

A Preliminary Comparison of Body-wearable Computers to Modern Audio Equipment in a Microgravity Environment

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Abstract

The capabilities of body-wearable computers (BWC) and modern audio equipment were compared in a micro-gravity environment. In the experiment carried out, the speed of performance on timed tasks was compared for BWC and the audio playback devices currently used by astronauts. The BWC provided faster performance times than audio equipment when used in a micro-gravity environment. In addition, the BWC was found to provide faster performance times in normal gravity than in zero gravity.

Keywords

Body-wearable computers, micro-gravity.

Introduction

The body-wearable computer (BWC) is one of the newest forms of technology emerging from the broad field of advanced human-computer interactions. The portability and easy access of the BWC allows it to be used to assist in the performance of complicated tasks in locations where it would be impossible to use another form of computer. The BWC generally consists of a PC computer and battery pack attached to a waist belt or vest, wireless communications hardware, a head mounted display (HMD), and an input device (keyboard, touchpad, or voice operated speaker). The BWC is confined to the personal space of the user and permits the operator to input or extract information while in the field for a variety of disciplines. Some studies have been conducted to compare the performance capabilities of the BWC to standard methods for accomplishing everyday tasks [1, 3-9].

However, no formal studies using the BWC have been conducted in micro-gravity although they have been suggested [2]. Most research has shown that the BWC can be effective in reducing time and effort in task performance. For example, research conducted at Carnegie Mellon University discovered that a typical inspection procedure required 40% less time using the BWC than using the conventional procedure [1]. In contrast, Ockerman [6] found that the BWC performed slower and less efficiently (albeit not significantly) than a book of instructions when completing an origami (the ancient Japanese art of paper folding).

Astronauts currently use audio technology and conventional notepad in order to perform installations, repairs, or maintenance on NASA equipment in space. The primary purpose of this research was to determine how the technology now used by astronauts compares with the technology and capabilities of body-wearable computers in the performance of various tasks under timed situations. The specific data to be collected was whether instructions for accomplishing tasks in micro-gravity using BWCs can be assimilated in less time and with greater efficiency than with audio equipment, thereby allowing for more rapid task completion. It is anticipated that if this technology proves superior, the audio equipment and conventional notepad will be replaced with BWC technology in the U.S. space program.

Materials and Methods

The BWC used in the experiment was the Mobile Assistant IV™ by Xybernaut Corporation. The computer unit consists of a 900g CPU module with 233 Mhz processing speed, 128 MB of RAM, a four-gigabyte hard drive, and dual PC cards.

The CPU module is worn on the body contained in a vest and is powered by 450g lithium battery that is attached in the rear of the vest. The screen image is projected onto a 470g head mounted display (HMD) with the display projecting outwards. The display consists of a VGA monocular color screen and can be worn on the left or right side of the head. The Mobile Assistant IV™ can be voice-operated with the optional microphone and earpiece speaker. In addition, it is capable of recording information with an integrated miniature video camera. This optional equipment was not used in the experiment.

The Mobile Assistant IV™ uses Windows 98™ as its operating system. Microsoft Word™ was utilized in the experiment to manipulate the trial files that were projected on the HMD. This program proved to be easy to use in the microgravity environment and simple to manipulate when files had to be opened and closed.

The audio equipment used in the experiment consisted of a Sony Walkman and adjustable headphones. The Walkman is powered by two reusable AA batteries and is capable of playing, rewinding, forwarding, and stopping a tape in progress at any time.

Twelve tapes were used to record task instructions for use in the microgravity environment. Tapes were placed in the Walkman prior to the experimental trials.

The micro-gravity environment for the experiment was simulated by the KC-135 aircraft located at Ellington Field in Houston, Texas. The plane flies to an elevation of 24,000 feet and then steeply climbs to 32,000 feet using a 45° trajectory. Once 32,000 feet has been reached, the plane glides for a period of 20-30 seconds before returning to 24,000 feet. Two gravity's (G's) are experienced during the rapid ascent and descent of the plane and zero G is experienced when the plane is suspended at 32,000 feet. The plane flew 40 parabolas with a 1-2 minute interval between each parabola. The experiment was conducted during the periods of weightlessness (zero G).

