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People and computers — some recent highlights

Brian Shackel*

HUSAT Research Institute, Loughborough University, Leicestershire, LE11 3TU, UK

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Abstract

This paper aims to review selectively a fair proportion of the literature on human–computer interaction (HCI) over the three years since Shackel (J. Am. Soc. Inform. Sci. 48 (11) (1997) 970–986). After a brief note of history I discuss traditional input, output and workplace aspects, the web and 'E-topics', web-related aspects, virtual reality, safety-critical systems, and the need to move from HCI to human-system integration (HSI). Finally I suggest, and consider briefly, some future possibilities and issues including web consequences, embedded ubiquitous computing, and 'back to systems ergonomics?'. © 2000 Professor B. Shackel. Published by Elsevier Science Ltd. All rights reserved.

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1. Introduction

When *Applied Ergonomics* began in 1969 (I had the excitement of being the first Editor) we talked (*pace* political correctness) about man–machine systems and man–computer interaction (the International Journal of Man–Machine Studies started in 1969, and see Shackel (1969)). Few realised that we were on the threshold of the development of a new sub-discipline or multi-discipline now generally called *human–computer interaction* (HCI). The growth has been phenomenal.

At that time, in an era still of hand-written manuscripts and carbon copies and retyping for any revision, I would have started writing this paper at least four months ago. Now, through laziness and old-age delay, real work began only two weeks ago and (owing to a computerised touch-typing training program created at HUSAT in 1976–1978) I type the text rather hectically myself and bless my former secretary for kindly typing all the references in a little over a day. That is merely one small example of the new possibilities, taken for granted by most people now, which have become available over the 30 years of *Applied Ergonomics*.

To read something of the development of HCI through these years, please refer to Shackel (1997); for the growth of relevant technology, see Myers (1996), and for more depth in specific topic areas see Baecker et al. (1995). In this paper we shall view the past only through Table 1, which notes some highlights of the growth of attention to ergonomic/human factors aspects of HCI; it is revised from Shackel (1997) so only references from 1992 are given in the reference list to this paper.

My aim here is to present a brief overview of some recent highlights. This is by no means intended as a comprehensive review of the last few years. It merely focuses upon some topics and themes which either interest me directly or which seem possibly to be important in the growing use of computers by people at the start of this new millenium.

2. Traditional input, output and workplace aspects

2.1. Input

There is still a range of typical ergonomics interface topics to be addressed, even though they are usually triggered by, or related to, some advance in technology or to the possibility of linking better with more of the human user's interaction capability.

Most HCI people seem to be ignorant that two-handed input was first used in the 1960s. At the Stanford Research Institute Engelbart (1963) built a group to develop the concept of augmenting human intellect via advanced computer tools; they foresaw the importance of

* Tel.: +44-01509-223010; fax: +44-01509-610724.
E-mail address: b.shackel@lboro.ac.uk (B. Shackel).

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Table 1
Growth of attention to ergonomic/human factors aspects of HCI (see Shackel, 1997, for references before 1992 below)

Date	Event
1959	1st recorded paper in the literature (Shackel, 1959 as reported by Gaines, 1985)
1960	Seminal paper by Licklider (1960) on 'Man–Computer Symbiosis'
1969	1st major conference ('International Symposium on Man–Machine Systems')
	International Journal of Man–Machine Studies started
	First four ARPANET nodes begin operation — leading later to computer conferencing, electronic mail and electronic journals
1970	Foundation of Xerox Palo Alto Research Centre (PARC)
	Foundation of HUSAT Research Centre (now Institute), Loughborough University
1970–73	Four seminal books published (Sackman, Weinberg, Winograd, Martin)
1976	NATO Advanced Study Institute on 'Man–Computer Interaction'
1979	Visicalc, the first electronic spreadsheet, is produced
1980	Conference and book on 'Ergonomics Aspects of Visual Display Terminals' (Grandjean and Vigliani, 1980). Four other major books (Cakir et al., Damodaran et al., Shneiderman, Smith and Green)
	Word-processing now available on microcomputers
1982	Journal *Behaviour and Information Technology* started
1982 to 1984	7 major conferences held in USA, UK and Europe with attendances ranging from 180 to over 1000 with an average of nearly 500
1983	European ESPRIT and British Alvey programmes begin
	Major book 'The Psychology of Human–Computer Interaction' (Card et al.)
1984	First International Conference on HCI — IFIP INTERACT'84 (London)
1985	Journal *Human-Computer Interaction* started
	From 1985 the conferences of the US and UK national societies ACM and BCS, on CHI and HCI respectively, become annual
1986	Three HCI Centres launched in the UK under the Alvey initiative
	Major book 'User Centered System Design' (ed. Norman & Draper)
1987	Second IFIP INTERACT International Conference on HCI (Stuttgart)
	OZCHI (Australian HCI conference) starts and is annual hereafter
1988	Major 'Handbook of HCI' published (ed. M. Helander)
1989	IFIP establishes Technical Committee on HCI (IFIP TC 13)
	Journal *Interacting with Computers* started
	International Journal of Human–Computer Interaction started
1990	Attendance at ACM CHI Conference reaches 2300
	Third IFIP INTERACT International Conference on HCI (Cambridge UK)
	CEC (1990) Directive promulgated on Work with Display Screen Equipment
	ARPANET has grown, changed, ended and been replaced by the academic and later commercial INTERNET, setting new HCI problems because of much more widespread use
1991	Research already developing towards collaborative tele-working in automotive design and manufacturing (Sinclair, 1992)
1992	Attendance at ACM CHI Conference reaches 2600
1993	CEC Directive on Display Screen Equipment comes into operation
	Fourth IFIP INTERACT International Conference on HCI combined with annual CHI Conference in Amsterdam to make INTERCHI'93 — over 1500 attendance
1994	Journal *ACM Transactions on Computer–Human Interaction* started
	Title of *International Journal of Man–Machine Studies* changed to *International Journal of Human–Computer Studies*
	World-Wide Web innovation of Berners-Lee et al. (1994) 'takes off'
1995	Fifth IFIP INTERACT International Conference on HCI (Lillehammer)
1996	APCHI (Asia-Pacific HCI conference) initiated in Singapore
	'E-commerce' as a concept comes into recognition
1997	Sixth IFIP INTERACT International Conference on HCI (Sydney) combined with APCHI'97
1998	APCHI'98 held in Kanagawa, Japan; APCHI to be biennial hereafter
1999	Seventh IFIP INTERACT International Conference on HCI (Edinburgh) combined with annual BCS HCI Group conference HCI'99
2000	'E-commerce' beginning to become a widespread reality

close coupling the human, and in 1966 I saw the workplaces fitted around the users with the (first) mouse and a 5-key keypad for simultaneous two-handed use, alongside a standard keyboard together with two screen displays for some. Already they had effectively invented What You See Is What You Get (WYSIWYG) word-processing, multi-window display and electronic meeting rooms (Engelbart, 1963; Engelbart and English, 1968). So

now Zhai et al. (1997) have shown that two-handed input with a mouse and a joystick, and Hinckley et al. (1998) with a mouse and a touchpad, is better than the status quo. Virtual reality brings with it three-dimensional control issues, and Fröhlich and Plate (2000) have devised and tested successfully with users a 'cubic mouse'. Most input controls provide relatively little haptic feedback, so Oakley et al. (2000) and Dennerlein et al. (2000) have devised methods of giving force-feedback to the controlling hand, and have proved advantages in speed or lower errors.

Another form of input to use human capabilities more fully is gesture. Moran et al. (1998) have integrated *domain objects* into an electronic whiteboard and then used them as the basis for enabling gesture input. With an electronic pad and stylus Forsberg et al. (1998) have devised an even more novel approach enabling music scores to be written by two-dimensional gesture. The range of gestures enabled by typical hand-held penpad computers do not allow users to become 'power users', in the view of Geissler et al. (1999) who have devised and tested an improved interface; also at INTERACT'99 there was a whole session on haptics and gesture (pp. 375–398).

