SESSION XI

COMPUTER SYSTEMS FOR THE VISUALLY IMPAIRED

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Computer use by the visually impaired

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Several recent developments have made computers accessible to the blind and partially sighted: hard-copy (paper) and softcopy (raised-pin) braille output, magnified high-resolution characters, and synthetic speech. We report survey data on these users' computer education, tasks, and goals; their hardware uses and preferences, particularly for special-purpose I/O devices; and seven classes of human-factors problems that affect the use of these I/O devices by the visually impaired.

In this paper, we present the results of a survey of visually impaired computer users. First, we characterize these computer users in terms of their personal and computer backgrounds. Second, we describe their experiences in learning to use computers. Third, we discuss their hardware uses and preferences, particularly for special-purpose I/O devices. And, finally, we report on their opinions about the nonoptimal computer products available for their use, in terms of seven classes of human-factors criteria.

The other papers presented in this section detail some aspects of each of these topics. DiLorenzo and Arditì (1987) describe a laboratory study on the learning of computer-related skills by visually impaired people. Lambert (1987) discusses the incompatibilities among commercially available hardware and software developed for blind computer users. Finally, on a more optimistic note, Foulke (1987) describes a new solution for some of these computer problems.

Let us start by considering some biographical information for our sample of 14 visually impaired computer

users. They ranged in age from 19 to 55, and 5 were female. Ten of the 14 were members of the New York Blind Computer Users Club, and the other 4 were recruited by some of our friends. All participants were volunteers, and \$5 was donated on behalf of each one to the New York chapter of the National Federation of the Blind.

Figure 1A shows the frequency distribution of participants having various amounts of vision. Five were totally blind, 2 had light perception, and another 4 had gross object perception. The last 3, although legally blind, could discriminate some amount of pattern with the use of special optical devices. Figure 1B shows that about one third were born without vision, about one third lost their vision during their childhood or teenage years because of diseases or accidents, and about one third lost their vision as adults, mostly because of diabetes-related problems. Figure 1C indicates that the sample was highly educated, with 13 of the 14 having completed bachelor's or more advanced degrees, or being in the process of doing so. Figure 1D shows their career fields. Although participants were not recruited from psychology departments, 5 are in mental health fields, generally clinical or counseling psychology or social work. Another 5 work with computers, 4 as programmers or engineers and 1 as a word processor. Ten of the participants use computers in connection with their work. In this context, the literature suggests that the larger companies have recently discovered that blind people can become excellent computer programmers and operators (Dooley, 1978; Filpus, 1980). For example, Manufacturers Hanover Trust Company has

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Figure 1. Frequency distributions of biographical information on the participants in the computer-users' survey.

been training its blind employees in special computer courses for several years.

Figure 2 shows some information on the computer use and background of our participants. Figure 2A shows a roughly uniform distribution of user experience: relatively new users with 2 years or less experience; users of moderate experience (3–4 years); and sophisticated users (5–6 years experience). The distribution of ages, education, careers, and computer experience for this sample is fairly close to that for a sample of sighted computer users surveyed by the first author a few years ago (Aaronson, 1982). We will make some comparisons between the two samples' computer experiences later on.

Figure 2B shows the major focus of the sample's computer use. On the average, the participants use computers over 40 h/month for their work, about 25 h/month for personal tasks, and about 15 h/month for school. In this context, the literature shows that some colleges now have special computer equipment and special courses for visually impaired students ("Computerized Braille," 1978; Ryan & Bedi, 1978). For example, at New York University (NYU) the computer center staff is familiar with the braille and visual-enlargement terminals, and provides individualized tutorials for new visually impaired users. Baruch College of the City University of New York has an entire computer center for visually impaired users, a wealth of special-purpose equipment, formal courses, and a very generous staff that is helpful to users throughout the greater New York area.

Figure 2C shows that 11 of the 14 participants in our survey know braille. This skill is extremely important to their success as computer users. If blind people are to ob-

tain hard-copy output, as opposed to speech output, it will generally be in braille. Unfortunately, many school and rehabilitation counselors are still actively discouraging visually impaired people from learning braille. NYU has over 100 highly intelligent blind students, who are incredibly dependent on tape recorders and who cannot read or write, in part because their counselors told them that braille was too difficult. We look forward to the day when someone writes a braille teaching machine for such students.