The "simple tasks" within the experiment were conducted using 24 2X2 inch Rubik's cubes supplied by the OddZon Corporation. Twelve tasks were developed using eight-step procedures that would enable the researcher to solve the cube puzzle. An outside observer was responsible for the development of these "simple tasks." This prevented researchers performing the tasks aboard the plane from witnessing the puzzle solutions prior to the experiment.

In order to prepare each individual task, the outside observer followed an eight-step procedure in reverse order to arrange the cube in the position to be solved. Then, during the experiment, the researcher was able follow the eight-step experimental procedure to solve the cube. A cube was considered "solved" when all six sides of the cube were in their proper color order. Pairs of cubes were kept in individual

storage bags in order to prevent a mismatch of cubes from occurring during the tests.

All of the procedures for solving the "simple tasks" were written in Microsoft Word™ and saved on the Mobile Assistant IV™ for use on the KC-135. Opening and closing of the trial files provided researchers with access to all twelve "simple task" solutions.

Each of the 12 "simple task" solutions were recorded on individual tapes in order to prevent a mismatch from occurring. Placing a tape in the audio recorder and pushing "play" allowed researchers to solve the cube for a particular procedure using audio instruction.

The time required to solve each task was monitored using stopwatches and recorded using data sheets created in Microsoft Excel™. All equipment was attached to the plane or secured in a bag aboard the KC-135. The experiment consisted of three phases in which both methods were tested in either the microgravity environment or under normal gravity. Phases one and two took place aboard the KC-135 under microgravity conditions. Phase three also took place aboard the KC-135 but under normal gravity conditions. Researchers 3 and 4 flew aboard the KC-135 for phase one, researchers 1 and 2 flew aboard the KC-135 for phase two, and researcher 5 conducted the ground trial (phase three) aboard the KC-135 on the runway.

To conduct phase one of the experiment, one of the two researchers aboard the plane wore the BWC and prepared the device to open and close solution files. The other researcher provided the proper cubes, disposed of used cubes, timed tasks, and recorded times to solve tasks on a datasheet. The researcher wearing the BWC began solving trial 1 when the plane was experiencing microgravity and ended the trial by either solving the task or failing to solve the task in the 20-30 second period of microgravity. During this period, the other researcher would time the trial by starting and stopping the stopwatch with notice from the researcher wearing the BWC. Once a trial had been completed, the time to complete the task would be recorded, cubes would be exchanged, and preparation for the next trial

Table 1a. Comparing BWC to Audio Equipment in Microgravity and Normal Gravity

TASK	Microgravity Data				Ground Data
	Audio Equipment		Body Wearable Computer		Rschr 5
	Rschr 1	Rschr 2	Rschr 3	Rschr 4	
	TIME (seconds)				
1	19.13	16.59	14.62		16.66
2	18.34	21.5	25.69	18.69	19.38
3	15.46	16.75	15.94		13.03
4	19.66	15.56	29.03		14.87
5	17.84	17.5	24.66	22.16	10.56
6	16.06	17.25	17.41		10.72
AVG	17.75	17.53	21.23	20.43	14.20
STD DEV	1.67	2.06	5.98		3.47

would take place (opening and closing of files in Microsoft Word). This procedure occurred for trials 1-6. When trial 6 had been completed, the BWC was exchanged in order for the other researcher to perform trials 1-6. The researcher who had been wearing the BWC now undertook the responsibilities of the other researcher. The same procedure was followed in order to complete the second pair of trials (1-6).

In order to complete the audio portion of the experiment, one of the two researchers aboard the plane wore the audio equipment and prepared the device to play the tape containing the solution for trial 7. The other researcher provided the proper cubes, provided the proper tapes, disposed of used cubes, timed tasks, and recorded times to solve tasks on a datasheet. The researcher wearing the audio equipment began solving trial 7 when the plane was experiencing microgravity and ended the trial by either solving the task or failing to solve the task in the 20-30 second period of microgravity. During this period, the other researcher would time the trial by starting and stopping the stopwatch with notice from the researcher wearing the audio equipment. Once a trial had been completed, the time to complete the task would be recorded, cubes would be exchanged, and prepara-

