SUMMARY
- Explores the feasibility of wearable EPSSs
- Investigates human factors considerations in designing wearable EPSSs
- Discusses collaborative uses of these systems

Designing Wearable Performance Support: Insights from the Early Literature

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INTRODUCTION

According to Gery (1991), an electronic performance support system (EPSS) is an electronic environment available to and easily accessible by employees that is structured to provide online access to all information to permit them to do their jobs with minimal intervention by others. Why do we assume that this support must be provided on a computer? If effective performance support must be "available" and "easily accessible," how can designers provide support to people whose jobs require mobility? Such jobs include (but certainly are not limited to) supervising a manufacturing operation, inspecting foods, and repairing equipment. A designer for any EPSS being developed to support jobs such as these would have to take the employees' mobility into account.

There are several ways to incorporate mobility into an EPSS. But doing so requires that designers take the concern that Gery expressed in her article in this issue to heart, when she advises designers to avoid the trap of the familiar—that is, designing performance support that looks suspiciously like traditional documentation and training.

One seemingly obvious way to avoid this trap may be developing an EPSS for a handheld device; users could carry their EPSS in their pockets. A handheld EPSS, however, would not be appropriate for workers such as automotive or aircraft mechanics because they need to use their hands to perform their jobs. Enter the wearable EPSS. Much research has been conducted over the past several years to assess the feasibility, effectiveness, and technical concerns of such systems.

This article describes developments in this unique area of EPSS design. It first explores the feasibility of wearable EPSSs. Next, it explores human factors considerations in designing wearable EPSSs. Last, it discusses collaborative uses of these systems. Note that the concept of wearable EPSSs is not a particularly new one; it was first proposed and tested in the mid-1990s. However, because this is a unique design strategy that is outside the norm of everyday work in technical communication and performance technology, because it offers a unique perspective on design, and because it offers early insights into some of the challenges faced by designers of EPSSs, it is appropriate to revisit the idea in the context of this special issue exploring the design of EPSSs.

THE FEASIBILITY OF WEARABLE EPSSs

Before designers of everyday EPSSs could conceive of designing wearable systems, researchers would have to prove the concept—that is, demonstrate its feasibility. Specifically, when assessing the feasibility of wearable EPSSs, researchers needed to demonstrate that workers would be able to perform tasks as effectively with wearable EPSSs as with traditional methods of working (if not more effectively) and that technology could address some of the challenges of the work environment, such as extremely loud noise.

In what is apparently the only study solely devoted to assessing the feasibility of wearable EPSSs, researchers from the Georgia Tech Research Institute developed a wearable EPSS to teach people how to do origami. The wearable EPSS included a Kopin headset with 640 × 480

Manuscript received 15 October 2001; revised 9 July 2002; accepted 10 July 2002.

Figure 1. Kopin headset used in 1997 study of the feasibility of wearable EPSSs (http://mime1.gtri.gatech.edu/MiME/papers/ISWC_Jenn.html).

monochrome visual display with integrated microphone and earphone (see Figure 1). Ten study participants were asked to perform three simple tasks with the EPSS, and a 10-participant control group performed the same tasks using a book.

Overall, the study demonstrated that a wearable performance support system is feasible, but it did not show that it provided better support than a book (Ockerman, Najjar, and Thompson 1997). The differences may result from the difference in presentation in the content in the book and the EPSS. The presentation in the book might have been easier to follow than that in the EPSS. More importantly, although study participants did have specific tasks to perform, the environment was not very similar to that of a real worker performing a real, complex task on the job. These same researchers also conducted a 1997 study assessing a wearable EPSS in a more realistic environment (Najjar, Ockerman, and Thompson 1997; Najjar, Thompson, and Ockerman 1997).

The Georgia Tech team later developed a wearable EPSS to support Quality Assurance (QA) Inspectors in a food processing plant (Najjar, Thompson, and Ockerman 1997). The QA inspectors in this study were like most mobile workers, who need to use their hands to perform their job tasks. Because they are mobile, they also use a pen and paper to record the data they collect in their work.

