caused an increase in the time taken to develop systems. This should come as no surprise to Foundation members, since, as we said in Report No. 8 on project management, a good start on a systems project is almost always a slow start. However, companies mainly regard the involvement of workers in the system development process as a one-way process of informing the unions, and researchers are expending considerable effort to develop effective methods that will produce real participation.

In other countries, the major industrial democracy legislation has established works councils and has also formalised negotiation procedures. However, voluntary experiments with worker directors, co-operative organisations and self-managing groups are taking place throughout Europe. Success in the well-published cases (e.g. at the Volvo plant at Kalmar) has encouraged others interested in improving employee morale and efficiency to consider such experiments. But there have also been failures. The British Post Office has cancelled its experiment with worker directors.

NATIONAL AND INTERNATIONAL STANDARDS

National and international standards exist for a wide variety of equipment used in the factory and in the office, and new standards are being added all the time. For example, in the Federal Republic of Germany there are more than ten DIN standards (including drafts) specifically concerned with visual display terminals and their associated workplaces. In some countries, the health and safety regulations stipulate that equipment must conform to the relevant standards, although in most countries the standards are advisory only. However, large government orders for equipment may specify that the equipment must comply with the relevant standards, and so make those standards virtually compulsory.

Considerable rivalry and differences of opinion can exist between bodies introducing national standards, and attempts to introduce international compromises are inevitably political. In many cases, an international standard is not appropriate, since the circumstances in different countries can be sufficiently diverse to make an international standard meaningless. For example, the average North American is considerably larger than the average Japanese, and equipment designed to meet the physical requirements of people in the one country may not be appropriate for the other.

Standards can also be a barrier to technological innovation if they specify methods of construction, or if major technological changes take place. In the United Kingdom, bathroom cabinets could not, until recently, conform to the relevant British standards, because the standards specified that bathroom cabinets were to be constructed from wood or metal. The standard was overtaken by developments in plastic technology that had created modern materials with superior properties.

Throughout Europe, considerable concern has been expressed over the possibility that rigid standards for visual display terminals might be similarly restrictive. The standards embodied both in the DIN standards and in widely accepted design guides (such as those in *Visual Display Terminals*) are based on current technology. Improvements in phosphors or the development of alternative display technologies may result in quite different recommendations.

The value that standards have in creating standardisation can also be questioned. For example, there are two international standards for the layout of numeric keypads. The standard for the layout of a calculator keypad has 7 8 9 in the top row, whilst the standard for the layout of a numeric telephone keypad has 1 2 3 in the top row. Research has shown that the telephone

Figure 3 Content analysis of UK trade union guidelines for the use of visual display terminals

Union	Document title	Hardware	Software	Physical environment	Job design	Training	Planning of change
Association of Professional, Executive, Clerical & Computer Staff (APEX)	Office technology — the trade union response	D	C	D	D	D	D
Association of Scientific, Technical and Managerial Staff (ASTMS)	Guide to health hazards of visual display units	D	C	D	E	E	E
Amalgamated Union of Engineering Workers (Technical, Administrative & Supervisory section) (AEUW-TASS)	Health hazards of visual display units	C	—	BR	BR	C	—
Banking, Insurance & Finance Union (BIFU)	Guidelines for the operation of visual display units	E	BR	E	C	—	C
General & Municipal Workers Union (GMWU)	Checklist for the installation and use of visual display units	E	—	E	BR	—	C
National & Local Government Officers Organisation (NALGO)	Visual display units (VDUs)	BR	—	BR	C	—	—
Society of Graphical & Allied Trades (SOGAT)	Interim guideline on operation of video display units within the printing and newspaper industry	E	C	E	BR	—	—

Key: D = Detailed discussion; E = Explanation
BR = Brief recommendation; C = Comment
— = No reference

(Source: B G Pearce)

layout is slightly faster to use and leads to less keying errors, but there is no prospect of a single standard emerging in the near future. We predict that the telephone layout will eventually become the *de facto* standard for numeric keypads, but this will result from market pressure (and the considerable influence of the telephone authorities) rather than from any action the standards bodies take.

A number of trade unions (as diverse as the Newspaper Guild in the USA and the National Union of Mine Workers in the United Kingdom) have created their own standards for use in negotiations with employers about the introduction of new technology. Technology agreements between unions and employers have been common in Scandinavia for some time, but they are only just beginning to appear in the United Kingdom. Typically, the agreements cover the effects of new technology on employment and re-training, as well as health and safety aspects. The differing scope of the guidelines for visual display terminals produced by seven trade unions in the United Kingdom is illustrated in figure 3 on the previous page.

Some of the agreements recently signed in the United Kingdom by the Association of Professional Executive Clerical and Computer Staff (APEX) contain negotiated standards that are either misleading or inappropriate. They specify a glare index for visual display terminals, when in fact a glare index relates to environmental lighting. Also, a compromise screen refresh rate of 57Hz has been agreed after the union asked for 60Hz and the employers wanted 50Hz. These inappropriate standards detract from an otherwise sensible concern for the health and safety of employees.

Several union statements about the introduction of new technology have been rather alarmist, and some union recommendations have, or may have been, largely motivated by negotiating strategy. But even so, the majority of trade unionists and users are genuinely concerned that there may be a hidden problem with visual display terminals that will be revealed only when it is too late for effective action. Even badly-worded or inaccurate agreements are an attempt to raise current ergonomic standards, and they are ignored by employers at their peril.

In addition to trade unions, a number of other bodies have produced their own guidelines. Although these guidelines are voluntary they may still have a significant effect. For example, the Swedish PTT (Televerket) has produced a handbook about the use of visual display terminals and their workplaces. The UK Business Equipment Traders' Association (BETA) has also produced guidelines on using visual display terminals, and various manufacturers (including IBM and Datasaab) have produced guidance for users. Major customers are stressing the importance of the ergonomics of visual display terminals in their invitations to tender (a recent example in the UK being the Inland Revenue PAYE system that will require about 20,000 terminals).

CHAPTER 3

THE EQUIPMENT INTERFACE

The elements of the equipment interface (i.e. the controls and the displays) must be both suitable and appropriate to allow the equipment to perform effectively the tasks and functions expected of it. The controls and the displays must be designed in such a way as to take account of the user's ability to use them and also of the amount of effort the user will have to expend in using them. The effort that a person is prepared to expend on using the equipment depends to some extent on the benefits the equipment provides. In general, the greater the benefits, the more prepared the user will be to tolerate equipment deficiencies, or to struggle with complex operating procedures. Good interface design aims to maximise the benefits for an acceptable level of effort.

For computer-based systems, the equipment interface depends as much on the software interface as it does on the equipment itself. In this chapter we concentrate on the design of the equipment, and in chapter 4 we consider the software implications of the interface between people and equipment.

The equipment designer aims to ensure that the various controls can be reached and operated, that the displays can be seen, read and understood, and that the controls and the displays integrate to form a coherent item of equipment. We now discuss the equipment interface in terms of its fitness for the function for which it will be used, its ease of use, and the compatibility of the controls and the displays. We conclude the chapter with guidelines for selecting equipment that take account of ergonomics considerations.

FITNESS FOR FUNCTION

Selecting or designing the best controls and displays involves matching them to the functions that the equipment will be required to perform. Much of the early work of ergonomics was concerned with knobs and dials, and that work was largely a product of the second world war. In that war, the need to make the best use of limited resources led to the application of psychology and physiology to the design of military equipment, and much of the emphasis was quite literally on knobs and dials. The military interest in ergonomics has continued and developed. One of the most comprehensive reference manuals, *Human Engineering Guide to Equipment Design*, was sponsored by the US armed forces. It contains over 750 pages of specific guidance for the designers of equipment on items such as the shape of control knobs for different types of control function and the relative suitability of dials or displays. For example, it recommends that analogue displays should, in general, be used to indicate a direction or a rate of change, but that digital displays should be used when precise values are important.

Conventional controls and displays (of the type covered by "knobs and dials" ergonomics) are widely used on office equipment. However, keyboards and cathode ray tubes (CRTs) are being used increasingly to provide a general-purpose interface to a wide variety of computer-based equipment. Ensuring that keyboards are fit for the functions for which they are to be used involves catering for factors such as:

— Selecting the optimum number of keys for the task.

— Allocating appropriate functions to individual keys.

— Laying out the keyboard to correspond to the sequence that best suits the task.

Ensuring that CRT screens are fit for the functions for which they are to be used involves catering for factors such as:

— Providing sufficient display capacity.

— Selecting facilities such as colour graphics or monochrome alphanumerics.

— Designing formats that correspond to the task requirements.

EASE OF USE

With much equipment, the requirements for the equipment to be easy to use cannot be considered in isolation from the specific demands of the task for which it is to be used. However, some factors that affect the ease of use apply to virtually all tasks and can be regarded as general requirements. For example, regardless of the task, the force required to operate a key must be within the user's capability. Also, the size of a character on a display must be large enough for the user to read. For a specific task, the ease of use depends on the amount of effort the user can reasonably be expected to exert. Also, if it is not possible to optimise all the interface components, the requirements of a specific task determine the relative importance of the components. Thus, when evaluating the visual display terminals that are to be used in a high-volume data entry task, the merits of the different keyboards are more important than the design of their associated screens.

When the user has to continuously contend with displays and controls that are difficult to use, the extra effort required may lead to errors, delays, aches, pains and fatigue. Because keyboards and screens are widely used, and the problems associated with them have been intensively researched and debated (even if not always in that order), the main issues relating to the use of keyboards and screens are summarised below. (More detailed information based on research in West Germany, Sweden, France and the United Kingdom can be found in *Visual Display Terminals*).