Figure 2D shows a distribution of the time spent by the participants on various computer tasks. The largest amount, close to 50 h/month, is on word processing. Next, technical tasks, such as mathematics, statistics, and programming, consume about 35 h/month. The third- and fourth-place uses, are, respectively, playing computer games and performing administrative chores, such as filing and accounting. This distribution is very similar to that obtained in our earlier survey of sighted computer users (Aaronson, 1982), except that word processing consumes a somewhat greater proportion of the blind users' time. This is consistent with our experiences at NYU. We obtained grants from the National Science Foundation and NYU for equipment and staff to further the scientific and mathematical use of computers by visually impaired students. However, the students use the equipment primarily for word processing. This provides them with a miraculous degree of independence from often incompetent or unwilling readers and secretaries.

Figure 3 provides information on the computer-learning experiences of the sample. The x-axis of Figure 3A suggests that the age at which they started was generally con-

Figure 2. Distributional information on the computer background and computer usage of the survey participants.

nected to school or work demands: namely, in college, in thesis research, or in business contexts. Thus the motivational forces were strong.

The Figure 3B data were obtained in response to the question "How long did it take you to learn the computer well enough to cause an improvement in your previous ways of handling related tasks?" The bar graphs indicate that a substantial amount of time was consumed in the learning stages, with about one third of the group taking from 2 to 7 months and one third from 8 to 18 months. Our earlier survey of sighted users indicated that the vast majority accomplished a similar degree of learning in a month or less. Part of the explanation for this difference is found in Figure 3D. The visually impaired users rated the learning aids, such as computer manuals and help programs, as *poor*, with many participants scoring the standard documentation as *useless*. In contrast, the sighted users in our earlier survey scored the same types of documentation on the positive side of the scale. Unfortunately, most computer documentation is not available in either braille or speech format. Accordingly, Figure 3C indicates that over 40% of the sample's learning sources were based on their own ingenuity. This was supplemented by courses and helpful friends.

Figures 4A and 4B deal with computer hardware. Figure 4A shows the frequency distribution for the types of computers used by our sample. The frequencies sum to

more than 14, because many people use more than one machine. The five IBM mainframes are university machines. The machines represented by the bar labeled "other" are mostly single occurrences of various microcomputers (e.g., Commodore, Leading Edge, and Hewlett Packard). The graph indicates that the leading personal computers for the sample are also among the national leaders in sales volume: IBM PCs and Apples. The IBM users often said they selected that machine to be compatible with machines at their jobs. The Apples were selected mainly because there is currently more special-purpose hardware and software (e.g., braille editors, translators, and output devices) for those machines than for the others.

Figure 4B shows that 11 of the 14 participants own machines, and Figure 4D indicates that state rehabilitation agencies paid about one third of the cost. Our feeling is that rehabilitation agencies should pay even more of the bill. In this technological world, computer-literate blind people will quickly repay such costs in the form of additional income taxes from higher paying jobs. Many employers would not hire a blind person if that would also cost an additional half-time secretary. But they would hire such a person if the extra cost were for a microcomputer. The equivalent sighted employee probably would increase productivity with the computer also. Finally, Figure 4C shows the distribution of costs for the participants' computer systems. Three users paid between \$10,000 and

Figure 3. Distributional and rating information on the computer-learning experiences of the survey participants.

\$20,000, a price higher than that of a typical home computer. These high costs are due to the special-purpose I/O devices needed to handle braille, speech, and visual enlargement.

Figure 5 focuses on these special-purpose I/O devices. Figure 5A shows that surprisingly half of our sample uses graphic output in their computer work. We say "surprising" because there is an incredible lack of graphic information available for blind people. For example, there are generally no pictures in books for blind children, even though research provides evidence that the blind can understand and draw raised tactile pictures fairly well (Gabias & Kennedy, 1986; Kennedy, 1982; Kennedy & Gabias, 1985). One of our participants works in urban planning and uses the computer for map work. Others in the sample need to examine mathematical or statistical output as graphs. Figure 5A shows that some of the graphic work is aided by an Optacon. This device presents the user with a vibrotactile array of 6×24 points corresponding to a photosensitive array on which the original print or CRT display is imaged (Williams, Lambert, & White, 1985). The other participants used enlarged-screen or enlarged-print displays, sometimes done by special magnifying hardware with increased resolution, and sometimes by software that increases the dimensions of normal output.