Table 1b. Comparing BWC to Audio Equipment in Microgravity and Normal Gravity

TASK	Microgravity Data				Ground Data
	Audio Equipment		Body Wearable Computer		Rschr 5
	Rschr 1	Rschr 2	Rschr 3	Rschr 4	
	TIME (seconds)				
7	16.63	14.62			15.78
8	14.44	17.13			15.32
9	17.06	17.05			17.15
10	13.56	16.78			16.44
11	17.78	15.9			18.31
12	13.22	15.79			15.16
AVG	15.45	16.21			16.36
STD DEV	1.95	0.97			1.21
Pct Diff	13%	7%			13%

tion for the next trial would take place (rewinding, removal of the existing tape, and placing a new tape in the tape recorder). This procedure occurred for trials 7-12. When trial 12 had been completed, the audio equipment was exchanged in order for the other researcher to perform trials 7-12. The researcher who had been wearing the audio equipment now undertook the responsibilities of the recorder/monitor. The same procedure was followed in order to complete the second pair of trials (7-12).

The same procedures were followed in phase two of the experiment except the trials were reversed for each method. That is, trials 7-12 were used when testing the BWC and trials 1-6 were used in order to test the audio equipment.

Again, the same procedures were used to complete phase three of the experiment except no equipment exchange occurred. Researcher 5 used trials 1-6 when testing the BWC and trials 7-12 to test the audio equipment.

Results

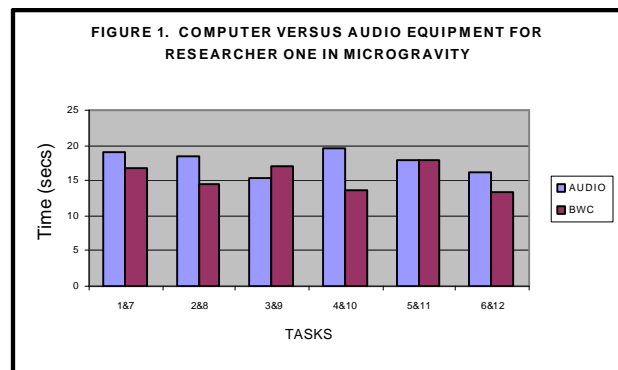
When comparing the BWC to the audio equipment, certain parameters had to be established relative to the level of difficulty for each simple task. For example, tasks 1 and 7, though being different tasks (having a differing eight step solution), were equal in difficulty if done using the same method in the same environment. It was initially intended to prove this generalization. However, unforeseen events prevented the acquisition of data from researchers 3 and 4. Second, it was believed that an individual's performance using both methods became more efficient with experience in solving "simple tasks." For this reason, tasks 1 and 7, 2 and 8, 3 and 9, etc. were compared throughout this paper.

Comparing BWC to Audio Equipment in Microgravity

Table 1a and Table 1b display data collected by all researchers in microgravity and in normal gravity. Although researcher 3 collected data for the BWC in microgravity, the trials were not completed due to spatial disorientation and were discarded. The average time to complete trials 1-6 using the BWC for researcher 3 was 21.23 seconds (5.78 seconds more than researcher 1 and 5.02 seconds more than the time for researcher 2). In addition, the standard deviation for trials 1-6 using the BWC for researcher 3 was 5.98.

The average time to complete trials 1-6 using the audio equipment for researcher 1 and researcher 2 was 17.75 and 17.53 seconds, respectively. The average time to complete trials 7-12 using the BWC for researcher 1 and researcher 2 was 15.45 and 16.21 seconds, respectively. Using the t test (p significant=.1), it was found that the values attained by researcher 1 (average times for audio and BWC) were significantly different ($p=0.05$). When the averages for researcher 2 (average times for audio and BWC) were compared using the t test, it was found that the values recorded were significantly different ($p=0.08$) as well.

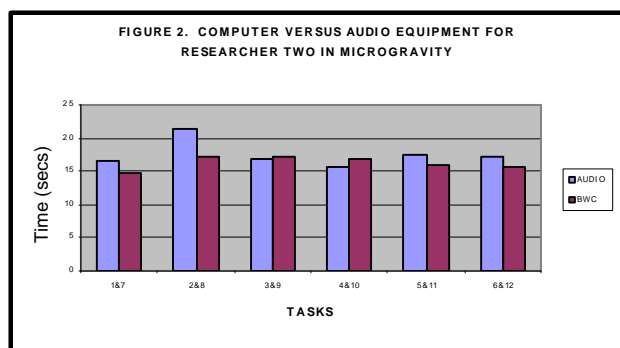
The recorded times for tasks 1-6 (audio equipment) and tasks 7-12 (BWC) were compared and analyzed for researcher 1 (Figure 1). The chart clearly illustrates that the BWC required less time to complete the "simple tasks" than did the audio equipment. In fact, performance using the BWC in micro-gravity was faster by 13%.