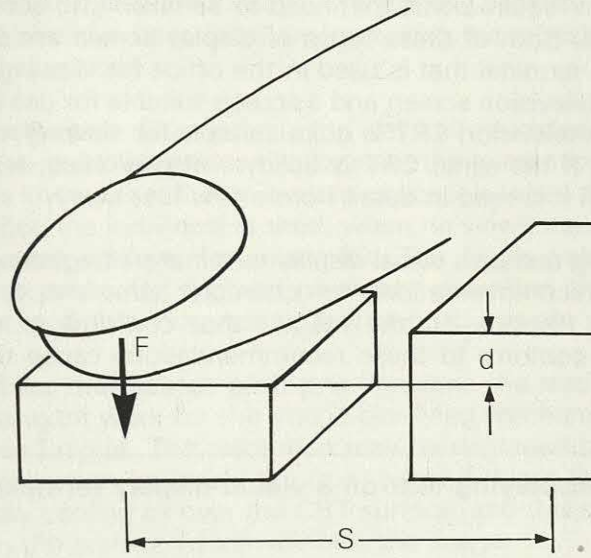
Easy-to-use keyboards

Keyboards have been the subject of considerable human factors research since the invention of the typewriter in 1873. Consequently, the optimum value for parameters such as key travel, operating pressure and keytop size are well established, and typically recommended values are shown in figure 4. Most full-sized keyboards conform to the recommended parameters and, as a result, they are easy to use.

However, recent research has demonstrated that the mobility of the keyboard and its thickness also have an important effect on the ease of use of the keyboard. The position of the keyboard tends to dictate the user's posture, and so he should be able to move the keyboard independently of the screen, so that he may optimise the positions of each. In this way, he may change his posture so as to combat or avoid fatigue.

The optimum height for the keyboard is at or slightly below elbow height when the user's fore-arms are approximately horizontal. The keyboard therefore needs to be as thin as possible, to allow the user to sit comfortably with sufficient legroom under the desk. In some workplaces (including typing desks) the work surface is lowered to optimise the keyboard height. However, doing this restricts legroom and often makes both access to the workplace and changes of posture difficult.

Figure 4 Typically recommended keyboard parameters



S	= Spacing between key centres	18 to 20mm
d	= Key travel (displacement)	0.8 to 4.8mm
F	= Key pressure	0.25 to 1.5 Newtons
t	= Size of square keytops	12 to 15mm

(Source: *Visual Display Terminals*)

On new models of visual display terminals and display word processors, manufacuturers have responded to pressure from ergonomists, users and trade unions by providing detachable thin keyboards.

The ergonomic requirements of full-sized keyboards are well defined, but miniature keyboards have been introduced recently for applications (such as videotex) that require hand-held terminals or control units. These keyboards often have little or no key travel, and because of this, many of them cannot be operated at a fast speed and also are prone to keying errors. On a conventional keyboard, the user receives an intrinsic feedback from his own fingers that confirms that the key has moved. When that feedback is lacking, errors result. Additional or enhanced feedback, such as an audible or tactile click, may help to reduce errors and increase keying confidence. However, keyboard technology is developing faster than the ergonomics knowledge in this area, and there is no clear evidence yet of the extent to which enhanced feedback makes small keyboards easier to use.

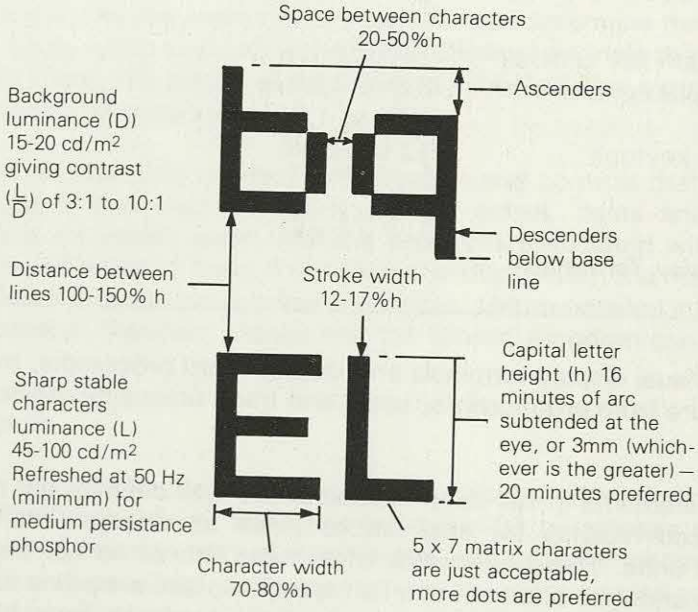
It is clear, though, that full-sized keys are necessary where speed, or accuracy or ease of use is important. Small keys are unavoidable on a pocket calculator, but there is little point in designing a pocket-sized videotex keypad if the display screen is a full-sized television.

Easy-to-use displays

Unlike the results of research into the use of keyboards, the results of the research into CRT readability have not been widely applied to the design of visual display terminals. A major reason for this is that the function of the display screen varies from application to application, whereas the function of the keyboard is broadly similar for all applications. As an example, CRTs suitable for monitoring radar traces are quite different from CRTs designed for broadcast television reception, and the human requirements that need to be taken into account are quite different for both types of displays. Both of these types of display screen are different again from the screen of a visual display terminal that is used in the office for viewing static text or images. The difference between a television screen and a screen suitable for use in the office is highlighted by videotex displays. A television CRT is quite suitable for viewing moving scenes from the far end of a living room. If the same CRT is used to display static text, the text is blurred and appears to flicker when it is read in detail from a few feet away.

The main requirements for displaying text on a visual display terminal are beginning to be established. Figure 5 summarises the recommendations for character size, shape, spacing and luminance, and there are several displays on the market that conform to these recommendations. Displays that do not conform to these recommendations cause three types of problem.

Figure 5 Recommendations for displaying text on a visual display terminal



Note: cd/m^2 = candelas per square metre (a measurement of luminance)

Firstly, the typography of the characters (including size, shape and intercharacter spacing) is frequently inadequate. Display designers often compromise on both the shape of characters and character spacing in order to make the characters as large as possible. This results either in tall thin characters or in characters or rows that are squashed together. The display is then less easy to read than it would be if the characters were smaller and better spaced.

Secondly, any instability in the display of a character is distracting, and it may even induce an epileptic seizure in a susceptible individual (approximately 1 person in 5000 in the United

Kingdom). Instability may result from interlacing (where alternate scan lines are refreshed in successive cycles), or from the decay of the phosphorescent image before it is refreshed by the electron scan. This latter problem (known as flicker) may be overcome by increasing the persistence of the phosphor. However, such phosphors reduce the life of the tube, and they cause problems when the displayed image is changed, because the previous image takes longer to decay. Flicker can also be reduced by increasing the refresh rate, but technical constraints may prevent this being done.

There are considerable differences in the way individuals perceive flicker. Consequently, it is not possible to give guidelines that will eliminate the perception of flicker for all of the population. However, it is known that flicker is more noticeable when the image size and the brightness are increased, when the individual is tired, when he views the image peripherally and when certain colours are used (yellow, for example). The single value "flicker-free" refresh rates that manufacturers quote for a given phosphor are often the result of calculation rather than empirical test, and they may not be sufficient to prevent users perceiving flicker.

The third aspect that causes problems concerns the resolution of the CRT image. A blurred image causes extra work for the image-clarifying mechanism of the human visual system and this can cause fatigue. The resolution may be degraded by grime or fingermarks on the front surface of the screen (or inside the front panel if this is fitted separately). Some visual display terminals draw cooling air over the CRT surface, and this can result in a fine layer of dust being deposited on the surface which will blur the image.

When visual display terminals are evaluated, the image quality parameters can be assessed by comparing manufacturers' specifications with standard checklists, such as those listed in *Visual Display Terminals*. But because the human visual system is an extremely sensitive instrument, the overall image quality can often be best judged by inspecting and measuring a working display.

A major feature that users of visual display terminals complain about is reflections on the screen. Reflections on the screen result more from the design of the workplace and the environment (both of which are discussed in chapter 5), rather than from the design of the terminal.

THE COMPATIBILITY OF CONTROLS AND DISPLAYS

When controls and displays are combined together in a piece of equipment their relationship to each other may be as important as the design of each individual component. Two aspects are particularly important — the control/display ratio and the relationship between the direction of movement of the control and the corresponding movement on the display.

The control/display ratio is relevant only to continuous controls. It is the ratio of the distance that the control is moved and of the distance moved by the appropriate element on the display (the pointer, the cursor, etc.). For some tasks, a good control/display ratio can save as much as five seconds in the time taken to position the display element. The control/display ratio must be optimised by experiment, and the ratio selected depends on the accuracy required and any time delay in the control system.

In complex control systems, the operator may not receive immediate feedback of the result of his control actions on the display. A technique known as "quickening" provides the operator with immediate knowledge of the predicted results of his control actions, and operator performance can be substantially improved when quickened displays are used.

The relationship between the direction of the control movement and the display movement is also important. There are several natural control movements that are consistent from one person to another, and these are called "population stereotypes". (For example, in the United Kingdom everybody expects to flick a light switch downwards to turn the light on.) However, stereotypes vary in different parts of the world, and the designer of equipment may need to take account of this factor. People can learn to operate a control that does not conform to their population stereotype, but in an emergency or stressful situation they usually revert to the stereotype. The relationship between control movement and display movement needs also to be consistent for different controls on the same piece of equipment.

EVALUATING EQUIPMENT

There are several sources of guidance for equipment designers, and prospective purchasers of equipment can use these sources to construct checklists that they can use in order to evaluate products. Checklists form a useful method of systematically comparing products in terms of their interface characteristics, and it is not difficult to construct a checklist appropriate to particular circumstances. However, it is extremely difficult to construct a checklist in which each item is equally important or in which a realistic weighting factor can be given to each item. Such a complex checklist will enable a clear quantified judgement to be made about each piece of equipment that is evaluated, but often this will be achieved only by a level of over-simplification that invalidates the exercise.