Head position/movement and eye gaze directions have also been explored more in the last few years, with proper comparative tests. Bérard (1999) showed that head movement to control the location of a window within a document space allows significant improvement in task completion times. Vertegaal (1999) showed that head and eye tracking could aid awareness and attention in video-conferencing. At CHI'2000 there was a whole session on eye gaze (Tanriverdi and Jacob, 2000; Salvucci and Anderson, 2000; Sibert and Jacob, 2000) which showed that eye gaze is getting nearer to being a practical tool; but there are still limitations, as noted by Sibert and Jacob (2000): "current eye tracking technology is relatively immature — our eye tracker has difficulties with hard contact lenses, dry eyes, glasses that turn dark in bright light, and certain corneas that produce only a dim glint when a light is shone from below". But the most serious difficulty is still, as discussed by Velichkovsky et al. (1997), the 'Midas touch problem' — how to differentiate the attentive saccades, made with an intended goal of communication, from the lower level random movements; that is to differentiate between the visual axis and the attention axis.

For years direct speech input has been claimed to be effective, but proving this has not been easy. In an award winning paper Halverson et al. (1999) studied one of the major problems; although automatic speech recognition systems have improved, even with 98% reported accuracy error correction still takes major time and effort. The error correction strategies adopted by users tend not to be flexible enough nor to be well matched by the strategies assumed by the design of the three commercial systems studied. By contrast, Golightly et al. (1999) showed that speech interaction during certain problem solving tasks can lead to significant reduction in the number of moves to solution without any increase in total solution times.

Finally, three papers catch the attention for different reasons. Sugiura and Koseki (1998) have demonstrated an unusual and intriguing concept; using a fingerprint recognition system they have linked the output from each finger to a different command or phrase (such as a letter template or one's full name and address); thus they have devised a 'fingerprint user interface'. First tests show practicality but not speed in use, and that care is needed in placing the fingertips correctly. Next, Wright et al. (2000) have tested data entry on various commercial handheld computers by older users; their carefully controlled studies show clearly a major loss in accuracy and speed when entering text via the touch-screen keyboard compared with even a small physical keyboard. Also, younger people were faster but not more accurate than older people at using the touch-screen keyboard. Finally, Blomkvist and Gard (2000) have studied computer use in a range of work situations in cold environments; from among the possibilities they recommend that a pen is used either as a touch pen or simply to press the keyboard keys.

2.2. Output

Compared with the many studies about some aspect of input, there are relatively few about output methods. Most that exist are concerned with whiteboards, or virtual reality, or display design to facilitate web navigation or handling large information stores, etc.; some of these topics will be dealt with separately. From among the few, three interested me and one of these is related to virtual reality.

Since head-mounted displays can be costly, Patrick et al. (2000) compared the development of cognitive awareness in a virtual environment, by the subjects producing a cognitive map, when using a desk-top monitor or a head-mounted display or a large projection screen. The results showed no significant difference in performance between the latter two, and they recommend that a large projection screen can be used as an inexpensive substitute for a head-mounted display.

Next, the most serious ergonomic display problem now must be the very limited size of the small screens on telephone mobile handsets, which are soon to be linked to the web via the Web Application Protocol (WAP). Many more studies will be needed similar to that using the small screen of Personal Digital Assistants (PDAs) by Buyukkokten et al. (2000). They developed a proxy server which linked to the web on behalf of the user's PDA and then processed the output to present it in the most effective way on the limited PDA screen. They report

a gain of 45% in web browsing speed and a reduction of 42% in required pen movements.

Finally, some light has been shed by Mackay (1999) on a source of long-running discord in air traffic control. For years, the computer advocates have been trying to convince management, with varying degrees of success, that the traditional printed flight strips should be removed in favour of on-screen display. Most air traffic controllers have resisted, pointing out how helpful it is to have the physical reality of a token to hand over as each flight progresses, upon which also handwritten notes can so easily and quickly be scribbled. She and her team, after an intensive study, have validated these and other considerations and are convinced that enough is not yet known to allow simple automation of the flight strips. Instead, they offer an alternative which involves retaining the flight strips but turning them into an interface to the computer.

2.3. Workplaces

Again there have been relatively few studies of workplaces in recent years, no doubt in part because designs have stabilised and because the EU Directive on Work with Display Screen Equipment (EEC, 1990) and the similar International Standard (ISO, 1995) have gradually had the necessary effect. However, there is still useful work to be done.

Cook and Kothiyal (1998) found a significant effect on muscular activity of the position of the mouse and mousepad, and recommend that working posture is improved by the removal of the numeric keypad from the right end of the keyboard. Bauer and Wittig (1998) similarly measured muscular activity and subjective preferences in 11 different positions of screen and copy holder; they recommend positions where the visual axis is horizontal or slightly downward and the copy holder aligned parallel with the screen surface and beside it.

Karlqvist (1998) did a model study of the process for developing, specifying and evaluating VDU work tables. Three different prototype designs derived from the study (all adjustable in height manually, pneumatically or electrically) were evaluated by comfort ratings. The main results were that the work table should enable the arms to be supported, should be adjustable to enable change between sitting and standing posture, and should prevent extreme outward rotation of the shoulder.

Finally, Aarås et al. (1998) made a comprehensive study, with experimental and control groups, of the effect of ergonomic interventions to improve the situation for VDU operators. Significant reductions in various health measures were found and are detailed, including a significant reduction of shoulder pain for both intervention groups two years after the intervention. This is an important study which bears detailed reading, because it is one of the most thorough and properly controlled, and because it proves the benefit of ergonomic attention actually to implement the EEC and ISO recommendations.

3. The web and 'E-topics'

3.1. Web site usability and navigation

Since general-access web pages became public there have been complaints of many bad designs and poor usability. Considerable HCI work has been done, and the best general design guidebook so far is that by Spool et al. (1998).

The overwhelming wealth of information on the web has, of course, led to studies of ways to aid the user. Navigation is one of the biggest problems for users. Berkun (1999) describes the development of the 'Explorer Bar' (a window which can occupy about $\frac{2}{5}$ of screen width on the left of the Internet Explorer screen) and summarises its usability testing. Robertson et al. (1998) and Czerwinski et al. (1999), both also from Microsoft, describe and give test results showing advantage for their proposed three-dimensional array of thumbnail images of web pages to support spatial location memory.

One of the common aids is the 'bookmark' or 'favourite' by which one can keep a list of sites to which one may wish to return. However, a serial list, even if partially sorted, is not very helpful; so Abrams et al. (1998) surveyed over 300 web users and analysed the bookmark archives of 50, from which they make recommendations for improving the organisation, visualisation, representation and integration of bookmarks. Two other studies developed programs to aid the user and both give data showing large improvements. Fang and Salvendy (2000) devised a keyword comparison procedure by which the software analyses all relevant homepages, retrieved since the search began, and displays a list of keywords ranked by their frequencies in terms of homepages in descending order; from this the user can select keywords to add to the search, and they report 77% increase in number of relevant web sites identified in one hour. Chen and Dumais (2000) used a text classification algorithm automatically to classify search results into an existing category structure and to present them in a category interface; they report 50% speed increase in finding information.

Finally, Hodkinson et al. (2000) have devised a diagrammatic method to represent web search behaviour; this, they consider, should help researchers better to interpret web search data and search styles, and thus assist in training web users to improve their search effectiveness. By contrast, in a preliminary practical study, Drori (2000) found a significant increase in satisfaction, though no difference in search times, when the results of searches in textual databases are not presented with the document title or the title with the first few lines of

text but with the title plus the first three lines from the segment in the document that matches the search criteria.

3.2. E-commerce and E-shopping

With the very rapid growth of technology and uptake by commerce and retailing, it is pleasing to see that work on usability and HCI aspects began quickly. Some of the first substantial work was done on the design of information and shopping kiosks. Martin et al. (1999) evaluated a PhotoKiosk and a Shopping Kiosk; the former was developed through three successive prototypes and was largely successful, but the latter had no usability design and the evaluation results were decidedly negative. Christian and Avery (2000) designed and tried two different types of intelligent kiosk; their findings were that people are attracted by an animated face, that colour is crucial, that speaker independent speech recognition is far too imperfect and that the quality of the information content is vital (all of which had already been found in European studies). A full set of guidelines on kiosk design and use have already been published by Maguire (1999).

Turning to on-line commerce and shopping, Stolze (1999) has studied support mechanisms for product selection such as catalogues, and aids to visualisation and filtering. Wolf et al. (1999) emphasise the importance of the quality of customer care, and point out that it needs different methods from the requirements for work group collaboration because of differences in users, tasks, goals and context of use. The importance of quality of service is also emphasised by Bouch et al. (2000).