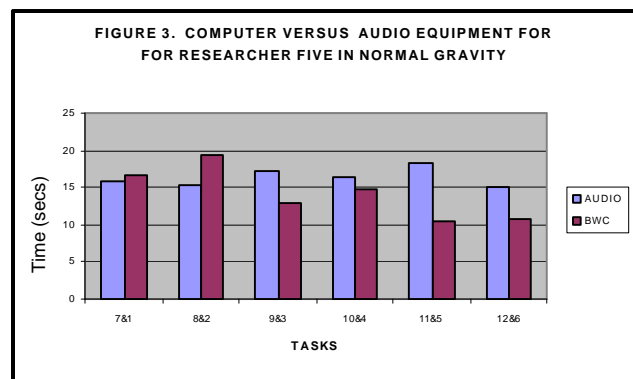
The recorded times for tasks 1-6 (audio equipment) and tasks 7-12 (BWC) were compared and analyzed for researcher 2 (Figure 2). Again, the BWC required less time to complete the “simple tasks” than did the audio equipment. It was found that the BWC was 7% faster than the audio equipment when solving the “simple tasks” in microgravity.

Comparing BWC to Audio Equipment in Normal Gravity

The average time to complete trials 1-6 using the BWC for researcher 5 was 14.20 seconds. The average time to complete trials 7-12 using the audio equipment for researcher 5 was 16.36. When these averages were subjected to a t test, they were found to be significant ($p=0.1$). However, these values proved to be less significant than the values attained by researchers 1 and 2. This was primarily due to a large standard deviation in the data for the BWC ($sd=3.47$).



When the individual trials were compared for both the BWC and the audio equipment (Figure 3), the BWC proved to be the faster method for solving tasks in normal gravity. The BWC was calculated to be 13% faster than the audio equipment. Although the individual data points are close in real time, it is the average time that is important in this experiment, not individual times. The overall time saved is what will reduce costs and labor for the space program.



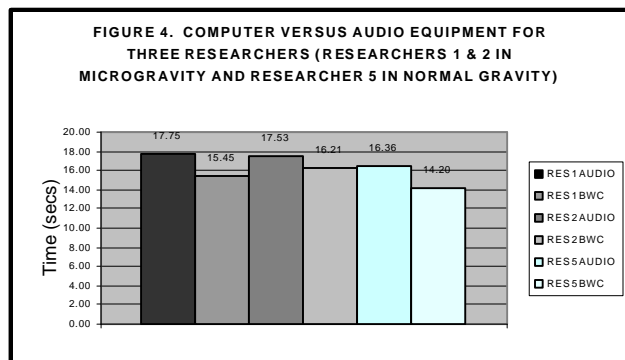
Comparing Two Methods in Microgravity and Normal Gravity

The average times required to complete the tasks using the BWC and the audio equipment for researchers 1, 2, and 5 constitute the overall results (Figure 4). The average times for both of the BWC data sets are clearly lower than the average times for both of the audio equipment data sets in microgravity. In addition, the average times for both the BWC and the audio equipment for researcher 5 in normal gravity are lower than the average times for the BWC and the audio equipment data sets for both researchers in microgravity.

The average time for the BWC in normal gravity was 1.25 and 2.01 seconds faster than the average times for researchers 1 and 2, respectively. The average time for the audio equipment in normal gravity was 1.39 and 1.17 seconds faster than the average times for researchers 1 and 2, respectively. The data on a per trial basis is presented in Figures 5, 6, 7, and 8.