There is, in fact, no need to produce a complex checklist that results in a simple "score". Man is good at interpreting complex patterns, and the time and effort involved in using a simple checklist to evaluate the equipment profiles will be well spent. It may also reveal some important considerations that are not formally stated in the checklist.

Checklists can be an invaluable aid to common sense. If, however, they are used as a substitute for obtaining an understanding of the real requirements, they become a misleading exercise in counting product features (many of which may not be necessary for the application for which the equipment is being evaluated).

CHAPTER 4

THE SOFTWARE INTERFACE

All equipment for human use should conform to the physical and psychological requirements of the user. With information processing equipment, these include the software interface as well as the hardware interface. The interface between the system software and the user's cognitive and conceptual processes is particularly critical. However, the need for good design of the software interface has often been obscured by man's mental ability to adjust his cognitive behaviour to cope with the most perverse of systems.

The cost of tolerating poor software interfaces is even more difficult to measure than the cost of tolerating poor hardware interfaces. However, Gilb and Weinberg in *Humanised Input* estimate that one software design fault resulted in thousands of errors. They claim that the unnatural use of a space to delimit the start of a variable length comment field in a control card in the job control language for the IBM/360 operating system cost more than $100 million in terms of re-runs, destroyed files, inefficient operation and searching for errors.

The software interface has three major components, and these are considered in turn in this chapter. The first component is the language that the system and the user share. The second component is the way in which that language is organised into procedures and operations, and the third component is the time base that underlines those procedures and operations. The chapter concludes with a brief review of an experimental spatial data management system that could have a future impact on the software interface between people and equipment.

LANGUAGE

For many business functions a task language exists already, and the software interface of a computer-based system introduced into that business function should take account of the conventions of the existing task language. An important early step when analysing an existing system is to establish the variations, the ambiguities and the inaccuracies in the existing language. Inconsistencies in the language used by different departments or by different locations require special attention. Differences in the use of technical expressions may be an important clue either to variations in task procedures, or to circumstances that could otherwise have remained concealed until much later in the project. These differences must be resolved, and to do this may require considerable political skill. It may be necessary to agree compromise terminology, and the future users of the computer-based system must not only be involved in resolving the differences, they must also be committed to any solutions that are agreed.

The ideal solution is often to use the natural language of the user without modifying or abbreviating it. Falling hardware costs are making this a much less expensive approach than in the past, and some systems for doing this are now available commercially. Figure 6 shows how the ROBOT database query system is able to translate the users' ambiguous commands into commands that the computer can understand. The ROBOT system combines an automatic parsing technique with a novel automatic facility for re-phrasing the request so that it is no longer semantically ambiguous. Any ambiguity is resolved by taking account of the ambiguous way in which the language is used, and also by taking account of the structure and the content of the database that ROBOT is accessing. Without a semantic analysis of the type that ROBOT carries out, natural language systems may mislead the user into believing that the system is far more knowledgeable than it really is. For example, an apparently natural language log-on procedure could result in the following dialogue:

Computer:	*What is your name?*
User:	*Which of my names would you like?*
Computer:	*Hello Which. What facility do you want?*

Figure 6 The ROBOT natural language database query system

User request	Translated by ROBOT
Print the salary of Smith and Jones	Print the salary, and name of any employee with name = Smith or Jones
Who earns between $20,000 and $30,000?	Print the name of any employee with salary between $20,000 and $30,000
List the name, job and salary of all Chicago employees	Print the name, job and salary of any employee with city = Chicago
Are there any people working as secretaries and earning a salary of $5,000 or more?	Is there any employee with salary > $5,000 and job = secretary

Note: The above user requests illustrate the lexical ambiguity of the word "and". Note the different ways in which "and" is translated in the formal rephrasing of the requests.

If a natural language dialogue between man and machine is to be meaningful, the user and the software need to share the same "world model". Without such a shared world model, the dialogue may be not only misleading, but also dangerous. The user may believe that the system understands what he is saying, and in that belief he may then assume that the system has the same inferential powers that a person making the same type of response has. At the present time, it is practical to share only limited world models with computers, and this limitation restricts the usefulness of totally natural language communication. However, many of the task languages that are already in common business use are either abbreviated or condensed subsets of natural language.

A natural language interface is not always desirable or even possible. Computer systems with limited storage facilities have traditionally required that information is structured, condensed and abbreviated. This is not necessarily detrimental to the user, since the words used most frequently in natural language tend to be shortened or abbreviated (e.g. taxi instead of taximeter cabriolet, TV instead of television, and can't instead of cannot). Brevity, in the form of coded information, can facilitate the assimilation of output and reduce the amount of keying effort required.

The two main principles that can be used for deriving codes from a full description are transformation and association. Transformation codes are derived by applying a rule to transform the full description into the code. If applying a simple rule results in too many identical codes, it may be better to use a more complex rule. (Thus, for example, a place name could be encoded by taking the first letter followed by the next two consonants.) The benefit of a transformation code is that if the user knows the full description of the rule he can derive an unfamiliar code. He can also make a good attempt at reconstructing the full description from which a given code was derived.

Associative codes bear no obvious relationship to the full description. The association between codes and the full descriptions is defined in a master table, and prolonged exposure to the association allows the user to learn the code. Many part numbers are derived in this way, and the user must learn, for example, that part number 02745 is a "left-hand bracket". The benefits of associative codes are that, for a given number of characters, many more codes can be constructed, and the code designer is not constrained by artificial rules. The obvious disadvantage is that each code must be learnt by the user or else must be looked up in the master table each time it is required.

Both types of code have their uses, but a transformation code with well-known rules is easier to remember and seems to be more "friendly" to the user. However, the need to abbreviate output should always be questioned. There is often no real reason to compress information so that it can be displayed as a single frame on a small terminal. Doing this may reduce storage and communication costs, but these savings may be more than offset by the additional time the user takes and the higher number of errors he makes when he reads the information.

PROCEDURES AND OPERATIONS

The language of the interface is organised into procedures and operations. These may be concerned with either the input of data into the system or the display of output, or a combination of the two (i.e. a dialogue). In practice, the distinction between input, display and dialogue may be blurred. Output is usually displayed only after some data has been input, and data entry operators usually receive some feedback from their input. However, it is convenient to consider the ergonomic issues under the three headings of data input, data display and dialogues.

Data input

The majority of the research about data input has concentrated on the problems of high-volume keyboarding in centralised data preparation departments. Although there are now alternatives to using keyboards for data input (scanners, digitisers, etc.), and also alternatives to centralised data preparation departments (e.g. on-line data capture by the end user), many punch rooms will still be around for some time to come. Even when the data input is decentralised, there is often a requirement to retain high-volume keyboarding as the main method of data entry.

Suitably designed keyboards and workstations are important if the keying rate is to be optimised and errors are to be minimised. Also, the speed and accuracy of data input are both increased if the source documents are clearly legible and are in the correct sequence. However, the software interface is also important. For example, the display on the screen of the information just entered via the keyboard greatly improves error detection, even though a skilled operator often knows that an error has been made without looking at the screen.

The aim of a data input operation is to create files of error-free data as quickly as possible, and at minimum cost. Better supervision, incentive schemes and general exhortations about quality will, in general, result in only a modest and temporary reduction of errors. The proper management of errors involves tackling the source of errors, and there are three main sources of human error:

1. The inherited error
   The inherited error already exists before it is received by the system. The emphasis in minimising errors of this type is, therefore, to improve detection procedures and to push out the system boundaries so as to increase control over the incoming data.

2. The data preparation error
   The data preparation error arises from faulty encoding, translation and classification when data is processed manually prior to data entry. This type of error can be minimised by reducing the need to preprocess data excessively.

3. The transcription error
   The transcription error arises when data is transferred from one source to another (for example, from a worksheet to a screen). About 50% of character transcription errors are substitutions of one character for another. The most frequently substituted pairs of characters are shown below:

I and 1	(25% of transcription errors).
O and zero	(25% of transcription errors).
B and 8	(10% of transcription errors).
Z and 2	(10% of transcription errors).

Typical error rates from the three different sources of errors are shown in figure 7. The character error rate shown is rather misleading, since one error in a field is sufficient to make the field incorrect. With an average of five characters per field, the field error rate is five times the character rate.

Figure 7 Typical error rates for different types of input errors

Error type	Error rate	
	Characters	Fields
Inherited	2% to 5%	10% to 25%
Data preparation	2%	10%
Transcription:		
— Keying and proof reading	0.02%	0.1%
— Keying and verifying	0.004%	0.02%

(Source: R W Bailey)

Accurate data input can be achieved by fully verifying all keyed input. Since all of the data has to be keyed twice, this accuracy is achieved only at the expense of time. However, Gilb and Weinberg, in *Humanised Input*, show how the sensible use of default values, automatic range checks and repetition can achieve levels of accuracy similar to those that are achieved by fully verifying the data. Their method requires far fewer keystrokes, and a welcome side effect is that the operator's job becomes more interesting.

The most common method of inputting data to a computer-based system is by keyboarding alphanumeric information. However, some specialised applications will require different methods of data input, such as by the use of a light pen, a joystick, a tracker ball, a mouse, or a writing stylus and an electronic tablet. Each of these methods requires special-purpose hardware with appropriate software, and figure 8 shows the relative merits of these alternative methods of controlling the screen cursor.

