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Preliminary Evaluation of a Small Wearable Display

By

R. J. Blaha
J. M. Kistner

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Chief
National Airspace Program

FOR THE COMMANDER

ROGER A. MOSELEY, COL, USAF
Program Director
Communications and Airspace Management
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A preliminary evaluation was performed on a small display called the Private Eye, which is worn in front of one eye. Seventeen subjects entered simulated air traffic controller flight strip information from this device. Subjective ratings on its various characteristics ranged from slightly favorable to neutral. When comparing the Private Eye to printed material, the Private Eye was slightly slower and more error prone. Although it is not the optimum display for continuous data entry, this evaluation found no intrinsic limitations in the Private Eye. It was concluded that the device could have advantages in appropriate applications.

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EXECUTIVE SUMMARY

A small, wearable high resolution display called "Private Eye" was evaluated. This monochrome (red) display, designed to be worn in front of one eye, measures about 1" x 1" x 3" and weighs 2 ounces. Using conventional semiconductor and optical techniques, it provides the equivalent amount of information to that of a 12-inch monitor driven by a PC.

A highly concentrated, data input task was chosen to obtain hands-on experience with this new display device, and to quickly identify the potential advantages and deficiencies in the device. This task required the keyboard entry of information from the Private Eye into simulated air traffic flight strips, with key entries displayed by a personal computer. Subjective evaluations were the emphasis of the study, and were quantified on a seven-point rating scale. Data entry rates and errors were also measured. Seventeen subjects were used, with a wide range of characteristics in terms of level of experience, corrected visual deficits, and keyboard skills. To obtain a performance baseline, the flight strips were entered from printed material as well as from the Private Eye.

The average ratings for the subjective evaluation are shown below. A rating of 1 or 2 is considered favorable, 3 to 5 is neutral, and 7 or 8 is unfavorable.

- Generally liked device: 3.2
- Helped/hurt ability to enter data: 3.4
- Ability to move attention between Private Eye and PC monitor: 3.0
- Ability to move attention between Private Eye and keyboard: 2.6
- Color of Private Eye characters: 2.8
- Legibility of Private Eye characters: 1.9
- Fatigue during/after task: 2.3
- Perceived display flicker (4 of 17 subjects): 3.5
- Comfort of device: 2.9

Thus the ratings of the Private Eye generally ranged from slightly favorable to neutral, perhaps affected by a "built in" bias toward mid-range ratings. The subjects had no difficulty with depth perception, although the device blocked a large portion of one eye's visual field. The red color of the display and its brightness and contrast likewise presented no problems to the subjects. The rather concentrated but brief use of the Private Eye apparently caused no appreciable eye fatigue; however, some minor discomfort was reported from the head harness, which the vendor is redesigning.

The character font employed in the Private Eye apparently caused confusion between certain characters. One of the subjects said he was unable to consistently see the entire Private Eye display and two others had difficulties when using bifocal glasses. These problems might have been corrected by careful repositioning or refocusing of the Private Eye. Five subjects also reported a transient "ghosting", flickering, or movement of the image, which might be explained by head or eye movement.

The differences were not significant when comparing keyboard performance with the Private Eye to performance with the paper material. Using the Private Eye, the subjects entered data at a rate of 76.6 characters/minute with a grand total of 95 errors made by all subjects;

using the paper material they entered at 80.1 characters/minute with a grand total of 70 errors. There appeared to be no consistent relationship between the subjects' individual characteristics and their ratings of the Private Eye.

As a general conclusion, this evaluation identified no intrinsic limitations in the usability of the Private Eye device, although it is not the optimum display for a continuous entry task. Used in conjunction with an appropriate input device, it could have significant advantages in applications where portability, privacy, and/or a "personal" window of a larger display is required. D63 is in the process of obtaining an updated model of the Private Eye. Combining the Private Eye with live input devices, such as voice recognition or head trackers, may provide for hand-free portable operations to support future field maintenance or virtual command post requirements.

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SECTION 1

INTRODUCTION

This report describes a preliminary evaluation of a small, monochromatic wearable device called the Private Eye. This miniature display, designed to be worn in front of one eye, can provide an equivalent amount of information to the full screen of a standard 12-inch monitor driven by a PC. Figure 1-1 shows a subject wearing the Private Eye seated in front of a personal computer (PC), the configuration used in this evaluation. (Note: the Private Eye in this illustration is positioned further from the subject's eye than the normal distance of about an inch.)