Figure 5B shows that 11 of the 14 people sampled use speech output. If hard copy is not needed, speech is generally the fastest and easiest way to obtain output (Behrmann, 1984; Nusbaum & Pisoni, 1985; Pisoni, Nusbaum, & Greene, 1985). ECHO and VOTRAX are inexpensive, a few hundred dollars or less, and of relatively low quality; VERT costs about 10 times more, has higher voice quality, and has more flexible computer features. Figure 5C shows that only 6 of the people use braille output, although we showed in Figure 2 that 11 know braille. The primary reasons for the low usage are that braille-output devices are costly, unreliable, and slow. Finally, Figure 5D shows a distribution of use for the several output modes: speech, enlarged visual characters, tactile images, hard copy, and paperless braille. This graph is a summary of a chart listing output modes for a dozen different computer tasks. According to the graph, speech is used almost twice as often as the next most popular mode: enlarged printed characters. Obviously enlarged print can be used only by the subset of the sample that has minimal pattern vision, and these users all complain that the enlargement or resolution of their devices is inadequate. The trends in this graph are a function of three factors: cost, the users' perceptual abilities, and the tasks in which they engage most heavily. Speech output wins on all three dimensions: minimal-quality synthesizers can be obtained

Figure 4. Distributional information on hardware use and cost factors.

Figure 5. Distributional information on the use of special-purpose input and output devices.

Table 1
Human-Factors Problems Relevant to Computer
Products for the Visually Impaired

1. Product usability severely limited.
2. Information unreliable or incomplete.
3. Perceptibility/intelligibility limited.
4. Human memory capacity stressed.
5. Human motor functions disrupted.
6. Feedback unreliable or slow.
7. Human and computer information processing slowed.

for a few hundred dollars, all of the users can hear, and the most popular task is word processing of normal text, which can often be heard as easily as read.

At a meeting of the New York Blind Computer Users Club, we had a discussion of the various I/O devices and the human factors relevant to their use. Table 1 presents a list of factors that the users felt to be most important (for more-detailed discussions of human factors in com-

puter usage, see Engel & Granada, 1975; Shneiderman, 1980). First, we discuss the list in a general way. Then we look at a checklist of these factors that characterizes the sample's views about specific types of I/O devices. The list in Table 1 is rank-ordered in terms of the importance of the various factors. Note, however, that the various users did not always agree. Their disagreements were heavily dependent on their own computer experiences. For example, devices learned first were viewed most favorably, and their human-factors problems were subjectively diminished.

The first item on the list is: *limited product usability*. Simple examples illustrate what we mean by this and why this item is first. Some speech synthesizers require special-purpose software that overwrites other standard memory-resident software, including, in some cases, parts of the machine's operating system. Furthermore, some I/O devices are not hardware compatible with many com-

USER COMPLAINTS ABOUT I/O DEVICES	VERY LIMITED USEFULNESS	INFO. UNRELIABLE OR INCOMPLETE	PERCEPTIBILITY LIMITED	MEMORY STRESSED	MOTOR DISRUPTIONS	FEEDBACK SLOW OR UNRELIABLE	INFORMATION PROCESSING SLOW
KEYBOARD INPUT							
"Home-keys" not tactilly marked				*	*	*	*
Function keys often in poor positions					*		*
Key pad often has no return key					*		*
OPTICAL CHARACTER-READER INPUT							
Makes errors		*					
Is slow							*
SPEECH OUTPUT							
Often not compatible with standard software	*						
Doesn't get 100% of screen information		*		*		*	*
Often has poor intelligibility			*				
Often too complex for easy use							*
Speech is often very slow							*
ENLARGED PRINT & VISUAL DISPLAY OUTPUT							
Hardware monitors don't get 100% of screen information		*		*		*	*
Enlarged print software often not compatible with standard software	*						
Need greater & more flexible zoom capability		*	*				*
TACTILE OUTPUT							
Braille software often not compatible with standard software	*						
Paperless and hard-copy braille hardware often not compatible with other devices	*						
Often don't echo 100% of screen information		*		*		*	*
Often give bad characters and are otherwise unreliable		*					*
Are generally line-oriented; no character or word mode				*		*	*
Generally have no cursor				*		*	*
Paperless braille writers generally permit only 20 character output				*			*
Generally very slow							*
No underlining capability							*
Optacon output field not really large enough for graphics	*		*	*			*
Total	5	6	3	8	3	6	17