Figure 8 Advantages and disadvantages of cursor control methods

Lightpen	Joystick, tracker ball or mouse	Stylus with tablet
ADVANTAGES		
Is fast for simple input	Has accurate, high resolution	Is good for graphics
Is good for tracking moving objects	Is comfortable to use	Is multi-purpose
Is good for gross drawing	Does not obstruct screen	Is similar to paperwork
Has a low error rate	Has vernier capability	Has vernier capability
Is efficient for multiple selection	Can be attached to keyboard	
DISADVANTAGES		
Is not really like a pen	Is slow for simple input	Requires extra worksurface
Lacks precision	Has poor control/display ratio (except with rate control)	Displaces visual feedback from motor activity
Is fatiguing on a vertical screen	Is poor for freehand input	
It obstructs part of the screen	Is difficult to include an "activate" switch	
Needs large targets	Mouse requires extra worksurface	

(Source: S E Engel and R E Granda)

Data display

There are several guidelines that the systems designer can use to help him format the information displayed on a screen and some of these are listed in the bibliography. There are, however, rather fewer guidelines that help him select the information that is to be displayed. In general, the task needs of the user determine the information that is required, and these needs vary considerably from task to task. In addition to the display of data, it is important to provide feedback about the effect of user actions, to label information appropriately, to inform the user about the status of the system and to indicate the options that are available to him. A number of experts suggest also that each screen of information should present no more than one logically connected thought or step at a time. A complex display should therefore be built up gradually, and not displayed suddenly in its entirety.

The most usual requirement is to display alphanumeric data on a visual display terminal, and the structure of the displayed information should correspond to both the task and the user's frame of reference. In practice, each screen layout should be tested out with real users on the actual equipment. It is possible, however, to give a number of general principles that should be followed when designing screen layouts, and six of these are set out below:

1. Logical sequencing
   The sequence in which the information is presented should, where possible, be logical in relation both to the system and the user's task or other information sources. If this sequence is not possible, the sequence in which the user requires the information should be used, even if this is not the most logical sequence to either the computer system or the system designer. If, as a last resort, it is necessary to design the sequence according to some other logical framework, the user should be informed of that logical basis to help him to make sense of what may otherwise be a meaningless sequence to him.

2. Grouping
   Grouping similar items together improves the structure of the display, and it can also highlight relationships between different items of data. Thus, the grouping of many similar items (such as lists of numbers) into manageable "chunks" allows them to be searched accurately and quickly.

3. Spaciousness
   Spaces and blanks on a display screen are necessary to help the user recognise and identify items of information. Spaces and blanks also maintain and emphasise the structure of the display. A cluttered screen greatly reduces the legibility of the display and increases both search times and errors. Where a large amount of information is required, it is often more satisfactory to provide a series of displays, rather than to try to condense all of the information onto one screen.

4. Relevance
   Only information that is directly relevant to the user should be displayed. Often, cluttered display formats are caused by displaying information that may be relevant only in some circumstances, or to some (but not all) users.

5. Simplicity
   Formats should be as simple as possible. This does not mean that highly-detailed or complex displays have no place, but if they are necessary they can still be structured and organised in such a way as to avoid unnecessary complexity.

6. Graphics
   Graphics can be a very effective method of communicating information, and it need not be unduly expensive. The benefits of visual communication need not be restricted to scientific

or technical applications. There are many office systems where either management information or clerical information could be assimilated or interpreted much more readily if it were displayed in a graphical form. Trends in financial data, for example, may be more readily perceived if the data is presented as a graph rather than as a table. Indeed, the human perceptual system constantly seeks to find structure in order to interpret the environment. Therefore a suitably structured graphical display greatly increases the user's speed of interpretation and reduces the error rate.

It is not necessary to use a high-resolution graphics terminal in order to provide powerful visual representations of graphs, bar charts and other data. All that is necessary is the ability to interact with the display in such a way that data can be explored either by trying out different graphs or by plotting different values. Frequently, the office user does not need to perform complex calculations. He simply needs to change the presentation of the data to make its meaning more apparent.

Dialogues

A dialogue involves sharing knowledge by exchanging information. Human dialogues are an important part of life, and they vary enormously in their length, their complexity and the richness of the information exchanged in them. Any restrictions that are imposed by the communications medium on either the nature, the size or the frequency of a dialogue usually reduce its success.

The success of a dialogue may also be reduced if one or both of the participants ignores the feedback from the other. Being responsive to the feedback involves modifying the communication to better suit it to the other party. This is particularly important when one participant has difficulty in understanding the other. The responsive participant will detect this difficulty and will either repeat the message or simplify it until the other participant understands it.

Good human dialogues may therefore involve withholding some information deliberately if it is unnecessarily detailed, or if it detracts in some way from the recipient's understanding of the message.

These general requirements for good human dialogues apply also to dialogues between humans and computers. However, in this situation the communication medium is considerably limited, as is the responsiveness of at least one of the participants. Despite this, the conscientious designer of a human/computer dialogue can build a remarkable degree of richness and responsiveness into his system.

The increasing amount of computing power available in terminal devices makes this easier and cheaper to achieve than in the past, but as the late Dr Chris Evans demonstrated, even the humble teletype could be made user-friendly with an appropriate dialogue. Figure 9 shows an extract from the beginning of a teletype dialogue for the automatic recording of medical histories.

The dialogue was highly successful, and the users found it friendly, polite, comprehensive and relaxing. This could be regarded more as a criticism of the patient's normal interaction with a harassed, impatient or overworked consultant than as praise for the computer dialogue. However, it does illustrate what can be achieved. The friendly, but wordy style of the dialogue seemed to be ideal for patients who had never seen a computer before, although it would become extremely irksome to anyone who experienced it several times a day.

The designer of a dialogue that will be used as a routine part of a job has to ensure that it is suitable for both the new user who is learning the system and the experienced user. Between these two extremes, there will be a continuous range of different users with different requirements.

Figure 9 Automatic recording of medical histories

PLEASE PUSH A BUTTON TO START? Y

HELLO. THIS IS AN EXPERIMENT TO SEE WHETHER COMPUTERS CAN HELP DOCTORS TO DIAGNOSE ILLNESSES. WE WOULD VERY MUCH LIKE YOU TO HELP US WITH THIS. IF YOU ARE PREPARED TO WOULD YOU PUSH THE BUTTON MARKED "YES", BUT IF YOU WOULD RATHER NOT, PUSH THE BUTTON MARKED "NO", BUT WE WOULD LIKE YOU TO HELP US. IF YOU DON'T UNDERSTAND WHAT TO DO PRESS THE "?" BUTTON. GO AHEAD NOW AND PUSH ONE OF THE THREE BUTTONS? (YES)

GOOD. THANKS VERY MUCH. I HOPE YOU'LL FIND IT INTERESTING WE'LL FIND IT VERY HELPFUL TO US.

THIS IS A COMPUTER TALKING TO YOU. I CAN ASK YOU QUESTIONS BUT I CAN ONLY UNDERSTAND SIMPLE ANSWERS, SO YOU CAN ONLY TALK TO ME BY PUSHING EITHER THE "YES", "NO" OR "?" BUTTON. YOU SHOULD ONLY PRESS THE "?" BUTTON IF YOU DON'T UNDERSTAND THE QUESTION I AM ASKING YOU. NOW, DO YOU UNDERSTAND EVERYTHING I'VE SAID UP TO NOW? PUSH ONE OF THE BUTTONS? (YES)

THANKS. NOW I WANT TO ASK YOU ONE OR TWO QUESTIONS ABOUT WHY YOU ARE HERE. PLEASE REMEMBER THAT THIS IS ALL IN COMPLETE CONFIDENCE JUST AS WITH DOCTORS. ONLY DOCTORS AND NURSES WILL SEE YOUR ANSWERS. ARE YOU QUITE HAPPY ABOUT THIS? PUSH ONE OF THE BUTTONS? (YES)

(Source: C R Evans)

These requirements will change as users gain experience of the system, forget what they had previously learnt after being absent, use only limited parts of the system, and so on. The ideal dialogue should be suitable for users from all points within the range.

One solution that can work well is to have a simple dialogue procedure that everybody uses when they first use a system. The progression to more advanced dialogue facilities can then be under the user's control. If an experienced user makes mistakes or has been absent he can revert to simpler procedures until he re-establishes his competence. The benefit of this solution is that the user's initial experience of the system is not jeopardised in the interests of its efficiency for the experienced user.

An example of this is provided by a technique known as entry-stacking. Initially, the operator uses the system in a simple menu and form-filling mode, where each item that he needs to input is clearly marked on the screen. As the operator gains experience he can stack or chain his responses, separating them by a slash (/). He can therefore enter details of each field before the system displays the form. A further benefit of this approach is that he can chain as many or as few responses as he can remember. The system reverts to form-filling mode if he does not use the slash.

Several distinct styles of dialogue can be identified. Figure 10 illustrates one classification of dialogue styles that distinguishes between navigational languages that help the user to manipulate the facilities, and non-navigational languages that essentially protect the user from the complexity (and inevitably the full potential) of the system.

Figure 10 A classification of different dialogue styles

Dialogue style	Navigational languages (formal)		Non-navigational languages	
	Linear language structures	Diagrammatic languages	Natural language systems	Constrained language systems
Examples	Algol	Query-by-example	ROBOT	Menus Prompts Displayed formats Form-filling

(Source: M J Fitter)

Menu selection works well for inexperienced users but regular users need to be able to take short cuts. Form-filling and prompts are suitable for data input, whereas query-by-example and natural language are most suitable for searching a database. The power of formal languages is usually suitable only for specialist users, although some beginners find query-by-example easy to use. Query-by-example uses skeleton tables, and the user fills in the spaces with an example of a possible solution. In this way, the user can construct complex searches of a relational database without having to remember many construction rules.