Providing a satisfying buyer experience is a key competitive element in electronic commerce. Instead of a catalogue search followed by interactive purchase, Pu and Faltings (2000) have produced a combined system (SmartClient); in the difficult task of 'buying' a multi-sector flight selection and reservation, their test subjects all found that it enabled overview of a much larger range of possible solutions than did a commercial travel system. Ensuring that customers revisit cyberstores is also the focus of Lee et al. (2000); they propose a multi-phased model of customer loyalty, and based on an analysis of customer survey data with this model they suggest implications for managers in developing internet stores. In another study, some of the same team (Kim and Yoo, 2000) have tried various combinations of links in navigation patterns as customers browse a cyberstore and recommend some practical contributions to the link structure of cyber malls.

Finally, from a survey of various internet shopping sites Miles and Howes (2000) point out the many different approaches to supporting buyer and seller goals using the internet. From their review and analysis of possibilities, they then propose a framework for understanding e-commerce technologies and the human factors issues.

4. Web-related aspects

4.1. Growth of net use and overcoming anxiety

Amid the hype which still tends to provide a halo for anything to do with the internet, it is important to keep feet on the ground by good data from factual studies. Kraut et al. (1998) gathered longitudinal data from 229 people in 110 households during their first year on the internet. They found that interpersonal communication was a stronger driver of internet use than information and entertainment applications. With the timescale for CHI conferences this study must actually have been done in about May 1996–1997. As other studies noted in this paper show, use of the internet for a wide range of activities is growing very fast. Nevertheless, these (Kraut et al., 1998) results may well still be typical for many households as they first start to use the internet.

In contrast with the home, Anandarajan et al. (2000) studied what antecedent factors were related to internet use in industry. They found that neither age nor gender nor any of the organisational variable were important antecedents. Those who perceived the internet as intimidating used the net less; perceived usefulness was the factor related to increased time of use and internet impacts. Overcoming internet anxiety among teacher trainees was studied by Wilson (1999a); from trials of therapeutic factors he gives 10 recommendations for assisting computerphobics to redress their anxiety imbalance.

4.2. Distance learning

With the growing need for economy in all educational services, it is a surprise not to come across more studies about distance learning. However, as Söderberg (2000) says, the challenge lies in producing competence for the individual student through good teaching while at the same time using technical solutions to create added value via the net.

Gnisci et al. (2000) conducted a virtual classroom experiment with real users to test two multimedia configurations with different levels of interactivity. No differences were found between the two systems for usability and socio-relational factors, but the surprising result was that learning performance increased in the less interactive configuration.

The other studies were all in a special journal number edited by Ivergård and Berns (2000). All papers are relevant but only two will be mentioned here; both are concerned with the provision of learning materials and success for people at work. Paulsson and Sundin (2000) studied what factors influence the possibility of integrating web-based distance learning into the work situation and the reactions of employees to various possibilities.

Mulholland et al. (2000) developed a 'document enrichment' approach to assist with the organisational learning process while minimising the increase in cost. This approach was tried in three different industrial settings and was successful but revealed the need for careful analysis and some revision and development of the key documents in the organisation.

4.3. Electronic publishing

Although there was considerable work in the 1980s and early 1990s (see Section 7.3 of Shackel, 1997, for a review), there has been hardly any research in the last few years. The rapid growth in use of the web has led to improvements in hardware and especially in software. There is no doubt that in time the shortcomings in technology will disappear, even the fact that an adequate size screen equivalent to two A4 pages side by side is as yet too costly. But there are still many issues to be solved, such as defence of copyright by publishers, preservation of authentication quality despite new procedures, agreed new archiving methods, and guaranteed preservation and readability of archived material when both hardware and software have changed in, say, 20 years time (let alone 200 years).

Just four studies have interest. In the fullest one, Sumner and Shum (1998) explore how "new forms of document interface can be used to support new forms of scholarly discourse". In essence they place a contents list menu of a document, e.g. journal paper, in a vertical window to the left, using about $\frac{1}{5}$ to $\frac{1}{4}$ of the screen width; when wanted and when using a large screen, a window about $\frac{2}{5}$ wide is placed on the right of the paper window to contain commentary material, illustrative animations, etc. Chang et al. (1998) support similar needs more simply, by providing facilities in the software to enable pop-up small windows to be inserted containing the extra material or animations, etc., but they did not test their designs. Bétrancourt and Bisseret (1998) did test them in comparison with presenting the pictures either close to the text or in separate areas on the screen, and found that the pop-up window led to higher performances both in speed and in accuracy of information recall. But this was first done by McKnight in 1988 (McKnight et al., 1991), so that when reading a paper one could instantly see in a pop-up window (without obscuring the exact text being read) a table or a figure or the full reference of a referenced item; for the first time in my experience their electronic version of journal articles had several advantages over the paper version.

Finally, in the shortest paper Rho and Gedeon (2000) have also presented journal papers on screen with the contents list menu in a vertical window to the left, using about $\frac{1}{5}$ of the screen width. This they called the two-frame format; it was compared with the common paper-like format using the full screen width (so that the user has to scroll or jump forward and backward through the text) and with paper-like format but with table of contents at the start, and with slides and cascades formats. They ran two surveys, one by email and one via the web; both gave similar results — the two-frame format was preferred by 47%, the paper-like with table of contents was preferred by 35%; the others received little preference and the cascade format of page windows was considered worst by 65% of the respondents.

5. Virtual reality

The paper by Benford et al. (1997) leads directly from the web to virtual reality (VR). From the analogy of the web as cyberspace they demonstrate how it could usefully be accessed via three-dimensional displays; these could represent, for example, a document archive shown as positions in space of icons for the papers (or there could be the thumbnail images of Robertson et al., 1998; Czerwinski et al., 1999) and the links between them. Browsing and navigating should be much easier than with the usual limited browser display of one document at a time, and several users could simultaneously browse the same space, access the same information, and also use web facilities to communicate with each other.

Having been the 'wonder of the age' for a few years in the late 1980s, VR fell out of favour described variously as being only fit for fancy games parlours, really nothing new (for example pilot training simulators had been around for years), suitable only for very expensive applications, or entered only by cheap 'do-it-yourself' methods, which for a time attracted much attention and became like the early days of computer kits for home hobbyists (cf. Hollands, 1996). This has now changed as professional systems have become robust, reliable and cheaper and both research and application have become respectable again.

An authoritative review of virtual reality by Stone (2000) outlines the history, provides evidence of the cost–benefit value of VR, and summarises and illustrates various applications — such as large-scale engineering and design, defence (especially for training), medicine and surgery, retail (e.g. product and supermarket designs), and heritage uses. With regard to ergonomics, he points out that not merely is VR now a proven tool to assist with ergonomics design when this would be cost-effective, but also that ergonomics research is still needed in VR application and commercial VR design needs good ergonomics.

Some of these examples and issues have been dealt with by other authors recently. Some aspects of the use of VR in surgery are discussed by Dubois et al. (1999), in particular augmented reality (AR) which makes use of special headgear, or modified optical instruments (such as microscopes), and superimposes virtual images onto

the user's view of the real world. Training for arthroscopic surgery is discussed and illustrated by Arthur et al. (1999).

Various issues of VR technology, usability, side and after effects and applications are discussed in a special issue of Applied Ergonomics. Wilson (1999b) introduces the subject, and exemplifies usage in the development and evaluation of virtual environments for training and in participatory workplace design. Kalawsky (1999) presents and describes VRUSE, a computerised questionnaire tool for evaluating the usability of VR systems; full details are given and also an example of its application.

Two papers discuss the problem of a tendency to motion sickness in vitual environments (Stanney et al., 1999; Howarth and Finch, 1999). The same topic is studied by Nichols et al. (2000) while also studying the measurement of 'presence' and a partial association is reported between sickness and presence. Finally, usability problems with typical physical VR components are considered by Nichols (1999), and Deol et al. (1999) discuss VR usability problems in general and propose a theory which their tests suggest to have some descriptive and predictive power.