The evaluation provided "hands-on" experience with a prototype of this device, which is in the process of entering the commercial marketplace. Subjects were given a brief task designed to require the repeated, continuous use of the displayed information, immersing them in the use of the Private Eye. The task was not chosen because it was an optimum application of the Private Eye. In fact, a highly concentrated, "worst case" keyboard interaction task was chosen, so that any perceived flaws in the device would become readily apparent. Thus the subject's task was to type information displayed on the Private Eye, a task requiring the concentrated use of this device in conjunction with a standard keyboard and a PC monitor. Subjects were given little time or opportunity to become accustomed to using the device, again, a worst-case condition.

Subjective evaluations of the Private Eye were the emphasis of this study. The subjects' opinions of the device were recorded, and were quantified via rating scales. Performance was also quantified in terms of typing rate and errors.

Figure 1-1. Flight Strip Data Being Entered from Private Eye into PC

The evaluation was structured to provide meaningful results within a short time, with a minimum amount of software and facility development, and using a variety of different individuals as subjects. Although its applicability is not restricted to a particular project, the evaluation was conducted within the context of an air traffic control task, namely the entry of flight strip data. In current air traffic control operations, these flight strips are manually prepared and maintained. The automated entry and maintenance of the strips thus is germane to the New Mobile RAPCON project.

Flight strip information was entered from printed material as well as from the Private Eye. Since it is likely that data entry would be faster and less error prone using the familiar paper material (especially for more skilled typists), there was no intent to directly compare the Private Eye to the printed material. Since the subject's relative keyboard skills were of primary interest, performance on printed material was intended to form only a general baseline for the Private Eye data entry task. The order of presentation of the printed material and the Private Eye material was counterbalanced to counteract some of the effects of learning.

The Private Eye vendor, Reflection Technology (Waltham, MA), has indicated that certain improvements to the evaluated prototype are currently being designed (e.g., the harness which holds the device on the viewer's head). It is likely that some of the shortfalls identified during this evaluation will be addressed in the enhanced version.

The following sections of this report describe the Private Eye and the system used for its evaluation; the detailed procedures used; the subjects' characteristics; the specific results in terms of the subjects' ratings, opinion, typing rates, and errors; and a discussion and interpretation of these results.

SECTION 2

EQUIPMENT

The Private Eye uses a proprietary display technology based on conventional semiconductors and optical techniques to create an image of a 12-inch monitor in a miniature package. It measures 1.1" x 1.2" x 3.2" and weighs 2 ounces. The image appears to be approximately 18 inches from the viewer's eye. Emissive display elements are used for the fast responding high resolution (720 x 280 pixels), monochrome (red) image. Because a black background is used, high contrast ratios are achieved. Both text and graphic information can be displayed; however, in this evaluation, only text data was displayed. See table 2-1 for a listing of the Private Eye specifications.

A 80386-based PC with a VGA monitor was used to support the display of information on this prototype Private Eye, to accept the subjects' inputs, and to store their performance data. The Private Eye was connected to the PC through a 4-foot wire cord. Figure 2-1 is a block diagram of the configuration used in this evaluation.

Font design was an important aspect of working with this prototype. Before beginning this evaluation, it was observed that standard PC monitor text when displayed on the Private Eye was too small. Reflection Technology provided a set of software to allow a new font to be designed on a MacIntosh computer using the standard "Superpaint" software package. Once built, using "Superpaint," the formatted displays were transferred to the PC via a LAN at the Bedford Computer Center. In addition, the "Superpaint" displays required 90° rotation, since the prototype Private Eye image plane is orthogonal to the PC bit plane. Attempting to optimize the font, several formats were examined before 18 point, proportionately spaced Times font was selected for use. To further minimize the effects of

Table 2-1. Private Eye Specification

Resolution:	720 x 280 pixels standard
Image color:	High contrast red pixels on black background
Image size:	22 degrees horizontal by 14 degrees vertical. Equivalent to viewing a screen 9.25 inches wide by 6.0 inches high, which is located 24 inches away.
Size:	1.1 x 1.2 x 3.2 inches
Weight:	2 ounces
Exit pupil:	0.4 inches square at 0.8 inches from the face of the case (location of user's eye to view entire image)
Focus range:	10 inches to infinity (user adjustable)
Refresh rate:	Approximately 50 hertz
Update rate:	Display can change images at the refresh rate. Choice of interface may limit speed.
Power:	5 volts DC. Average power under 1/2 watt. Idle power when no pixels are illuminated is negligible.