The mobile EPSS that the researchers developed, Factory Automation Support Technology (FAST), was field-tested by a quality assurance worker. After taking about 10 minutes to train the system to recognize his voice, the worker spent 30 minutes performing the typical job task of collecting actual meat sample temperatures. Interestingly, although the researchers reported that industrial noise provided design challenges as far as speech input was concerned, this field study was conducted in a plant loud enough that hearing protection was required (Bass and colleagues 1997). Yet the study showed that the EPSS had 100% accuracy of speech recognition, at least for the one participant in the study (Najjar, Thompson, and Ockerman 1999). The study participant reported that he really enjoyed using the system and speculated that user acceptance of the system would be high because it eliminated the need for QA workers to carry clipboards, pens, papers, and paper towels.

Together, these studies suggest that wearable EPSSs can provide an advantage to workers in jobs requiring mobility and use of the hands for job tasks. The rise of mobile systems, such as the wearable check-out devices used by staffs at automobile rental facilities, attest to the growing interest in this area. The cost-effectiveness of these systems, however, has not yet been carefully assessed by the research community.

HUMAN FACTORS CONSIDERATIONS FOR DESIGNING WEARABLE EPSSs

Wearable computers present several human factors concerns. Safety, ergonomics, anthropometry, and ease of use must all be considered in the design and development of a wearable EPSS.

Consider the problems created by attention-hungry input devices. Inherent in the concept of wearable EPSSs is the idea that the user is working on a relatively complex task while using the system. It follows, then, that the user's attention is divided between interacting with the computer and performing the job-related task and that paying too much attention to the computer at the wrong time could have very serious consequences. It would be advantageous

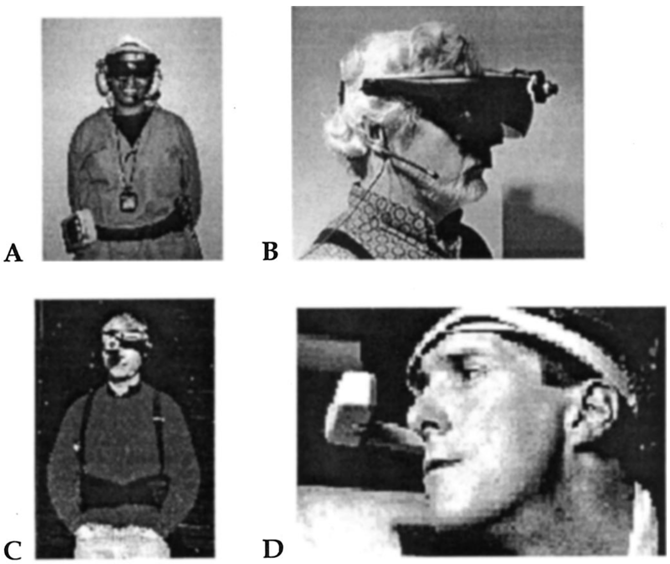

Figure 2. Examples of head-mounted displays. Each occludes the user's vision to some degree (images A, B, and C from http://wearables.gatech.edu/; image D from www.cs.cmu.edu:80/afs/cs.cmu.edu/Web/People/hcii/Research/Projects/CollaborativeOnsiteWearabl.html).

to know which of the available input devices requires the least attention from the user.

Although one 1997 study evaluated the required training, data entry speed, and error rates of three input mechanisms for wearable computers, it did not directly address the question of the wearer's attention distribution (Thomas, Tyerman, and Grimmer 1997). A further shortcoming of this study is that the mechanisms it evaluated required the use of at least one of the wearer's hands; a microphone with speech recognition, such as that used in the Georgia Tech studies discussed above, was not among the evaluated instruments. There is a very brief mention of data gloves as an input device (Bass and colleagues 1997), but it is not discussed in detail.