The likelihood of data input errors occurring as a result of the dialogue can be minimised by ensuring that the dialogue is consistent for different procedures, by creating logical sequences of operations, by avoiding unnecessary keyboard shift changes in the required input, etc. Even so, errors will occur, and it is important that the designer should check that the likely errors will not have a catastrophic effect. For example, if a control key has two different functions depending on whether the keyboard is in upper or lower shift, it is essential to ensure that using the key in the wrong shift will not have a disastrous effect.

An extreme example of a dialogue failure concerns an information retrieval system in which users specified their request by completing a form displayed on a screen. Each field on the form was displayed initially with a different symbol, and the user was required to overwrite each field. If the user inadvertently left the displayed symbol in a field, the system interpreted the request as a non-routine, record-by-record search. The normal indexed searches took only a few seconds, but the non-routine searches were processed by a different method and could require all the resources of the system for up to one hour. If a non-routine search was initiated by accident, all the user could do was to telephone the computer centre staff, who then telephoned the other users to tell them what had happened. The system was then switched off and on again, and the users were then reconnected.

TIMEBASE

The timing that underlies the software interface is particularly important to the user. When the user is engaged in solving a problem, delays are disruptive to his thought processes, and the time he is willing to wait for a response from the system is a function of his perceived complexity of the request he has made to the system. The response times that are suggested as the maximum that is acceptable for various actions are listed in figure 11.

Figure 11 Acceptable response times for different user actions

Action	Response time definition	Acceptable maximum
Keyboarding into the system	Key depression until response Key depression until appearance of character	0.1 secs 0.2 secs
Initialising the system	End of request until response	3 secs
Inserting badge reader	From insert to response	2 secs
Making a simple request	End of request until response	2 secs
Making a complex request	End of request until start of response	5 secs
Turning a page	End of request until first few lines visible	1 sec
Scanning a page	End of request until text begins to scroll	0.5 secs
Selecting a function	Selection of command until response	2 secs
Pointing	Input of point to display of point	0.2 secs
Manipulating graphics	End of request until beginning of response	2 secs
Manipulating complex graphics	End of request until beginning of response	10 secs
Making light pen entry	Activation of light pen to response	1 sec
Executing problem	End of request until response	10 secs
Updating file	End of request until complete	10 secs
Feeding back errors	Entry until error message appears	2 secs

(Adapted from S E Engel and R E Granda)

A variable response time is particularly disruptive. Consequently, it can be of great value if the system acknowledges the request immediately, even though it may not be able to process the request for a few seconds.

It is important that early users of a system should be aware that response times may become longer when the system is fully loaded. Indeed, in this situation, it may be prudent to artificially increase the response times to correspond with those that will be experienced with a fully loaded system.

However, system response time is not the only consideration. The user is frequently concerned with the "task completion time", and to him all malfunctions and failures represent disruption. He needs to know how quickly he can find out what has happened, whether any action is required from him, and how long the delay will be until the system is functioning correctly again. It is particularly important that he should know whether it is worth his while to wait for the system to recover, or whether he should switch to some standby procedure.

EXPERIMENTAL SYSTEMS

The Machine Architecture Group at the Massachusetts Institute of Technology (MIT) have built an interesting experimental system that uses spatial data management techniques to interface with a database. These techniques view the database as a "dataland" that the user can "fly over" and "navigate" through. In the MIT system, a variety of novel input devices, such as touch pads, a voice recognition system and a joystick are built into the user's chair. Through these devices, the user inter-reacts with several displays, including a CRT projection that covers one wall. In this way, he can use various spatial and graphical cues to search the databases. A world view, or a map, is provided on a small monitor and the detail is projected on to the wall display. Various navigational aids are provided, including audio output in which the noises get louder as the user moves closer to the "target".

The system is, however, very expensive (even for its sponsors — the Advanced Research Projects Agency) and its obvious benefits have not yet been justified in terms of cost. However, more down-to-earth systems have been developed (for example by Computer Corporation of America) that still offer a degree of multi-media interaction and spatial imagery. In the future, such powerful interfaces are likely to become more common, since they exploit man's capability to handle pattern recognition and memory association and his ability to use complex cues.

CHAPTER 5

THE WORKPLACE AND THE WORKING ENVIRONMENT

Manufacturers are now beginning to take note of ergonomic factors when designing equipment. In particular, some manufacturers now supply visual display terminals that have clear character images, adjustable screens and detachable thin keyboards. However, the workplaces and the working environments in which the equipment is used were often either in existence long before visual display terminals were thought of, or were designed as direct replacements for traditional office furniture. Either way, they take no account of the unique requirements of the tasks people perform with a visual display terminal.

In this report we have already shown that poorly-designed hardware and software can adversely affect the interface between people and equipment. That interface will also be adversely affected by the design of the workplace and the environment in which the equipment is used. The eyestrain from which operators sometimes complain they suffer when using visual display terminals can often be traced back to the poor design of the workstation (causing bad working posture), or the poor design of the environment (for example, excessive lighting causing glare and reflections, or inadequate ventilation causing stuffiness and dryness).

In this chapter we discuss the ergonomic requirements of both the workplace and the environment, with particular reference to the use of visual display terminals. We then discuss some tools that are now available to help to design suitable workplaces and working environments.

THE WORKPLACE

Poor design of the workplace results in bad working postures that can lead to inefficient operation, reduced output, eyestrain, fatigue and even to accidents and injury. A well designed workplace, however, supports the equipment, the person, the working materials and any other job aids required (such as manuals, calculators, stationery, pencils and rulers). The location and size of the work area should be determined by the size of the equipment and the type and amount of the working materials, the movements the operator has to make in performing the task and the forces the operator needs to exert in performing the task. Where several people use the same workplace then its design must allow for all their different sizes, shapes and methods of working. Workplaces that are used frequently for short periods need to be sited in such a way as to provide safe and easy access. This need for accessibility may conflict with the need to place the equipment and the work surfaces in the optimum position for efficient use.

The operator needs to maintain a stable position to perform tasks that may require precise or fine movements. Consequently, workplaces designed for seated work that does not require a lot of physical effort need to support the body and the equipment in relatively stable positions. However, the human frame is designed for movement, and sedentary workplaces need to take account of this. Even an apparently good posture will be excessively fatiguing if it is static for too long.

There are four main requirements for a comfortable seated working posture.

Firstly, some physical movement is essential to maintain or restore proper circulation of the blood. This movement can be catered for by providing flexible and adjustable equipment and ensuring that there are sufficient worksurfaces on which the operator can spread out and re-arrange the work. Also, sufficient legroom is required so that the operator can change posture to combat or avoid fatigue.

Secondly, the seat should have a back support that maintains the inward curve of the lower spine (known as the lumbar lordosis). The support is needed mainly at the second, third and fourth lumbar sections to prevent the pelvis rotating around the protuberances of bone at the base of the pelvis (known as the ischial tuberosities). If this rotation is not prevented by a suitable back support, it deforms the spine, compresses the lumbar discs and stretches the ligaments, and so causes discomfort, pain and eventually damage.

Thirdly, the chair seat should be firm. Contrary to popular belief, people sit on the bones of their bottom (the ischial tuberosities) not on their buttock muscles (which would become numb within minutes). A soft cushion under the thighs imposes an outward splaying movement as the thigh bones sink past the hamstrings. The splaying movement can be prevented if the legs are crossed or jammed against the furniture, but this imposes other stresses. The seat surface should therefore be slightly padded, angled back a few degrees and curved at the front so that is does not cut into the thighs.

Fourthly, the height of the seat should allow the feet to be placed squarely on the floor, with the angles between the spine and the thighs and between the thigh and the lower leg each at approximately 90 degrees, and with the soft tissue under the thigh not crushed. The recommended sitting position required to perform a task using a visual display terminal is illustrated in figure 12 overleaf.

THE WORKING ENVIRONMENT

The environment in which the workplace is located has a considerable impact on the efficiency and comfort of the person. The four major components of this environment are heating and ventilation; lighting; noise; and the social and organisational structure that affects every workplace. Some of these can be considered in isolation, but often the components interact. For example, windows provide light, but they are also a source of heat, air movement and noise. To design a good working environment is a complex job for a multidisciplinary team. All too often, however, the job is carried out in a piecemeal and haphazard fashion that results in various human problems.

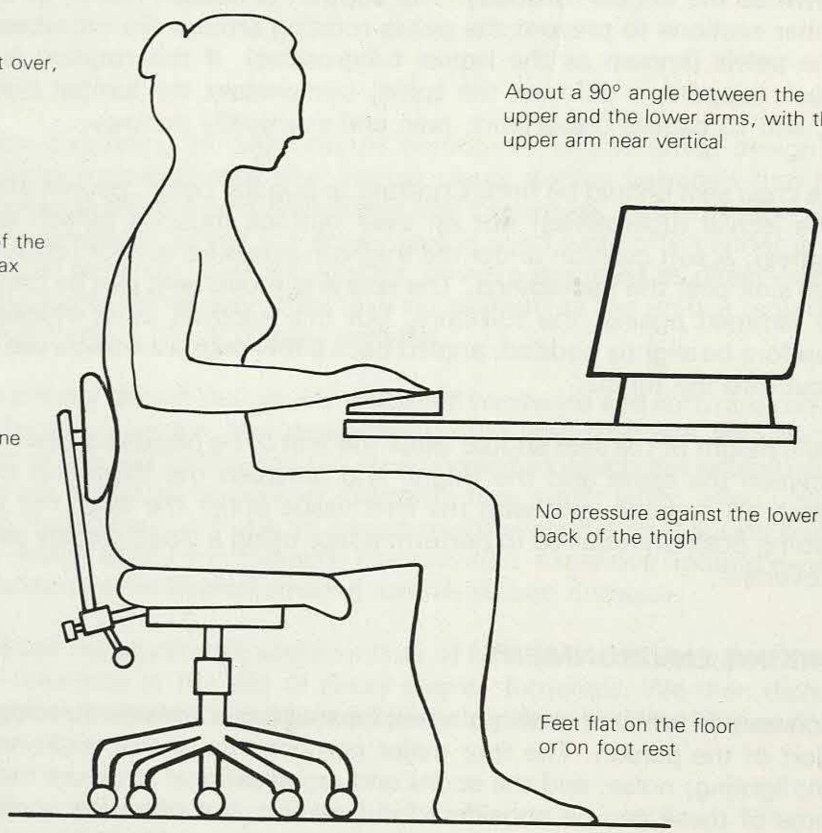
The four main components of the working environment are discussed below in more detail.