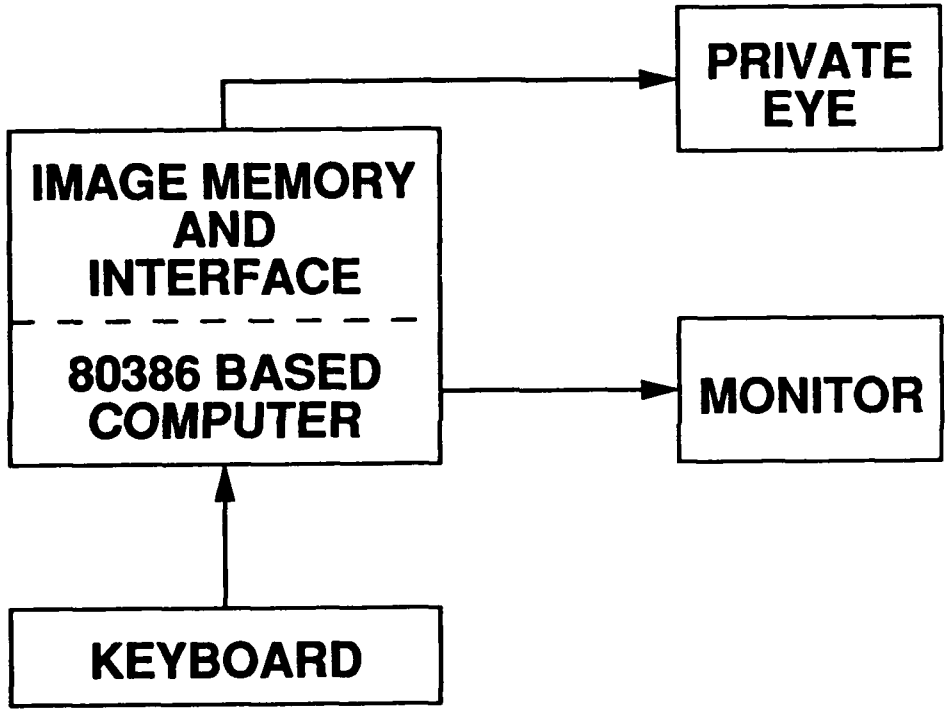


Figure 2-1. Evaluation System Configuration

the font design, neither the letter "O" nor the zero was used. Appendix A contains the data that was entered during the evaluation and is printed in the Times font as presented on the MacIntosh computer.

The evaluation was run in a relatively quiet room with minimum distractions. The ambient light was subdued and was from the subject's side, thus eliminating glare on the PC display.

The selected font results in a 12 pixel high by 8 pixel wide character. At 24 inches away, the image plane appears 6 inches high, which translates into 40 pixels per inch. The net result is a character height that subtends 40 minutes of visual angle, which exceeds minimum requirements (15 minutes) by a large margin.

SECTION 3

PROCEDURE

3.1 SEQUENCE OF EVALUATION ACTIVITIES

The subjects were first briefed on the overall purpose of the evaluation, emphasizing that their typing ability was not being tested and that their personal opinions of the Private Eye were the focus of the evaluation. Each subjects's job title, level of experience, prior experience with a keyboard, vision defects, and eye dominance were recorded. (The dominant eye is the one preferred for aiming a gun or a camera, analogous to right or left handedness.) Appendix B is the form used for recording this information as well as for recording the subjective rating data.

Next, the subjects were shown the flight strip formats. (These flight strips are currently used in air traffic control to post current data, providing documentation of each flight's departure, en route, and arrival instructions.) After being instructed in the data entry procedures, subjects were asked to work as quickly and accurately as possible. When using the Private Eye, they were instructed to put it in front of their dominant eye, and to take their time in adjusting it into the most comfortable position, up/down, left/right, and front/back.

Key entries, on a stroke-by-stroke basis, were displayed on the PC's monitor in the flight strip format shown in figure 3-1. Fields 1, 2, 3, 6, 7, 8, and 9 were always entered; field 9a required data entries on 16 of the 22 flight strips. Fields 3 and 6 contained only numeric characters, field 8 contained only alpha characters, and the remaining fields were