6. Safety-critical systems

Despite the first edited book related to this area by Broadbent et al. (1990), it is only now that attention is being given to the fundamental problems inherent in the general area of safety-critical systems. Of course, these problems are not limited to software, although the name arose in this context, and far too little attention is being given to all aspects despite dramatic accidents such as Three-Mile Island, Herald of Free Enterprise and the Kegworth Air Crash. I suppose it is at least not totally unsatisfactory that I only found one conference session and one journal special number, but this seems rather meagre in view of the anxiety we must all sometimes feel about the great complexity of modern systems and the unknown risks they pose.

Johnson organised a conference session in which his first paper (Johnson, 1997a) shows how formal methods of analysis (which can provide a common language for systems engineering and human factors development) will help to represent the factual and procedural information that must be included in training courses. Palanque et al. (1997) also support the application of formal models and illustrate their approach with an analysis of part of an air traffic control situation. In his second paper Johnson (1997b) describes some of the shortcomings of accident reports and illustrates how mathematical proof techniques could help to clarify the preceding events and their exact relationship to the report findings.

In their introduction to the journal special number Gray et al. (1999) highlight the challenge of analysing, designing and building reliable and usable safety-critical interactive systems. Mackay (1999) describes her team's intensive study of the role of flight strips in air traffic control and shows why controllers are almost all very resistant to proposals to automate them. She proposes an alternative solution which could well resolve the whole problem. Galliers et al. (1999) describe a method to assess the possibility of user interface design contributing to human error. They then propose, and demonstrate by a case study, an impact analysis method by which to run scenarios against a causal model of error; thus they suggest this can help to focus on relevant guidelines for safe user interface design. Fields et al. (1999) also propose a method for comparing and evaluating design options. They suggest that it can help to focus designers' attention on the interactions where problems are likely to occur, and they describe a trial of the method applied to communication design in air traffic control.

Finally, in an amusing but sound article, harking back to the Greek philosophers, Bowen (2000) discusses the ethics of trying to design software for safety-critical systems. He particularly suggests that there are seven deadly sins to avoid when deciding which methods to adopt and pursue as a basic part of the design process : (1) epideictic (used for effect); (2) hyperbole (exaggeration); (3) pistic (too trusting); (4) oligarchic (rule by a few); (5) ephemeral (transitory); (6) epexegesis (additional words); and (7) maiandros (meandering). He then considers various ways, such as the codes of practice of the professional institutions, to try to ensure an ethical approach by software engineers despite being beset by managers focussed primarily upon the business financial goals.

7. From HCI to HSI (human-system integration)

The arrival of the new millenium has of course led to reflections and predictions by many. It is pleasing, in the IEA Congress volume (Brown, 2000), to see some thoughtful papers suggesting changes of emphasis for the future. Ergonomics/human factors has never been unduly restricted in its scope, but the time has come to return to some of the broader perspectives from the past.

Hoc (2000) rightly points out some of the limitations of work in HCI, with its tendency to be restricted to interface design issues. Now information technology is involved in managing more and more complex and coupled systems. These dynamic situations are not fully controlled and are affected by unpredictable factors. To handle this new complexity and uncertainty the human and the machine must be able to work in cooperation. A new approach is needed to understand and design for these new, highly dynamic, human-–machine relationships.

Rasmussen (2000) argues similarly that human factors contributions must now be based on models of adaptive

human behaviour in complex, dynamic systems. He then emphasises, from his experience in research on industrial risk management and decision support, that it is now a major problem to establish conditions for cross-disciplinary research oriented toward the behaviour of complex socio-technical systems. He suggests that the problem has two sources — the very dynamism of societal systems and the constraints of the academic research environment — and he explains and discusses these in some detail. Finally, he suggests the need to use a higher level of representation as the basis for addressing both research and design problems of dynamic human-system situations — Cognitive Systems Engineering (Rasmussen et al., 1994).

Moray (2000) also argues for change and development in ergonomics. To help solve the many serious global problems, ergonomics needs to be open to new disciplines, particularly those in the social sciences. Also, it may be difficult to generalise research on human-centred socio-technical design without taking into account national characteristics, economics and political constraints. Currently, he says, there is more interest than ever in what ergonomics has to offer, but to deliver its promise will require a much broader approach than hitherto.

From the above, and as also discussed in Section 8.3 at the end of this paper, it seems that the time is ripe for a major change in emphasis. The focus, which has satisfactorily been on human–computer interaction for over 20 years, now needs to broaden out and deal with the human(s) in the context of the whole system and with a combined user and system orientation. So we need a name change to provide a stimulus and reminder that we must now enlarge from HCI to human-system integration (HSI) or system-human integration (SHI) or user-system integration (USI).

8. Future possibilities and issues?

From the various themes and topics discussed above, three seem likely to lead to substantial changes in the ways in which people interact with computers and, consequently, in the type and the extent of research and application of human sciences knowledge and methods. As with any attempt to guess the future, these suggestions are fallible.

8.1. Web consequences?

Clearly, we are only at the very beginning of the revolution in commerce, in industry, in shopping, in work methods and location, and in publishing that may well come about with another generation of Internet users and of usage experience. What started as an academic curiosity and a first linking, then grew prolific with military funding, changed to a service for the entire higher academic community (UK JANET from 1984 and US NSFNET from 1985), and finally, from 1995, became a privatised service for which users pay the network cost, usually via the telephone bill (Leiner et al., 1997). However, it was the invention of the World-Wide Web concept (Berners-Lee et al., 1994) and connectivity, followed closely by the development of browser software much easier to use than previous programs (MOSAIC, NETSCAPE and Internet Explorer), which has led to the dramatic growth in a mere five years. So how much will inevitably change in the next 50 years, with child users growing up with the web?

8.1.1. Cyber shopping

Nevertheless, there are many HCI problems to be solved. The work on various aspects has already been noted. Cyber shopping will not become widespread until screen design, system speed and content structure have been improved; a quick survey by Scott (2000), Insley (2000) and Mathiason (2000) for The Observer of four supermarket web sites (Sainsbury, Asda, Tesco and Iceland) criticised all except Tesco for shortcomings on some of the above points and also, in some cases, for delay in delivering the ordered goods. Above all, user confidence must be built by mastering the virus problem (Bissett and Shipton, 2000) and by overcoming internet credit card fraud. However, mankind has a long history of seeing and feeling the goods before purchase, so it may be quite some time before supermarkets become solely cybermarkets.

8.1.2. Changes in work and society

It is even more difficult to foresee exactly how work and society will change, though they will change. Some possibilities and issues for the 'next generation office systems' were discussed in one session at INTERACT'99 (Edwards and LaMarca, 1999; Mynatt, 1999; Girgensohn et al., 1999; Adams and Sasse, 1999). But on the much wider work and societal questions, only Bradley (2000) and Ivergård (2000) have made a first essay; their ideas are stimulating and should lead into many more studies and debates.

8.1.3. Electronic publishing

The impact on publishing might seem more obvious and many have predicted the demise of the traditional paper book (Press, 2000). But the 500 years since Gutenberg have evolved a very successful technology with all the necessary associated structures such as editors, quality refereeing, referencing methods and archives in libraries. Nevertheless, especially in academia, the growing cost of journals is stretching library budgets to the limit; so the pressure to cut costs somehow will soon be irresistible. One successful approach may be 'on-line print-on-demand' (Maio, 2000). The first stage is to reproduce

existing paper books in electronic form and enable extra sales much more cheaply; this conversion will soon be done at 25,000 books a month using the new Versaware technology (Machlis, 2000). Later new books will be set electronically into standard page and book form but then only sold via print-on-demand. The similar initial approach of parallel publishing for academic journals has already been explored in the SuperJournal project (Eason et al., 2000). With regard to newspapers, however, there is no doubt that present electronic technology cannot match economically the way in which a broadsheet enables rapid eye scanning and selection (Newing, 2000); instead, the industry is already providing supplementary information on proprietary websites (Vernon, 2000).

Finally, much is yet to be done on the specific HCI features needed for all the web users of the future (including older, younger, and handicapped people), for new applications on the web such as virtual reality, and for all the other new modalities (3D graphics, voice, gesture, etc.) of multimedia interaction.