Figure 6. Chart of human-factors limitations for special-purpose input and output devices.

puters, and they may interfere with the use of other I/O devices. The second item is: *unreliable or incomplete information*. This refers, for example, to braille printers that do not always emboss the appropriate "bits" in the 6-cell character matrix, generally because the solenoids stick, or to braille or visual-enlargement devices that do not transmit certain classes of normal video information, because of buffering problems or problems in responding to control characters.

The other items on the list can generally be handled by the user with extra time, effort, and aggravation. Item 3, *limited perceptibility*, refers to visual-enlargement devices without sufficient resolution or to only semi-intelligible speech. However, English is sufficiently redundant for the clever user to figure out the missing information most of the time, or to get it repeated. The fourth item, *stressed human memory capacity*, was the second highest frequency complaint about I/O devices. An example is that some paperless braille outputs have pins to represent only 20 characters at a time. Thus, users receive only two to four words at a time and must maintain large amounts of prior output in their memories in order to integrate words into sentences, and sentences into paragraphs. Such piecemeal presentation also makes debugging difficult for long program statements.

Item 5 on the list is: *disruption of motor tasks*. For example, when some keyboards have function keys in nonoptimal locations, users must frequently remove their fingers from the home-key positions and thus lose their place on the keyboard. This is one of the many problems that also implicates Item 7, *slowed information processing*. Item 6 regards *unreliable or slow feedback* to the user about what is going on. An example of this problem occurs for most hard-copy braille printers. They only give output a whole line at a time, preventing the possibility of feedback at the word or letter level. Furthermore, they have no tactile or audio cursor, again preventing the user from getting feedback about letter- or word-level operations. Thankfully, evaluative and purchasing information on specific computer products for the visually impaired is now available to help users avoid some of the types of problems listed in Table 1 (Gerber, Luxton, & Henry, 1985; Lauer & Mowinski, 1983; McGillivray & Gast, 1983).

Figure 6 shows a compilation of complaints from all the computer users in the survey. For space and time reasons, the compilation is necessarily general, listing classes of complaints rather than complaints about specific makes and models of I/O devices. Generally, however, such complaints are relevant to many particular models. This rather large chart shows that every type of special-purpose input and output device has the two most serious human-factors problems: namely, those that severely restrict its usefulness in conjunction with other hardware and software and those that sometimes yield wrong or missing information. In the right-most column, the most frequent

complaint, but certainly not the most serious, is the inordinate amount of time used by slow hardware, slow software, and excess mental effort required to make sense out of erroneous, missing, or partially forgotten information. In terms of I/O devices, the largest number of complaints, and the most serious ones, concerned the tactile-output devices. Speech devices ranked next, and enlarged character displays received the fewest complaints.

In summary, this survey suggests that there is an open and growing market for high-quality hardware and software for visually impaired computer users. Tactile, speech, and enlarged print output devices are needed that are more reliable, more compatible with other computer devices, and more user friendly in terms of several human-factors criteria. If such computer products increase in quality and decrease in price, thousands, if not millions, of purchasers will be waiting. In fact, sighted users will also buy the speech synthesizers. Currently, almost all of the special-purpose I/O hardware and software is developed by very small outfits; many are still "cottage industries." We hope that in the future the large computer companies, such as IBM and Apple, will take on some of the responsibility for producing products that are better engineered and more user friendly to visually impaired computer users.

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