Heating and ventilation

Heating and ventilation at the workplace together form the thermal environment, and both are subject to various statutes and regulations in most countries. The thermal environment has a considerable effect on the efficiency and the comfort of the staff, but people vary in their response to temperature, air movement and humidity. Consequently, it is difficult to establish a suitable thermal environment for a range of people, especially when they are expending different amounts of effort on different tasks.

Under identical conditions, some people will feel that the temperature is too hot, some will feel it is too cold, and some will feel that it is just right. Also, those people who find it too cold are more likely to complain than those who find it too hot, because the perceived discomfort is greater as the temperature falls than it is as the temperature rises. The consequence of this is that many heating and ventilation systems have been set at too high a temperature. This reduces the relative humidity (because the hotter air is now able to hold more water vapour) and may cause the surface of the eyes to become dry. This dryness may in turn cause irritation and discomfort.

Figure 12 Recommend sitting posture for a visual display terminal task



Note: Although this posture may be considered correct in the ergonomic sense, any static posture soon becomes fatiguing if it has to be maintained for too long a period.

(Source: *Visual Display Terminals*)

Dryness of the eyes is a frequent problem in environments in which visual display terminals are used, because the operators' fixed posture makes them particularly aware of draughts. A common, but usually a misguided reaction to complaints of draughts is to turn up the thermostat settings. This reaction is misguided because turning up the thermostat settings often leads to even greater air movement, and hence it may actually increase draughts.

The optimum environment for comfort may not be quite the same as the optimum environment for efficiency, and when the environment is too warm, the efficiency of people is likely to deteriorate before they feel uncomfortable. Thus, the temperature at which a train driver feels most comfortable may be higher than the temperature at which he is most vigilant in spotting abnormal signals. The exact relationship between comfort and efficiency has not been defined, but it is certainly possible to create a compromise environment that provides acceptable levels both of comfort and efficiency.

Apart from overheating and draughts, the most common problem with the working environment in an office concerns the quality or freshness of the air. In most buildings, a lack of oxygen or an excess of carbon dioxide does not represent a problem. Even when the oxygen level in the air falls to as little as 13% (from the normal level of 20%), or even when the carbon dioxide level rises to as much as 2% (from the normal level of 0.03%), the inhabitants of the building are unlikely to notice the difference.

What is important however, is the slight odour that generally comes from the occupants. The regulations concerning fresh air requirements and ventilation rates are therefore geared to the removal of odour. In the United Kingdom, the statutory minimum air volume per person in factories and offices is 11.5 cubic metres, with a minimum fresh air supply of 4.27 litres per second per person. These statutory figures are based on research carried out in the 1930s, which noted that standards of personal hygiene had an effect on the requirements for fresh air. The standards included an estimate of hygiene based on socio-economic status. School children from poorer families required more than twice the amount of fresh air per minute, compared with children from wealthier families.

The thermal environment of the workplace is affected also by people who smoke. Excessively vigorous ventilation is often required to protect non-smokers from irritation.

Lighting

It is commonly assumed that brighter lighting means that people will be able to see better. Consequently, the level of illumination in industrial and office workplaces has increased in recent years, and in many cases this has led to a reduction in the number of accidents and also to greater safety. However, there is now a growing awareness that there is an optimum level of illumination for both comfort and efficiency. Excessive illumination causes problems of glare that can affect both comfort and performance. The glare that affects comfort is called discomfort glare and the glare that affects performance is called disability glare.

Glare is essentially unwanted light, and various methods are used in different countries to calculate its magnitude. These calculations are usually complex, but they produce a simple figure signifying the extent of the problem. In the United Kingdom, the Illuminating Engineering Society (IES) Glare Index provides a method by which designers can assess the likely incidence of discomfort glare in a proposed installation. There is also a classification system, known as the BZ system, that indicates the distribution of light from luminaires (light fittings).

When people use a visual display terminal, they are likely to suffer from glare for two reasons. Firstly, a typical visual display terminal has a dark screen, and so the eyes adjust themselves to this low light level. Secondly, the line of sight is higher than is usual for conventional paperwork, and this means that the user of a visual display terminal is more likely to see the luminaires.

Both of these reasons for glare can be overcome if the terminals are positioned at right angles to the sources of light, if the light fittings are provided with proper glare shielding, and if an intermediate level of illumination of between 300 and 500 lux is provided.

Windows provide visual access to the exterior and are useful when people need a distant view to rest their eyes. However, when visual display terminals are used near windows, some form of control over the amount of daylight that comes through the windows is usually necessary. This may be achieved by installing solar control films, blinds, curtains or shutters. But, in many offices, it may be difficult to resolve the conflicting requirements of people in different parts of a large room. When new buildings are being designed or evaluated it should be remembered that smaller windows provide visual access to the exterior, but do not create the thermal and glare problems associated with walls of glass.

The way in which a workplace is decorated has a significant effect on the distribution of illumination. The actual colours used are a matter of preference, but the reflectances of the surfaces should match the requirements of the task. For an office in which visual display terminals will be used, the floor, walls and ceiling should reflect about 30%, 50% and 70% respectively of the light that strikes them. Also, gross colour variations, such as a black ceiling or a white floor, may be impressive in an advertising brochure but are not conducive to effective work.

The colour temperature of the lighting is not usually a major problem. Intermediate or neutral white is compatible with daylight without being unduly harsh on skin tones. However, where the task requires the operator either to match or to discriminate between colours, special lighting is required.

Noise

Noise levels are measured in decibels, ranging from zero at the threshold of human hearing, to 60 decibels for a conversational voice heard at a distance of five feet, to 140 decibels for a jet engine with an after burner heard at a distance of 20 feet. Prolonged exposure to noise levels above 85 decibels is likely to cause damage to the ears, and a single noise peak of more than 145 decibels is likely to cause permanent damage to the ears. Safety regulations usually stipulate a maximum noise level based on an "equivalent continuous sound level", which permits the effects of different noise levels to be combined.

In an office environment, harmful levels of noise are unlikely, although some computer printers generate surprisingly high levels of noise. However, a sudden short burst of noise can startle a person, and it produces a reaction that makes the body ready to fight or run away. This is typified by an increase in muscle tension, in heart rate and in breathing rate. Startled people make mistakes, because the noise distracts their attention.

A more usual problem in offices is the adverse effect that the noise of impact printers has on communication and concentration. Impact printers typically operate at between 75 and 80 decibels and concentration begins to suffer at noise levels between 55 and 65 decibels. Acoustic enclosures can be an effective way of reducing noise levels, but they limit access to the equipment and may cause overheating problems.

In some circumstances there can be too little noise. Background noise of less than 50 decibels may be insufficient to mask extraneous noises and/or to provide privacy. In general, however, problems associated with too much noise can be expected to increase as more and more equipment is installed in offices where the key activities are communication and concentration.

Social and organisational considerations

The physical layout of adjacent workplaces can have several social and organisational implications. The relationships between staff members or between staff members and supervisors may be defined, or reinforced or blurred by the physical arrangement of the workplaces. In many organisations, an individual's position in the hierarchy is reflected by his entitlement to such items as a bigger desk, a softer chair, more space, extra cupboards and a thicker carpet. These entitlements represent a reward to the individual, and they remind him and others of his worth to the organisation. They also emphasise the distinction between a supervisor and his staff, or between a group leader and group members. However, unnecessary distinctions may impede effective communication, and many Japanese and North American companies have gone to some lengths to eliminate such distinctions.

Nonetheless, those who plan office layouts should take account of social and organisational groupings. Workstations that are grouped together to facilitate inter-communication, or partitions that are erected to provide privacy, should reinforce the social and organisational structures, not impede them.

DESIGNING SUITABLE WORKPLACES AND WORKING ENVIRONMENTS

Heating and ventilation systems and lighting systems are often designed without the designer having any knowledge of what the space will be used for. This is particularly true in office buildings, where an entire floor may be illuminated, heated and ventilated without any regard for the location of partitions, desks and other office furniture. In theory, a uniform treatment of the environment permits maximum flexibility, but in practice the treatment is often a poor and unimaginative compromise. In addition, the schemes that the specialists originally planned are often modified subsequently for reasons of economy. Such economy may well be shortsighted, because it could result in considerable post-installation expense in trying to make an inadequate environment cope with the users' requirements. Nevertheless, the environment can be designed to suit people, provided that their needs are first clearly established and then form the starting point for the design project.

On the other hand, methodologies that can be used in designing workplaces are not so well developed. Some people have used work study and organisation and methods techniques to good effect when designing certain types of workplace, but those techniques are more suited to modifying and improving existing equipment than to improving basic design. However, two recent developments in ergonomics techniques have the potential to improve the design of workplaces.

One of these is a three-dimensional movement recorder of exceptional accuracy and versatility, known as CODA 3. It uses opto-electronics to provide parallax-free cartesian coordinates for up to eight "landmarks". These landmarks are small prisms that weigh less than one-tenth of a gram each. They require no wires or batteries, and they can be attached to any object for the purpose of monitoring its movement relative to a coordinate system. Using this recorder system, the movements of a person at either a real or a simulated workplace can be accurately monitored without interfering with his work.