8.2. Embedded ubiquitous computing — back to basic ergonomics?

To introduce this area I cannot do better than quote, with his permission, Naughton (2000):

The PC is an incredibly complex device because it is a general-purpose machine. With the appropriate software you can use it to process words, do numerical calculations, create dazzling graphics, edit video and audio tapes, listen to the radio, play music CDs, send e-mail, browse the Web, chat to other people online, create genealogical charts of your family, build a database of bootleg Elvis recordings and so on ad infinitum. The present-day PC, in other words, is a bit like the domestic electric motors that appeared on the market in the early years of the last century. I have before me as I write a page from the 1918 Sears-Roebuck catalogue. Under the heading 'Aids that Every Woman Appreciates' [sic] it extols the virtues of the 'Home Motor'. With the right attachments, the ad explains, one can use the motor to power a fan, drive a sewing machine, power a portable vibrator ('very useful and satisfactory for home service'), drive a butter churn, whip cream, mix dough, etc.

The electric motor was the ultimate in domestic high-tech in 1918. But spool forward eighty years and look what's happened. Electric motors are everywhere — in wristwatches, in high-fi systems, VCR machines, cameras, fax machines, shavers, toothbrushes — and, yes, even in vibrators. Electric motors have become ubiquitous, miniaturised, highly specialised and, well, invisible. Why? Because in the end people value specialised machines which enable them to do specific jobs, rather than a clumsy generalised machine which, with the right attachments, can do anything.

Much the same will happen to the PC. Most people nowadays buy a PC because they want to send e-mail and browse the Web. But in order to do this they have to acquire an expensive, ludicrously over-powered, general-purpose machine which is extraordinarily difficult to master. What they really need is a simple device they can plug into the phone line, switch on and use to send and receive messages. You have to be a masochist to use a PC.

This theme was developed by Norman (1999) in Chapter 3 of The Invisible Computer, and his book addresses various aspects of embedded computers. He gives examples of possible 'information appliances' in an appendix, and he describes in Chapter 3 three axioms for the design of such appliances: simplicity, versatility and pleasurability.

While these axioms are valid, especially for new design concepts, embedding computers to aid existing task situations can bring additional and new ergonomics problems to be solved. For example, automated call direction through pre-recorded voice plus menus is becoming commonplace, but is by no means widely acceptable (Settle et al., 1999); methods to lessen the dislike and improve performance are recommended by Settle et al. (1999) and by Goldstein et al. (1999). Again, wearable computers are a form of embedded use and Baber et al. (1999) describe a trial of a working prototype wearable computer for paramedics; this showed shortcomings in the current technology and led to a new industrial design concept for a better ergonomic harness solution.

Thus, the more computers (and communications) are embedded into appliances and products, the less relevant will be the specifics of HCI design and the more will design for the user depend upon basic ergonomics principles and practice.

8.3. Not HCI but user-system integration — back to systems ergonomics?

In the early days of ergonomics work for computer systems, the human factors specialist (practitioner or researcher) was typically involved with many aspects of a whole system. So the focus of work was upon system design in the round, upon allocation of function and on the place of the human in the system (see, for example, the books by Sinaiko, 1961; Sackman, 1967; De Greene, 1970; Beishon and Peters, 1976). Interface design (often called 'knobs and dials') was the logical endpoint of design but was fitted in as time allowed. Even where detailed design topics were addressed, the orientation was still from a system viewpoint (e.g. Barmack and Sinaiko, 1966; Jones, 1970). As computing developed, especially with the microcomputer from 1980, the single user came to the fore and both research and application became focused upon the individual human's interaction

with his/her specific computer, usually in an office environment. Interface details became paramount (cf. Shneiderman, 1987). Usability was recognised as the key concept, and was developed from a difficult target to a definable specification to be engineered and evaluated (cf. Shackel, 1981/1984; Bennett, 1984; Bennett et al., 1984; Whiteside et al., 1988; Whitefield et al., 1991; Sweeney et al., 1993; Nielsen, 1993; Jordan et al., 1996).

The huge amount of work on individual HCI has until recently overshadowed work on the group and system aspects. The latter work continued, however (E.g. Damodaran et al., 1980; Mumford, 1983; Hirscheim, 1985; Eason, 1988; Klein and Eason, 1991), and its conceptual approach is gradually gaining ground. Although many design process prescriptions these days include fuller consideration of users, Eason (1988) reflects the broader approach:

many authors … consider that it is not sufficient to provide users with a formal role within a technically dominated design process. Hirscheim (1985), for example, considers that successful system design is primarily an exercise in organisational change and as such user-dominated socio-technical design methods should be employed (p. 28).

In the rest of his book Eason then presents structures and techniques (as developed by the mid-1980s) for a systematic user-centred approach to the application of information technology in organisations.

In his keynote address to INTERACT'99 Gaines (1999) presented a world view of the prospects and possibilities for HCI if those involved are willing to enlarge their vision and their orientation. He indicated how the increasing openness of our societies, stimulated by many factors including the march of information technology, will pose many human and societal problems. Their solution will certainly not come from HCI alone, and HCI workers will need to work on a broader basis with sociology, economics, anthropology, politics, etc., to achieve a larger vision and a new understanding of the complex world systems which are the environment for future users and their machines. Similarly Shackel (1997) drew attention to the need for the focus to move back and outwards to system design issues.

Thus, progress is bringing HCI full circle back to a proper recognition that the system context is crucial. Social and organisational factors will always strongly influence, if not dominate, outcomes; if HCI researchers and practitioners fail to deal with them, or to bring in relevant expertise to do so, then others will have to deal with them and probably at the expense of good HCI. Therefore, much more attention than hitherto must be given to concentrating first and foremost on the wider orientation of the whole system within which the humans are major participants; that is, the focus must move from HCI to user-system integration (USI) or human-system integration (HSI).

With the necessary move back to ergonomics focussed on system design comes as an important change in emphasis. Too often the inclusion of human factors in a design has depended upon the chance availability of a specialist. There is growing awareness of the need to ensure the involvement of user-centred design by structuring the design process to include a complete human factors strategy (Damodaran, 1991). Thus, if at last HCI does grow away from the single user (ec)centricity and returns to the broader issues of system design, then in doing so we need to work even more closely with software design colleagues to build system design methodologies that include human factors strategies and are truly comprehensive.

9. Conclusion

From the overview of recent publications carried out to write this paper, what has impressed me most is the very quantity and diversity of research and application topics being addressed. On the other hand, although this may be a false impression, there appear to be very few groups or teams who are undertaking a coordinated and consistent attack upon a major problem area. It seems possible that the way in which research is funded, and the way in which academic research is assessed under government and similar pressure, tends to promote individual prominence. Similarly, application projects seem to be more narrowly focussed to answer the specific question, with no latitude for related wider study leading to useful publication. This is unlikely to handicap the research into, and development of, more usable web applications or embedded information appliances, but what about larger problem areas? How will groups and teams be assembled to research into user-system integration and to address the ergonomics of major system designs?

No-one would wish to return to the international tensions which led to the ample research funding from military sources to help establish some of the best work on systems ergonomics in the 1960s and 1970s. But the question I leave to my successors is — whence will the size and scope of research teams and the funding needed to support them come from, as user-system integration becomes again one of the prominent areas of human factors research?

References

Aarås, A., Horgen, G., Bjørset, H.-H., Ro, O., Thoresen, M., 1998. Musculoskeletal, visual and psychosocial stress in VDU operators

before and after multidisciplinary ergonomic interventions. Appl. Ergon. 29 (5), 335–354.

Abrams, D., Baecker, R., Chignell, M., 1998. Information archiving with bookmarks: personal web space construction and organization. CHI 98 Conference Proceedings. ACM, New York, pp. 41–48. ISBN 0-201-30987-4.

Adams, A., Sasse, M.A., 1999. Privacy issues in ubiquitous multimedia environments: wake sleeping dogs, or let them lie? Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 214–221. ISBN 0-9673355-0-7.

Anandarajan, M., Simmers, C., Igbaria, M., 2000. An exploratory investigation of the antecedents and impact of internet usage: an individual perspective. Behav. Inform. Tech. 19 (1), 69–85.

Arthur, J.G., McCarthy, A.D., Wynn, H.P., Harley, P.J., Baber, C., 1999. Weak at the knees? Arthroscopic surgery simulation user requirements, capturing the psychological impact of VR innovation through risk-based design. Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 360–366. ISBN 0-9673355-0-7.

Baber, C., Arvanitis, T.N., Haniff, D.J., Buckley, R., 1999. A wearable computer for paramedics: studies in model-based, user-centred and industrial design. Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 126–132. ISBN 0-9673355-0-7.