Consider the issues raised by head-mounted displays, like the ones pictured in Figure 2. They occlude users' vision to some degree. The degree of acceptable occlusion will likely be inversely proportional to the risk of the environment in which the system is used, but designers need to minimize the extent of occlusion as much as possible.

Finally, consider the after-effects of using wearable EPSSs. For example, Bass and colleagues point out that undesirable symptoms including headaches and fatigue sometimes resulted after extended use (1997). Najjar and colleagues noticed the same thing and recommended using "light, small, and adjustable wearable computer components" and mounting the computer components on the back and sides of the user's waist to avoid interfering with the user's tasks. They even went on to recommend letting the computer automatically perform many user tasks to minimize the number of voice inputs (and, it follows, strain on the user's voice) (Najjar, Thompson, and Ockerman 1997). To further aid in the development of comfortable wearable computers, designers should consult with anthropometry experts to ensure that the belts and headpieces are of an appropriate length and diameter for most of the population in question.

COLLABORATIVE USES OF WEARABLE EPSSs

Most of the wearable EPSSs described until now only involved a single user. But most mobile workers are collecting data for people in other locations. Wearable EPSSs must therefore let users communicate with people and computers in other locations—that is, collaborate in their work. To provide a brief insight into how these interactions work, this section provides descriptions of three early applications of wearable EPSSs that allow for collaboration.

For example, the QA inspector participating in the FAST field study discussed earlier had to report his quality findings to superiors, and those findings had to be logged into a computer system for recordkeeping. The researchers successfully integrated this reporting and logging into the FAST system by automatically flagging unacceptable quality (that is, values of data that did not meet criteria) and sending e-mail notifications to food processing supervisors via a wireless network connection (Najjar, Thompson, and Ockerman 1999).

One prototype collaborative wearable computing system developed by researchers at the University of Rochester and the MIT Media Laboratory allowed dermatologists to collaborate remotely to diagnose various integumentary ailments (Pentland and colleagues 1997). Physicians participating in the clinical interactions wore a device that allowed the doctor to access text and image medical records and laboratory results for the patient in question as well as the vast databases of medical information already online. The device also provided a communication link with physicians in a remote location.

Despite serious technical limitations, including very low image resolution, the diagnoses made based on data provided by the wearable EPSS were correct 72% of the time in simple cases. For complex cases, the success rate dropped to 33% because the technical limitations posed nearly insurmountable hurdles. (Comparative success rates for a control group of doctors interacting directly with the patients were not provided. Although it is probably an unreasonable hope that the diagnostic success rate would be close to 100% for both simple and complex cases, it probably *is* reasonable to think it would be higher than 33%.)

A very early study from Carnegie-Mellon's Human Computer Interaction Institute showed enhancements in coordination and ease of work in aircraft maintenance workers using wearable devices with visual interfaces and collaborative EPSSs that support troubleshooting and repair. The preliminary results of this study found that performing tasks with an experienced helper who shares the video to coordinate the work is most effective (Siegel and colleagues 1995).

APPLYING THE LESSONS LEARNED

These early studies of wearable EPSSs show that they can present significant advantages to mobile employees who need to work with their hands. Although ongoing research continues to assess the technical, environmental, ergonomic, and ease-of use issues associated with wearable EPSSs, initial field studies offer some practical insights. Specifically:

- Wearable EPSSs are feasible to design and develop.
- Wearable EPSSs must be at least as effective as the methods of communicating that they replace.
- Designs must address safety issues in the workplace; for example, input devices that require too much attention from users can cause potentially serious problems.
- Designs must minimize after-effects, such as headaches.
- Wearable EPSSs can be significantly more effective if they let users interact with central databases and other workers.

As technical communicators move into designing less traditional EPSSs, the lessons from the early studies of wearable EPSSs provide practical insights and design tips and encouraging insights into the acceptance and performance of these systems. Although the studies examined here address wearable EPSSs in manufacturing, maintenance, and clinical medicine, the design lessons transfer to a number of other fields, including retail operations, systems intended to assist people with disabilities, on-the-job training, and field medicine, and the future for development in this area seems promising. TC

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