The second development is a computer-aided design system known as SAMMIE (System for Aided Man Machines Interaction Evaluation). SAMMIE permits workplaces to be designed and evaluated using a three-dimensional simulation of the human body. The system can simulate movement at all the major body joints, and it can be used to assess such ergonomic criteria as reach, access and visibility. The dimensions and body shapes used in the system can be varied to cover the full range from short fat men to tall thin women. SAMMIE has been used to produce initial designs for workstations as diverse as the driver's cab in a bus and a bank cashier's desk that incorporates a visual display terminal. The two designs are illustrated in figure 13 overleaf.

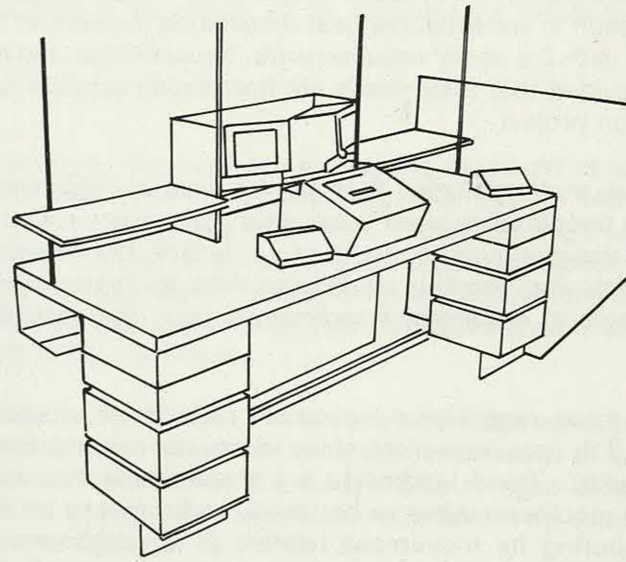
Both CODA 3 and SAMMIE offer considerable possibilities for designing ergonomic workplaces, but their effectiveness depends on the designer asking the right questions. They are useful and powerful tools, but they are not a substitute for ergonomic analysis and design.

Another development that appears at first sight to offer substantial ergonomic benefits to users of visual display terminals is the adjustable terminal desk. It is essential that the workplace permits the user to make some adjustments, but many of the adjustable desks now available provide excessive scope for adjustment that is neither useful nor usable. Making everything adjustable does not ensure that the equipment will be used properly.

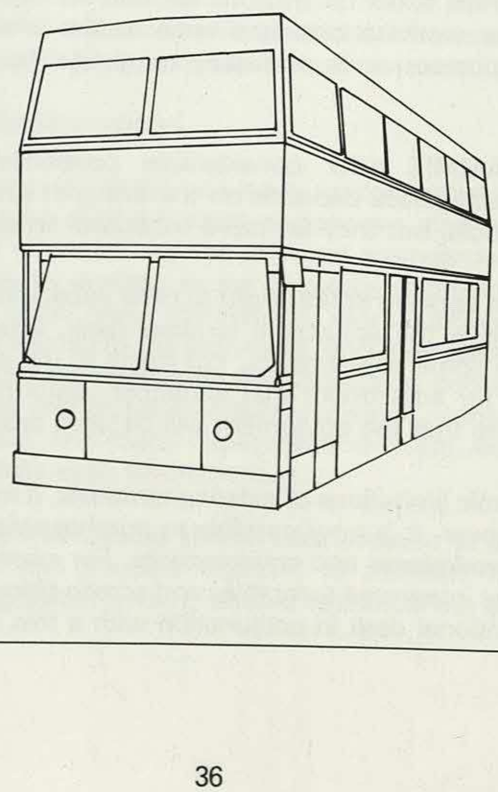
To overcome the ergonomic limitations of existing terminals, it may be necessary to have desks that are adjustable. However, it is now possible to purchase visual display terminals that fit a wide variety of existing workplaces and environments. For example, many manufacturers now supply terminals that have integrated turntables and screen tilting-mechanisms. Such terminals can be used on a conventional desk in conjunction with a thin detachable keyboard.

Figure 13 Designs produced by the SAMMIE system

Bank cashier's desk



Mirror positions on bus



CHAPTER 6

APPLYING ERGONOMICS TO COMPUTER-BASED SYSTEMS

In this report we have shown how poor interfaces between people and equipment can have an adverse effect on the use of a system. We have also shown that the discipline of ergonomics is able to analyse the interface problems that occur, and that techniques are available both to put right existing problems and to prevent new problems occurring. In this chapter, we first re-emphasise the reasons that are making it important for organisations to improve the interface between people and equipment. We then provide guidelines for the way in which ergonomics standards can be applied to computer-based systems.

THE REASONS FOR IMPROVING THE EQUIPMENT INTERFACE

Many of the equipment interface problems that we have identified in this report are neither new nor unique to computer-based systems, but they are often hidden. In the past, users have managed to overcome the limitations of poor equipment interfaces, and there is no reason to doubt that, to some extent, they will continue to do so in the future. People are adaptable, and in many situations they can tolerate inefficiency. However, there are several developments that make it increasingly important that human factors should be properly considered in the future.

Skilled staff of all types are increasingly expensive to recruit and employ. At the same time, computer-based technology is becoming smaller, cheaper and more powerful. These two factors mean that organisations need to make the best use of their skilled staff, and, to help themselves achieve this, they will be prepared to invest in computer-based equipment. It will therefore become increasingly important to ensure that the interface between the skilled staff and the equipment they use does not create unnecessary problems and costs.

The perceptions of an acceptable equipment interface change as improved equipment is introduced. Once a user has experienced an improved interface, he will no longer accept the previously acceptable equipment. An illustration of this growth of expectation is provided by secretaries, who today expect to be provided with an electric typewriter (rather than a manual model), but who in the future may expect to be provided with a word processing facility.

Trade unions are taking a broader view of their responsibilities towards their members. They are putting more emphasis on working conditions, on the use and misuse of skill, on career progression and on the humanisation of work. They are also formulating policies concerned with the introduction of new technology, and in some cases are organising themselves for a long struggle over this issue. Trade unions are rightly concerned about poor equipment design and poor interfaces, and they are using them as a weapon against the employer who leaves himself open to such attack.

Health and safety authorities are also taking a broader view of their responsibilities. In several countries, the emphasis is changing from expressing concern about the need to avoid hazards and ill-health, to actively promoting psychological and physical well-being. Public attitudes, which at one time tolerated deafness and asbestosis as acceptable occupational hazards, are now starting to question the acceptability of backache and eyestrain. Working conditions (such as unpleasant conditions, boredom, alienation and excessive fatigue) that were accepted in the past, are not likely to be acceptable in the future. Also, the qualities that professional staff and managers value in their job (such as variety, autonomy, discretion, and so on) are now being demanded and obtained by production workers, clerks and other lower-level staff.

The final reason why it is increasingly important to improve the interface between people and equipment is that it is cheaper to get the right interface early in the design process. A modest amount of additional effort and cost at the system design stage will result in an ergonomically correct system that users easily accept and use. By contrast, the cost of implementing a system that is not easy to use can be very high indeed.

Equipment interface failures are common, and frequently they are costly too. The errors, delays and frustrations caused by these failures may not be attributed to poor interfaces, and the costs of the failures may be hidden, because people can adapt to overcome the problem. However, the attitudes of staff to what they will accept in a working environment are changing, and there is a growing awareness of the need to improve the interface between people and equipment.

GUIDELINES FOR APPLYING ERGONOMICS TO COMPUTER-BASED SYSTEMS

In order to improve the interface between people and equipment it is necessary to modify both equipment and working environments. It is also necessary to introduce ergonomic criteria into the procedures used in evaluating purchases. It may also be necessary to change the way in which people work, or are managed, or are supervised, and such changes may in turn require the structure of the organisation to be changed. For new systems, an integral part of the systems design process should be the planning of those organisational changes that are required in order to optimise the interface between people and equipment.

One of the most common mistakes organisations make when introducing change is to copy an approach that worked elsewhere. For example, many of the participative design and industrial democracy practices that are required by the law in Scandinavian countries may not be acceptable to either management or employees in some UK organisations.

The designer of a computer-based system is often responsible for designing tasks that will form the full-time job of the system user, and the quality of the jobs so created is an important element of the interface between the users and the system. In many new systems, there is a tendency to group the tasks into jobs without trying to design the jobs to meet the needs of the people who will be doing them. Often, then, the jobs are of poor quality, and the job holders probably achieve little job satisfaction in performing them. Yet there is nothing inherent in computing technology that makes it necessary to go this way about it. For example, a number of tasks are often made into one job because they are performed at a terminal. It is easier to obtain and control one operator, rather than several, but when there is only one operator there is less flexibility (for example, in times of absence) and health risk considerations become more important. Consequently, it may be better to make the terminal tasks form part of several jobs. If the jobs are properly designed it should be possible to achieve the same level of equipment utilisation as would be achieved with just one operator.

The correct design of jobs can bring many benefits, including:

- Improved productivity.
- Improved quality of output.
- Greater flexibility.
- Better manpower utilisation.
- Improved customer service.

— Improved responsiveness to crises.

— Greater job satisfaction.

There has been substantial research into what makes a satisfying job, and the Work Research Unit (reference number 7 in the bibliography) has identified the following major components:

- A degree of challenge.
- Variety.
- Discretion and responsibility.
- An opportunity to use skills and abilities.
- Scope for learning and development.
- Social contact.
- The opportunity to participate in decisions that affect life at work.