Baecker, R.M., Grudin, J., Buxton, W.A.S., Greenberg, S., 1995 Readings in Human–Computer Interaction: Toward the Year 2000. Morgan Kaufman, San Francisco. ISBN 1-55860-246-1.

Barmack, J.E., Sinaiko, H.W., 1966. Human Factors in Computer-Generated Graphic Displays, Institute for Defense Analyses: Study 234 Arlington VA, AD 636170.

Bauer, W., Wittig, T., 1998. Influence of screen and copy holder positions on head posture, muscle activity and user judgement. Appl. Ergon. 29 (3), 185–192.

Beishon, J. Peters, G. (Eds.), 1976. Systems Behaviour. Harper & Row (for the Open University), London. ISBN 06-318057-X.

Benford, S., Snowdon, D., Brown, C., Reynard, G., Ingram, R., 1997. The populated web: browsing, searching and inhabiting the WWW using collaborative virtual environments. Human–Computer Interaction INTERACT'97 Proceedings. Chapman & Hall, London, pp. 539–546. ISBN 0-412-80950-8.

Bennett, J.L., 1984. Managing to meet usability requirements: establishing and meeting software development goals. In: Bennett, J.L. et al. (Eds.), (qv) pp. 161–184.

Bennett, J.L., Case, D., Sandelin, J., Smith, M. (Eds.), 1984. Visual Display Terminals: Usability Issues and Health Concerns. Prentice-Hall, Englewood Cliffs, NJ. ISBN 0-13-942482-2.

Bérard, F., 1999. The perceptual window: head motion as a new input stream. Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 238–244. ISBN 0-9673355-0-7.

Berkun, S., 1999. The explorer bar: unifying and improving web navigation. Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 156–162. ISBN 0-9673355-0-7.

Berners-Lee, T., Cailliau, R., Luotonen, A., Nielsen, H.F., Secret, A., 1994. The World Wide Web. Comm. ACM 37 (8), 76–82 (also in Baecker et al., 1995, pp. 907–912).

Bétrancourt, M., Bisseret, A., 1998. Integrating textual and pictorial information via pop-up windows: an experimental study. Behav. Inform. Technol. 17 (5), 263–273.

Bissett, A., Shipton, G., 2000. Some human dimensions of computer virus creation and infection. Int. J. Human–Comput. Stud. 52 (5), 899–913.

Blomkvist, A.-C., Gard, G., 2000. Computer use in cold environments. Appl. Ergon. 31 (3), 239–245.

Bouch, A., Kuchinsky, A., Bhatti, N., 2000. Quality is in the eye of the beholder: meeting users' requirements for internet quality of service. CHI 2000 Conference Proceedings. ACM, New York, pp. 297–304. ISBN 0-201-48563-X.

Bowen, J., 2000. The ethics of safety-critical systems. Comm. ACM 43 (4), 91–97.

Bradley, G., 2000. The information and communication society: how people will live and work in the new millennium. Ergonomics 43 (7), 844–857.

Broadbent, D.E., Reason, J., Baddeley, A., 1990. Human Factors in Hazardous Situations. Clarendon Press, Oxford.

Brown Jr., O., 2000. Editorial to special number on 'Ergonomics for the New Millenium' of plenary papers for XIV Triennial Congress of the International Ergonomics Association 30 July–4 August 2000. Ergonomics 43 (7), 829–832.

Buyukkokten, O., Garcia-Molina, H., Paepcke, A., Winograd, T., 2000. Power browser: efficient web browsing for PDAs. CHI 2000 Conference Proceedings. ACM, New York, pp. 430–437. ISBN 0-201-48563-X.

Chang, B.-W., Mackinlay, J.D., Zellweger, P.T., Igarashi, T., 1998. A Negotiation Architecture for Fluid Documents. UIST'98 Proceedings of the ACM Symposium on User Interface Software and Technology. ACM, New York, pp. 123–132. ISBN 1-58113-034-1.

Chen, H., Dumais, S., 2000. Bringing order to the web: automatically categorizing search results. CHI 2000 Conference Proceedings. ACM, New York, pp. 145–152. ISBN 0-201-48563-X.

Christian, A.D., Avery, B.L., 2000. Speak out and annoy someone: experiences with intelligent kiosks. CHI 2000 Conference Proceedings. ACM, New York, pp. 313–320. ISBN 0-201-48563-X.

Cook, C.J., Kothiyal, K., 1998. Influence of mouse position on muscular activity in the neck, shoulder and arm in computer users. Appl. Ergon. 29 (6), 439–443.

Czerwinski, M.P., van Dantzich, M., Robertson, G., Hoffman, H., 1999. The contribution of thumbnail image, mouse-over text and spatial location memory to web page retrieval in 3d. Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 163–170. ISBN 0-9673355-0-7.

Damodaran, L., 1991. Towards a human factors strategy for information technology systems. In: Shackel, B., Richardson, S.J. (Eds.), Human Factors for Informatics Usability. Cambridge University Press, Cambridge, pp. 291–324. ISBN 0-521-36570-8.

Damodaran, L., Simpson, A., Wilson, P., 1980. Designing Systems for People. NCC Publications, National Computing Centre, Manchester. ISBN 0-85012-242-2.

Dennerlein, J.T., Martin, D.B., Hasser, C., 2000. Force-feedback improves performance for steering and combined steering-targeting tasks. CHI 2000 Conference Proceedings. ACM, New York, pp. 423–429. ISBN 0-201-48563-X.

Deol, K.K., Sutcliffe, A.G., Maiden, N.A.M., 1999. Towards a better understanding of usability problems with virtual environments. Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 527–535. ISBN 0-9673355-0-7.

Drori, O., 2000. Displaying search results in textual databases. ACM SIGCHI Bull. 32.1, 73–77.

Dubois, E., Nigay, L., Troccaz, J., Chavanon, O., Carrat, L., 1999. Classification space for augmented surgery, an augmented reality case study. Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 353–359. ISBN 0-9673355-0-7.

Eason, K.D., 1988. Information Technology and Organisational Change. Taylor & Francis, London. ISBN 0-85066-388-1.

Eason, K.D., Yu, L., Harker, S.D.P., 2000. The use and usefulness of functions in electronic journals: the experience of the Super Journal Project. Program 34 (1), 1–28. ISSN 0033 0337.

Edwards, W.K., LaMarca, A., 1999. Balancing generality and specificity in document management systems. Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 187–195. ISBN 0-9673355-0-7.

EEC, 1990. Directive on minimum safety and health requirements for work with display screen equipment. European Union, 90/270/EEC.

Engelbart, D.C., 1963. A conceptual framework for the augmentation of man's intellect. In: Howerton, P., Weeks, D. (Eds.), Vistas in Information Handling, Vol. 1. Spartan Books, Washington, DC, pp. 1–29.

Engelbart, D., English, W.K., 1968. A research center for augmenting human intellect. AFIPS Conf. Proc. 33, 395–410.

Fang, X., Salvendy, G., 2000. Keyword comparison: a user-centered feature for improving web search tools. Int. J. Human–Comput. Stud. 52 (5), 915–931.

Fields, R., Paternò, F., Santoro, C., Tahmassebi, S., 1999. Comparing design options for allocating communication media in cooperative safety-critical contexts: a method and a case study. ACM Trans. Comput. –Human Interact. 6 (4), 370–398.

Forsberg, A., Dieterich, M., Zeleznik, R., 1998. The music notepad. UIST'98 Proceedings of the ACM Symposium on User Interface Software and Technology. ACM, New York, pp. 203–210. ISBN 1-58113-034-1.

Fröhlich, B., Plate, J., 2000. The cubic mouse: a new device for three-dimensional input. CHI 2000 Conference Proceedings. ACM, New York, pp. 526–531. ISBN 0-201-48563-X.

Gaines, B.R., 1999. HCI in the next millenium: supporting the world mind. Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 18–30. ISBN 0-9673355-0-7.

Galliers, J., Sutcliffe, A., Minocha, S., 1999. An impact analysis method for safety-critical interface design. ACM Trans. Comput. –Human Interact. 6 (4), 341–369.

Geissler, J., Gauler, M., Streitz, N.A., 1999. Evaluating Gedrics: usability of a pen-centric interface. Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 222–230. ISBN 0-9673355-0-7.