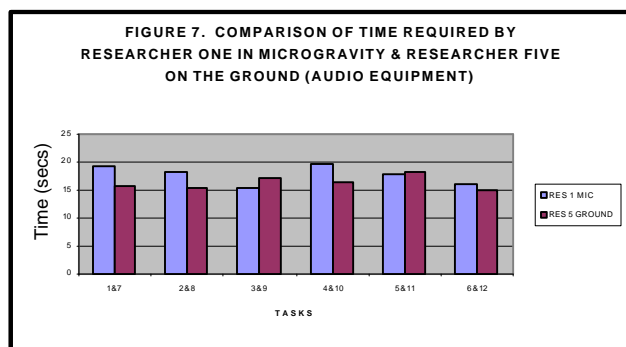
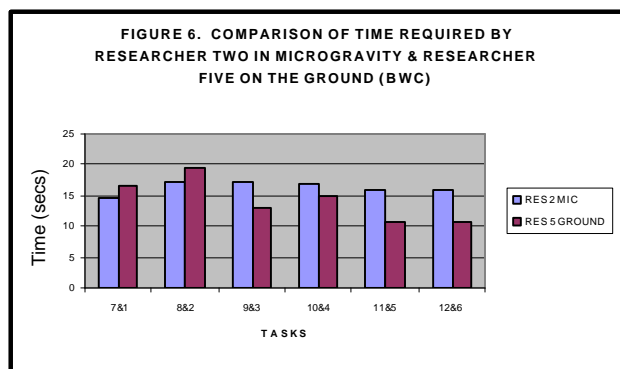
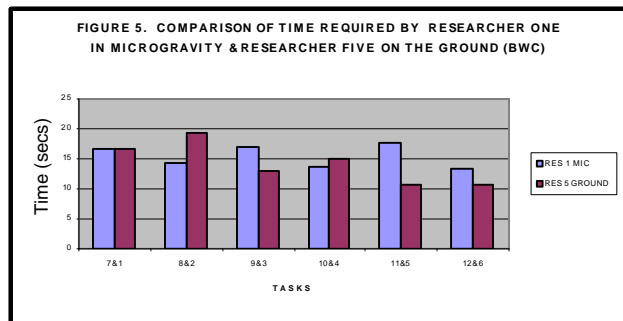
Discussion and Conclusion

Based upon the research performed, the BWC, when compared to audio equipment, is a faster and more efficient method for providing instructions for solving simple tasks in a micro-gravity environment. Further research is indicated in order to determine with certainty that the BWC can be used efficiently in a micro-gravity environment to ensure that it will be able to conserve time and money in the future for the space program. Using the BWC and the audio equipment on the ground (normal gravity) proved to be faster in solving “simple tasks” than using these same methods in a microgravity environment.



It is recognized that only a limited amount of data was obtained because of physical problems beyond the control of the research. The lack of data from researchers 3 and 4 (phase 1) was primarily related to spatial disorientation associated with weightlessness. In addition, it was not possible to collect audio data because of poor headphones on the cassette recorder. Noise within the aircraft made it impossible to hear and understand the audio instructions from the pre-

recorded tape during phase 1. Feedback from these researchers enabled researchers 1 and 2 (phase 2) to overcome these unexpected problems by 1) obtaining a high quality headphone in order to hear audio instructions and 2) employ an additional strap that would hold the researchers firmly to the deck of the plane in order to reduce excess



movement and spatial disorientation. Because of the use of U.S. Air Force aircraft for this research, it was impossible to reschedule the lost mission.

Specifically, it was determined that the BWC is between 7-13% more efficient than audio equipment when solving “simple tasks” in a microgravity environment. Although in real numbers in the tasks performed in the research, this percentage may seem insignificant, it constitutes a substantial amount of time over the duration of a shuttle mission or a

space station shift. When added up, these savings in time translate into a task that normally takes eight days to perform in space would only require a little under seven days to complete. In case of emergency, a one or two second difference might also be life saving.

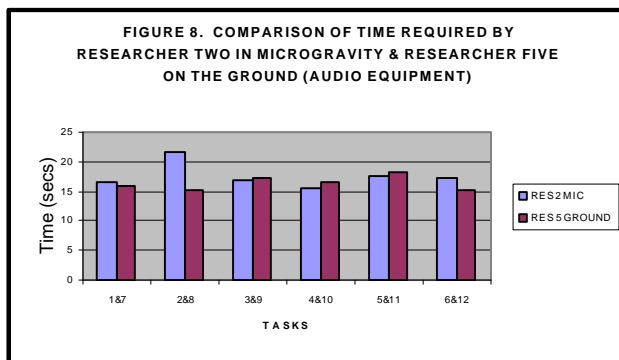
There was a 13% difference between the BWC and the audio equipment when “simple tasks” were performed on the ground. This indicates that the BWC may be able to be used at the same efficiency in micro-gravity as it can be used on the ground. However, the data obtained by researcher 2 suggests that time saved using the BWC may vary with the individual. That is, human and environmental factors may have a direct effect on an individual’s ability to perform using a BWC.