Management sciences techniques can provide the system designer with tools that permit him to design optimum task procedures and jobs without needing to refer to the users of the system. However, such an approach is likely to meet with resistance from the users, and it will not encourage them to feel committed to the system. The effectiveness of computer-based systems, particularly those used in offices, depends heavily both on the commitment of the users to the system and on their knowledge, skills and motivation.

Thus, a necessary condition for designing an ergonomically correct system is to involve the users of the system at the design stage, and to allow them to participate in the planning of changes in their working environment. There may be scope, in some situations, for allowing the user department to experiment in deciding on the new jobs, rather than for the system designer to specify each job precisely. Good design practice is often a matter of knowing when to leave options open.

User participation is necessary when analysing the task requirements, and one of the most successful methods of tapping the user's task experience is to provide a simulated system to which he can respond. The simulation may be anything from a series of mock-ups of possible input routines and output displays to a full prototype system. Users may not be very good at identifying their requirements in an abstract or conceptual way, but they respond readily when they see or can experiment with a facility that has been designed specially to meet their needs. Knowledge gained from the prototype system can then be incorporated in the final design of the full operational system.

If those staff members who will actually use the system (and not just the managers and the supervisors of the user departments) participate in the system design process, it will help them to come to terms with the new development, and it will also help them to play a role in establishing the kind of system they can and will use. Every user who comes to view the system as his own, rather than something imposed on him from above (or outside), represents a major ally when the system is implemented.

There are, however, pitfalls to be avoided when users participate actively in the system design process. The nominated person from the user department may not be a typical user, and it is easy for the system designer to see only those users that are the most co-operative or have the most time, and they will not necessarily be the best people to consult. Also, it is easy to consult only those who will be the primary users of the system. This is dangerous, because the whole system could fail if the secondary users are provided with an inadequate service.

To ensure that computer-based systems are ergonomically correct when they are implemented, the ergonomics of the equipment interface needs to be considered both at several stages in the design process and from several points of view. We suggest that organisations need to establish a procedure through which systems designs are reviewed from an ergonomics point of view at several check-points during the design process.

The best person to carry out ergonomics reviews of computer-based systems will vary, depending on the skills and responsibilities of existing staff. However, the selected person need not be a member of the project team responsible for the development of the system. He might be drawn from any of the following departments or functions:

- Manpower development.
- Personnel.
- Systems quality assurance.
- Health and safety.
- Training.

Some large organisations, in which complex man-machine relationships are an integral part of the products (for example, companies in the aerospace industry), or of the production process (for example, mining companies), may already have an ergonomics department. In such organisations, the responsibilities of the ergonomics department can be widened to include the auditing of computer-based systems.

Where the skills do not exist already within the organisation, it will be necessary to provide those involved in the systems design and systems implementation process with the skills that will enable them to ergonomically evaluate hardware and software. The required skills are those that will enable the ergonomics of the system to be evaluated in advance of implementation, and various short courses and conferences are available to help system designers to understand enough about ergonomics to tackle many of the straightforward issues. Such training also helps system designers to recognise those equipment interface problems that require professional or specialised guidance.

Those who carry out the ergonomics review of computer-based systems should construct ergonomics standards and checklists, and these should then be used throughout the organisation. The standards must reflect the unique circumstances of each organisation, but general guidance on the content and the scope of the standards and checklists can be found in several guides on human factors design. For example, *Visual Display Terminals* contains basic checklists that can be adapted for use by those responsible for the purchase of computer-based equipment, especially when they evaluate the keyboard and the CRT display of a visual display terminal. The checklists should also be used by those responsible for designing the environment in which the equipment will be used (i.e. the design of the workplace layout and seating, and the thermal, lighting and acoustic environments).

Ergonomics standards and checklists should also be used when evaluating the software interface. These software standards and checklists will need to be used both by system designers when they design application dialogues, and by those who evaluate hardware, since the supplier's software often determines the overall characteristics of the software interface.

To develop and use ergonomic standards and checklists requires specialist skills. This applies even for the physical interface between people and equipment, where the ergonomic requirements are well researched and defined. The ergonomic requirements of the software interface is a relatively new field, and the skills required to define ergonomic standards and checklists for software are unlikely to exist within the organisation. Organisations should therefore consider using a professional ergonomist for a short period to help them establish ergonomics standards and checklists that are relevant to their circumstances, and also to advise them on the procedures they should establish for ergonomically reviewing computer-based systems.

The ergonomics of computer-based hardware (certainly the physical interface, and to a lesser extent the software interface) is determined by the manufacturers. Improved equipment interfaces will therefore come about if purchasers specify ergonomics criteria as part of the equipment selection process. This in turn will encourage manufacturers to take more account of ergonomics when they design new equipment.

BIBLIOGRAPHY

1. Anon. "Back pain in industry". *Health and Safety Information Bulletin Number 43,* Industrial Relations Services, London.

2. Anon. *CODA 3*. Movement Techniques Limited, Leicestershire.

3. Anon. "Employee participation and company structure in the European communities". *Bulletin of the European Communities — Supplement 8/75*, 1975.

4. Anon. *Bildschirm — Arbeitsplätze. Bestell-Nr: ZH1 Sicherheitsregein für Bildschirm — Arbeitsplätze un Bürobereich*, Hauptverband der gewerblichen Berufsgenossenschaften eV, Bonn, 1980.

5. Anon. "SAMMIE Research Group" Department of Production Engineering and Production Management, University of Nottingham.

6. Anon. "The lessons learned at Three Mile Island". *New Scientist*, 4 October 1979.

7. Anon. *Work Research Unit Information Note 1*. Work Research Unit, Department of Employment, London.

8. Bailey, R. W., "Human Error in Computer-Based Data Processing Systems". *Bell Laboratories Report, Business Information Systems Programs Area*, 1973.

9. Bignell, V., Peters, G., and Pym, C., *Catastrophic Failures*, The Open University Press, 1977.

10. Bjorn-Anderson, N., (ed). *The Human Side of Information Processing*, North Holland Publishing Company, 1980.

11. Cakir, A., Hart, D. J., and Stewart, T. F. M. *Visual Display Terminals*, John Wiley and Sons, 1980. (Originally published by IFRA, Federal Republic of Germany in 1979 as the VDT Manual).

12. Chapanis, A., "Ergonomics in a world of new values". *Ergonomics*, Volume 19, Number 3. Taylor and Francis Limited 1976.

13. Eason, K. D., Damodaran, L., and Stewart, T. F. M., *MICA survey in Man Computer Interaction in Commercial Applications*, SSRC Project Report Grant Number AR 1844/1, 1974.

14. Engel, S. E., and Granda, R. E., *Guidelines for Man/Display Interfaces*, IBM Technical Report TR00. 2700, 1975.

15. Evans, C. R., *An automated medical history taking project*, National Physical Laboratory Reports, Com Sci 55, 1972.

16. Fitter, M. J., "Dialogues for Users". *Proceedings of Infotech Conference on User Friendly Systems*, March 1979.

17. Fitts, Paul M., and Jones, R. E., "Analysis of factors contributing to 460 pilot-error experiences in operating aircraft controls". *Selected Papers on Human Factors in the Design and Use of Control Systems*, Dover Publications Inc., New York, 1961.

17. Fitts, Paul M., and Jones, R. E., "Analysis of factors contributing to 460 pilot-error experiences in operating aircraft controls". *Selected Papers on Human Factors in the Design and Use of Control Systems*, Dover Publications Inc., New York, 1961.

18. Gilb, Tom and Weinberg, Gerald M., *Humanised Input: techniques for reliable keyed input*, Winthrop Publishers Inc., Cambridge, Massachusetts, 1977.

19. Grandjean, E. (Ed). *Proceedings of the International Workshop on Ergonomic Aspects of Visual Display Units*, Taylor and Francis Limited, London, 1980.

20. Herbst, P. G., *Socio-technical design: Strategies in Multidisciplinary Research*, Tavistock Publications, London, 1974.

21. Katz, D., and Kahn, R. L., *The Social Psychology of Organisations*, John Wiley & Son, 1966.

22. Kotter, J. P., and Schlesinger, L. A., "Choosing Strategies for Change". *Harvard Business Review*, March/April 1979.

23. Manos, John, "EEC action report". *Health and Safety at Work*, April 1980.

24. Maslow, Abraham H. *Towards a psychology of being*, Van Nostrand, New York, 1962.

25. Möller, Lennart and Olson, Arne. *Krav och rekommendationer för utforming av terminalarbetsplatsmiljö*, Televerkets Författningssamling B:50, Farsta, 1979.

26. Mumford, Enid and Sackman, Harold (Eds). *Human Choice and Computers*, North Holland Publishing Company, Amsterdam, 1975.

27. Murrell, H., *Men and Machines*, Methuen Essential Psychology Series, London, 1976.

28. Pearce, B. G., *A Content Analysis of British Trade Union Guidelines Relating to VDUs*, HUSAT Memo No 217R, Loughborough University of Technology, 1980.

29. Shackel, B. (Ed). *Applied Ergonomics Handbook*, IPC Science and Technology Press, Guildford, 1974.

30. Shackel, B., (Ed). *Man Computer Communication*, Infotech State of the Art Report, Infotech Limited, 1979.

31. Stewart, T. F. M., "Problems caused by the continuous use of visual display units". *Lighting Research and Technology*, Volume 12, Number 1, 1980.

32. Surry, J., *Industrial Accident Research*, Labour Safety Council, Ontario Department of Labour, 1977.

33. Trine, A., *Employers' liabilities under Social Service Legislation in Countries of the European Common Market*, C. E. D. Samson, Brussels, 1979.

34. Van Cott, H. P., and Kincade, R. G., *Human Engineering Guide to Equipment Design*, US Government Printing Office, Washington, 1972.

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