Girgensohn, A., Boreczky, J., Wilcox, L., Foote, J., 1999. Facilitating video access by visualising automatic analysis. Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 205–213. ISBN 0-9673355-0-7.

Gnisci, A., Papa, F., Spedaletti, S., 2000. Usability aspects, socio-relational context and learning performance in the virtual classroom: a laboratory experiment. Behav. Inform. Technol. 18 (6), 431–443.

Goldstein, M., Bretan, I., Sallnäs, E.-L., Björk, H., 1999. Navigational abilities in audial voice-controlled dialogue structures. Behav. Inform. Technol. 18 (2), 83–95.

Golightly, D., Hone, K.S., Ritter, F.E., 1999. Speech interaction can support problem solving. Human–computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 149–155. ISBN 0-9673355-0-7.

Gray, W., Palanque, P., Paternò, F., 1999. Introduction to special issue on interface issues and designs for safety-critical interactive systems: when there is no room for user error. ACM Trans. Comput. –Human Interact. 6 (4), 309–310.

De Greene, K.B. (Ed.), 1970. Systems Psychology. McGraw-Hill, New York.

Halverson, C.A., Horn, D.B., Karat, C.M., Karat, J., 1999. The beauty of errors: patterns of error correction in desktop speech systems. Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 133–140. ISBN 0-9673355-0-7.

Hinckley, K., Czerwinski, M., Sinclair, M., 1998. Interaction and modeling techniques for desktop two-handed input. UIST'98 Proceedings of the ACM Symposium on User Interface Software and Technology. ACM, New York, pp. 49–58. ISBN 1-58113-034-1.

Hirscheim, R., 1985. Office Automation: A Social and Organisational Perspective. Wiley, Chichester.

Hoc, J.-M., 2000. From human–machine interaction to human–machine cooperation. Ergonomics 43 (7), 833–843.

Hodkinson, C., Kiel, G., McColl-Kennedy, J.R., 2000. Consumer web search behaviour: diagrammatic illustration of wayfinding on the web. Int. J. Human–Comput. Stud. 52 (5), 805–830.

Hollands, R., 1996. The Virtual Reality Homebrewer's Handbook. Wiley, Chichester. ISBN 0-471-95871-9.

Howarth, P.A., Finch, M., 1999. The nauseogenicity of two methods of navigating within a virtual environment. Appl. Ergon. 30 (1), 39–45.

Insley, J., 2000. Best thing about ASDA was the delivery man. The Observer, Cash section, 11 June, pp. 18–19.

ISO, 1995. ISO 9241 Ergonomics requirements for office work with visual display terminals; Part 5 Workstation layout and postural requirements. Geneva, International Standards Organisation.

Ivergård, T., 2000. An ergonomics approach for work in the next millenium in an IT world. Behav. Inform. Technol. 19 (2), 139–148.

Ivergård, T., Berns, T., 2000. Guest editorial for special issue on information technology and learning. Behav. Inform. Technol. 19 (3), 151–152.

Johnson, C., 1997a. Beyond belief: representing knowledge requirements for the operation of safety-critical interfaces. Human–Computer Interaction INTERACT'97 Proceedings. Chapman & Hall, London, pp. 315–322. ISBN 0-412-80950-8.

Johnson, C., 1997b. Reasoning about human error and system failure for accident analysis. Human–Computer Interaction INTERACT'97 Proceedings. Chapman & Hall, London, pp. 331–338. ISBN 0-412-80950-8.

Jones, J.C., 1970. Design Methods. Wiley, Chichester. ISBN 0-471-44790-0.

Jordan, P.W., Thomas, B., Weerdmeester, B.A., McClelland, I.L. 1996. Usability Evaluation in Industry. Taylor & Francis, London. ISBN 0-7484-0460-0.

Kalawsky, R.S., 1999. VRUSE — a computerised diagnostic tool: for usability evaluation of virtual/synthetic environment systems. Appl. Ergon. 30 (1), 11–25.

Karlqvist, L., 1998. A process for the development, specification and evaluation of VDU work tables. Appl. Ergon. 29 (6), 423–432.

Kim, J., Yoo, B., 2000. Toward the optimal link structure of the cyber shopping mall. Int. J. Human–Comput. Stud. 52 (3), 531–551.

Klein, L., Eason, K.D., 1991. Putting Social Science to Work. Cambridge University Press, Cambridge. ISBN 0-521-37242-9.

Kraut, R., Mukhopadhyay, T., Szczypula, J., Kiesler, S., Scherlis, W., 1998. Communication and information: alternative uses of the internet in households. CHI 98 Conference Proceedings. ACM, New York, pp. 368–375. ISBN 0-201-30987-4.

Lee, J., Kim, J., Moon, J.Y., 2000. What makes internet users visit cyber stores again? Key design factors for customer loyalty. CHI 2000 Conference Proceedings. ACM, New York, pp. 305–312. ISBN 0-201-48563-X.

Leiner, B.M., Cerf, V.G., Clark, D.D., Kahn, R.E., Kleinrock, L., Lynch, D.C., Postel, J., Roberts, L.G., Wolff, S.S., 1997. The past and future history of the Internet. Comm. ACM 40 (2), 102–108. (Also at http://info.isoc.org/internet-history/.)

Machlis, A., 2000. How electronic publishing is 'reinventing Gutenberg'. Financial Times Survey Monthly Supplement on Information Technology, 7 June, p. xv. (Also at http://www.ft.com/ftit/.)

Mackay, W.E., 1999. Is paper safer? The role of flight strips in air traffic control. ACM Trans. Comput. –Human Interact. 6 (4), 311–340.

Maguire, M.C., 1999. A review of user-interface design guidelines for public information kiosk systems. Int. J. Human–Comput. Stud. 50 (3), 263–286.

di Maio, P., 2000. Print costs fall in radical new business models. Financial Times Survey Monthly Supplement on Information Technology, 7 June, p. xv. (Also at http://www.ft.com/ftit/.)

Martin, D., O'Neill, J., Varey, R., Wastell, D., 1999. Pushing all the right buttons: lessons from two case studies of touch-screen kiosks. Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 62–69. ISBN 0-9673355-0-7.

Mathiason, N., 2000. Nothing wrong with my cookies but where's the fresh veg.? The Observer, Cash section, 11 June, pp. 18–19.

McKnight, C., Dillon, A., Richardson, J., 1991. Hypertext in Context. Cambridge University Press, Cambridge. ISBN 0-521-37488-X.

Miles, G.E., Howes, A., 2000. A framework for understanding human factors in web-based electronic commerce. Int. J. Human–Comput. Stud. 52 (10), 131–163.

Moran, T.P., van Melle, W., Chiu, P., 1998. Spatial interpretation of domain objects integrated into a freeform electronic whiteboard. UIST'98 Proceedings of the ACM Symposium on User Interface Software and Technology, ACM, New York, pp. 175–184. ISBN 1-58113-034-1.

Moray, N., 2000. Culture, politics and ergonomics. Ergonomics 43 (7), 858–868.

Mulholland, P., Zdrahal, Z., Domingue, J., Hatala, M., 2000. Integrating working and learning: a document enrichment approach. Behav. Inform. Technol. 19 (3), 171–180.

Mumford, E., 1983. Designing Human Systems for New Technology: The ETHICS Method. Manchester Business School, UK. ISBN 0-903-808-285.

Myers, B.A., 1996 A brief history of human–computer interaction technology. Carnegie Mellon University School of Computer Science Technical Report CMU-CS-96-163, also available at http://www.cs.cmu.edu/ ~ amulet/papers/uihistory.ps, and ACM Interact. 1998, 5 (2), 44–54.

Mynatt, E.D., 1999. The writing on the wall. Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 196–204.ISBN 0-9673355-0-7.

Naughton, J.J., 2000. Cheer up Bill, the PC is on its way out anyway. The Observer, Business section, 11 June p. 8. (Also available from j.j.naughton@open.ac.uk - the Observer's Internet columnist.)

Newing, R., 2000. For now, the familiar printed page looks hard to beat. Financial Times Survey Monthly Supplement on Information Technology, 7 June, p. vi. (Also at http://www.ft.com/ftit/.)

Nichols, S., 1999. Physical ergonomics of virtual environment use. Appl. Ergon. 30 (1), 79–90.

Nichols, S., Haldane, C., Wilson, J.R., 2000. Measurement of presence and its consequences in virtual environments. Int. J. Human–Comput. Stud. 52 (3), 471–491.