Recommendations

For future research using the BWC in a microgravity environment, it is imperative that a visor type HMD be worn rather than the left or right side HMD arm attachment. This recommendation is important especially for research done aboard the KC-135 aircraft. The two G force that is exerted upon the BWC during ascent and descent of the aircraft causes the extended HMD to be pushed downward. Similarly, the zero G force that is experienced during weightlessness pulls the extended HMD upward. This phenomenon complicates tasks because readjustment of the HMD is continuously needed. A visor type HMD would not be affected by such forces.

This research, because of the small amount of data, cannot be considered definitive in describing the capabilities of the BWC in a microgravity environment. It is recommended that future research include performing additional ground comparisons of the BWC and audio instructional equipment. If possible, additional comparisons in the micro-gravity environment would be helpful also.

Toub [10] described the importance of usability studies and experimental design evaluations for wearable computers and believes these investigations to be an underused tool in the field of computer science. This study provides useful data for the progress of BWC research and development, and helps to fill the void in BWC usability research.



Acknowledgments

This work would not have been possible without the donation of the body wearable computer by the Xybernaut Corporation. We also thank the OddZon Corporation for their kind donation of 36 Rubik's cubes and Southwest Airlines for providing transportation.

A special thank you is due to the following employees of the Kennedy Space Center for their expertise and kindness: Irene Long, MD., Shannon Potter, and Gus Koerner, Ph.D. and special thanks go to Patricia Currier, Mission Scientist and the project manager at the Kennedy Space Center, for her insights and guidance.

References

Department of Defense. 1995. DARPA TIA-Smart Modules-Technology Programs. ETO. August, 1995.

Matias, E., I. S. MacKenzie, and W. Buxton. 1996. A Wearable Computer for Use in Microgravity Space and Other Non-Desktop Environments. In *Companion of the CHI '96 Conference on Human Factors in Computing Systems* (p. 69-70). New York, NY: ACM.

Najjar, L. J., J. J. Ockerman, and C. Thompson. 1997a. Using a Wearable Computer for Mobile Training and Performance Support. In T. Muldner & T. C. Reeves (Eds.), *Educational Multimedia/Hypermedia and Telecommunications*, 1997 (p. 1461). Charlottesville, VA: Association for the Advancement of Computing in Education.

Najjar, L. J., C. Thompson, and J. J. Ockerman. 1997b. Using a Wearable Computer to Improve the Performance of Quality Assurance Inspectors in a Food Processing Plant. Paper Presented at the CHI '97 Workshop on Wearable Computers. Atlanta, GA.

Ockerman, J. J. and A. R. Pritchett. 1998. Preliminary Investigation of Wearable Computers for Task Guidance in Aircraft Inspection. In *Proceedings of the 2nd. International Symposium on Wearable Computers*.

Ockerman, J. J., L. J. Najjar, and C. Thompson. 1997. Evaluation of a Wearable Computer Performance Support System. In T. Muldner & T. C. Reeves (Eds.), *Educational Multimedia/Hypermedia and Telecommunications*, 1997 (pp. 788-793). Charlottesville, VA: Association for the Advancement of Computing in Education.

Pentland, A. P., M. Petrazzuoli, A. Gerega, and T. Starner. 1997. The Digital Doctor: An Experiment in Wearable Medicine. In *Proceedings of the First International Symposium on Wearable Computers (ISWC '97)*. IEEE Computer Society.

Siegel, J. and M. Bauer. 1997. A Field Usability Evaluation of a Wearable System. In *Proceedings of the First Interna-*

tional Symposium on Wearable Computers (ISWC '97). IEEE Computer Society.

Thompson, C., L. J. Najjar, and J. J. Ockerman. 1997. Wearable Computer Based training and Performance Support Systems. In S. Aronberg (Ed.), *19th Interservice/Industry Training, Simulation and Education Conference Proceedings* (pp. 746-752). Arlington, VA: National Training Systems Association.

Toub, R. 1996. The Importance of Usability Studies and Experimental Design Evaluations for Wearable Computer. (Online Report): Eugene, OR: University of Oregon, Department of Computer and Information Science

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