Nielsen, J., 1993. Usability Engineering. Academic Press, New York. ISBN 0-12-518405-0.

Norman, D.A., 1999. The Invisible Computer. MIT Press, Cambridge, MA. ISBN 0-262-14065-9.

Oakley, I., McGee, M.R., Brewster, S., Gray, P., 2000. Putting the feel in 'look and feel'. CHI 2000 Conference Proceedings. ACM, New York, pp. 415–422. ISBN 0-201-48563-X.

Palanque, P., Bastide, R., Paternò, F., 1997. Formal specification as a tool for objective assessment of safety-critical interactive systems. Human–Computer Interaction INTERACT'97 Proceedings. Chapman & Hall, London, pp. 323–330. ISBN 0-412-80950-8.

Patrick, E., Cosgrove, D., Slavkovic, A., Rode, J.A., Verratti, T, Chiselko, G., 2000. Using a large projection screen as an alternative to head-mounted displays for virtual environments. CHI 2000 Conference Proceedings. ACM, New York, pp. 478–485. ISBN 0-201-48563-X.

Paulsson, K., Sundin, L., 2000. Learning at work — a combination of experience-based learning and theoretical education. Behav. Inform. Technol. 19.3, 181–188.

Press, L., 2000. From P-books to E-books. Comm. ACM 43 (5), 17–21.

Pu, P., Faltings, B., 2000. Enriching buyers' experiences: the SmartClient approach. CHI 2000 Conference Proceedings. ACM New York, pp. 289–296ISBN 0-201-48563-X.

Rasmussen, J., 2000. Human factors in a dynamic information society: where are we heading?. Ergonomics 43 (7), 869–879.

Rasmussen, J., Pejtersen, A.M., Goodstein, L.P., 1994. Cognitive Systems Engineering. Wiley, New York.

Rho, Y., Gedeon, T.D., 2000. Reading patterns and formats of academic articles on the web. ACM SIGCHI Bull. 32 (1), 367–371.

Robertson, G., Czerwinski, M., Larson, K., Robbins, D.C., Thiel, D., van Dantzich, M. 1998. Data mountain: using spatial memory for document management. UIST'98 Proceedings of the ACM Symposium on User Interface Software and Technology. ACM, New York, pp. 153–162. ISBN 1-58113-034-1.

Sackman, H., 1967. Computers, System Science, and Evolving Society: The Challenge of Man-Machine Digital Systems. Wiley, New York.

Salvucci, D.D., Anderson, J.R., 2000. Intelligent gaze-added interfaces. CHI 2000 Conference Proceedings. ACM, New York, pp. 273–280. ISBN 0-201-48563-X.

Scott, M., 2000. Will net shopping send you bananas? The Observer, Cash section, 11 June, pp. 18–19.

Settle, R.B., Dillon, T.W., Alreck, P.L., 1999. Acceptance of the phone-based interface for automated call direction. Behav. Inform. Technol. 18 (2), 97–107.

Shackel, B., 1969. Man-computer interaction: the contribution of the human sciences. Ergonomics 12, 485–499.

Shackel, B., 1981. The concept of usability. Proceedings of the IBM Software and Information Usability Symposium, Poughkeepsie, NY, 15–18 September 1981, pp. 1–30, Poughkeepsie NY, IBM Corporation.

Shackel, B., 1984. The concept of usability. In: Bennett, J.L., et al. (Eds.), Visual Display Terminals: Usability Issues and Health Concerns. Prentice-Hall, Englewood Cliffs, NJ, pp. 45–88. ISBN 0-13-942482-2.

Shackel, B., 1997. Human–computer interaction — Whence and Whither? J. Am. Soc. Inform. Sci. 48 (11), 970–986. (Please email the author for an electronic copy.)

Shneiderman, B., 1987 Designing the User Interface. Addison-Wesley, Reading, MA. ISBN 0-201-16505-8.

Sibert, L.E., Jacob, R.J.K., 2000. Evaluation of eye gaze interaction. CHI 2000 Conference Proceedings. ACM, New York, pp. 281–288. ISBN 0-201-48563-X.

Sinaiko, H.W. (Ed.) 1961. Selected Papers on Human Factors in the Design and Use of Control Systems. Dover Publications, New York.

Sinclair, M.A., 1992. Human factors, design for manufacturability, and the computer-integrated enterprise. In: Helander, M. (Ed.), Human Factors and Design for Manufacturability, Taylor & Francis, London (Chapter 8).

Söderberg, U., 2000. Competence via the web. Behav. Inform. Technol. 19 (3), 229–232.

Spool, J.M., Scanlon, T., Schroeder, W., Snyder, C., De Angelo, T., 1998. Web Site Usability: A Designer's Guide. Morgan Kaufmann, San Francisco. ISBN 1-55860-569-X.

Stanney, K.M., Kennedy, R.S., Drexler, J.M., Harm, D.L., 1999. Motion sickness and proprioceptive aftereffects following virtual environment exposure. Appl. Ergon. 30 (1), 27–38.

Stolze, M., 1999. Comparative study of analytical product selection support mechanisms. Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 45–53. ISBN 0-9673355-0-7.

Stone, R.J., 2000. Virtual Reality. Virtual and synthetic environments: technologies and applications. In: Karkowski, W. (Ed.), International Encyclopaedia of Ergonomics and Human Factors. Taylor & Francis, London, to be published.

Sugiura, A., Koseki, Y., 1998. A user interface using fingerprint recognition – holding commands and data objects on fingers. UIST'98 Proceedings of the ACM Symposium on User Interface Software and Technology. ACM, New York, pp. 71–79. ISBN 1-58113-034-1.

Sumner, T., Shum, S.B., 1998. From documents to discourse: shifting conceptions of scholarly publishing. CHI 98 Conference Proceedings. ACM, New York, pp. 95–102. ISBN 0-201-30987-4.

Sweeney, M., Maguire, M.C., Shackel, B., 1993. Evaluating user-computer interaction: a framework. Int. J. Man–Mach. Stud. 38, 689–711.

Tanriverdi, V., Jacob, R.J.K., 2000. Interacting with eye movements in virtual environments. CHI 2000 Conference Proceedings. ACM, New York, pp. 265–272. ISBN 0-201-48563-X.

Velichkovsky, B., Sprenger, A., Unema, P., 1997. Towards gaze-mediated interaction: collecting solutions of the "Midas touch problem". Human–Computer Interaction INTERACT'97 Proceedings. Chapman & Hall, London, pp. 509–516. ISBN 0-412-80950-8.

Vernon, M., 2000. More online news services complement printed page. Financial Times Survey Monthly Supplement on Information Technology, 7 June, p. xv. (Also at http://www.ft.com/ftit/.)

Vertegaal, R., 1999. Designing awareness with attention-based groupware. Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 245–255. ISBN 0-9673355-0-7.

Whitefield, A., Wilson, F., Dowell, J., 1991. A framework for human factors evaluation. Behav. Inform. Technol. 10 (1), 65–79.

Whiteside, J., Bennett, J.L., Holtzblatt, K., 1988. Usability engineering: our experience and evolution. In: Helander, M. (Ed.), Handbook of Human–Computer Interaction. North-Holland, Amsterdam, pp. 791–817. ISBN 0-444-70536-8.

Wilson, B., 1999a. Redressing the anxiety imbalance: computerphobia and educators. Behav. Inform. Technol. 18 (6), 445–454.

Wilson, J.R., 1999b. Virtual environments applications and applied ergonomics. Appl. Ergon. 30 (1), 3–9.

Wolf, C.G., Lee, A., Touma, M., Daijavad, S., 1999. A case study in the development of collaborative customer care: concept and solution. Human–Computer Interaction INTERACT'99 Proceedings. IOS Press, Amsterdam, pp. 54–61. ISBN 0-9673355-0-7.

Wright, P., Bartram, C., Rogers, N., Emslie, H., Evans, J., Wilson, B., Belt, S., 2000. Text entry on handheld computers by older users. Ergonomics 43 (6), 702–716.

Zhai, S., Smith, B.A., Selker, T., 1997. Improving browsing performance: a study of four input devices for scrolling and pointing tasks. Human–Computer Interaction INTERACT'97 Proceedings. Chapman & Hall, London, pp. 286–293. ISBN 0-412-80950-8.