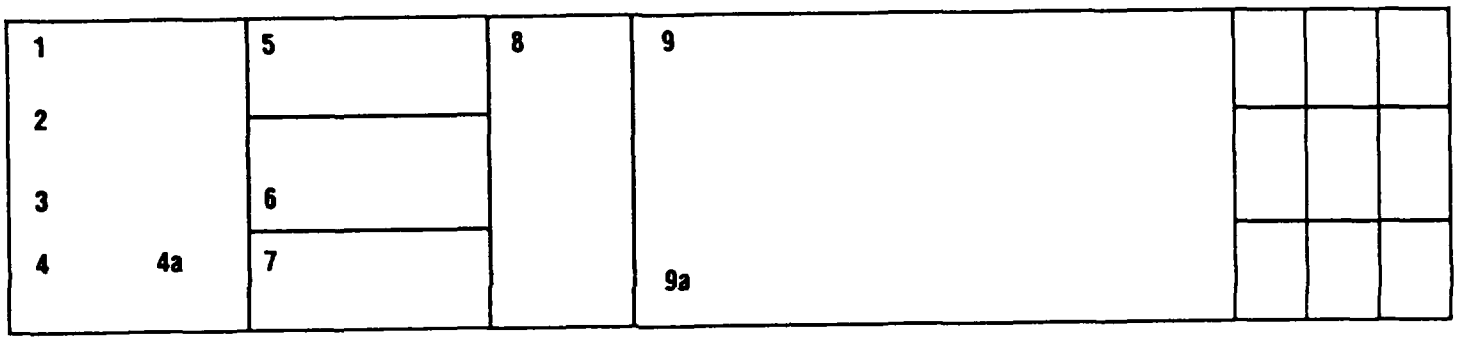


Figure 3-1. Flight Strip Format

mixed; only fields 9 and 9a contained spaces. All characters were keyed without regard for capitalization, since all entries were displayed in upper case. When a field was completed, the subject checked the accuracy of the entry and hit the ENTER key; the system then automatically "tabbed" to the next field. When all fields of a flight strip had been entered, the subject hit the ESCAPE key to proceed to the next strip.

Errors detected by the subjects during entry of a field were corrected by backspacing and reentry, and were not counted as errors by the data collection software. If the errors were not detected before hitting ENTER, they could not be subsequently corrected, and were recorded.

To counterbalance the order of presentation, nine subjects began entry of data from paper, and eight subjects began data entry from the Private Eye. When all 22 flight strips had been entered, the subjects switched to the alternate presentation mode and again entered the same 22 strips in the same order.

After the flight strips had been entered from both the paper and Private Eye, the rating scales in appendix B were read to the subjects and each rating and its explanation were recorded verbatim. The subjects required about 20 minutes to enter the information from the Private Eye, about 20 minutes to enter it from the paper, and about 20 minutes to perform the ratings. Each subject's evaluation session thus lasted about an hour.

3.2 SUBJECT CHARACTERISTICS

The primary restriction on the selection of subjects was that they have some amount of technical training, since it is likely that any USAF application of the Private Eye will be technical in nature; for this

reason, purely clerical personnel were excluded. Aside from this restriction, an effort was made to include subjects with a wide range of characteristics in terms of level of experience, vision, and keyboard skills.

A total of 17 subjects were used in this evaluation, none of whom had any previous experience with the Private Eye. Thirteen of them were MITRE technical staff, ranging in level of experience from recent hires to individuals with over 20 years of experience; the remaining four subjects were either technical aides or co-op students.

Twelve of the subjects had right eye dominance, and five had left eye dominance. (The dominant eye was used to view the Private Eye.) Nine of the subjects wear eyeglasses or contact lenses, which were always worn throughout the study session. Of these nine subjects, one required correction only for close-up, four only for distance, and four for both close-up and distance; four of the nine subjects requiring corrections were also corrected for astigmatism.

Five of the subjects reported typically using a keyboard from 1 to 8 hours per week; five reported using a keyboard 8 to 24 hours per week; five reporting using a keyboard over 24 hours per week. Two subjects very seldom use keyboards and were quite unfamiliar with them; for this reason, their data was not included in the key input results reported in section 4.2, "Performance Data."

SECTION 4

RESULTS

4.1 SUBJECTIVE DATA

The first few questionnaire items requested general observations and comments from the subjects, and then the questionnaire progressed to more specific topics. They included a rating scale, which required the subject to quantify his/her opinion in whole numbers on a scale from 1 to 7. More favorable responses were given smaller numbers, and less favorable responses were given larger numbers; subjects were only allowed to give whole number ratings. After each rating was recorded, the subject was asked to explain why the particular number had been given.

Ratings considered to be generally favorable are 1 or 2; those considered to be generally neutral range between 3 and 5, around the scale's midpoint of 4; unfavorable ratings are 6 or 7. Figure 4-1 summarizes the ratings.

Figure 4-1 summarizes the results of the rating scale questions. Each question is individually listed below, along with the average rating given by all 17 subjects, the rating's standard deviation, and a sample of the subjects' rationales for the ratings.

- "In general, how did you like the Private Eye?"

  A rating of 1 = liked; a rating of 7 = disliked

  Mean Score: 3.2
  Standard Deviation: 1.1

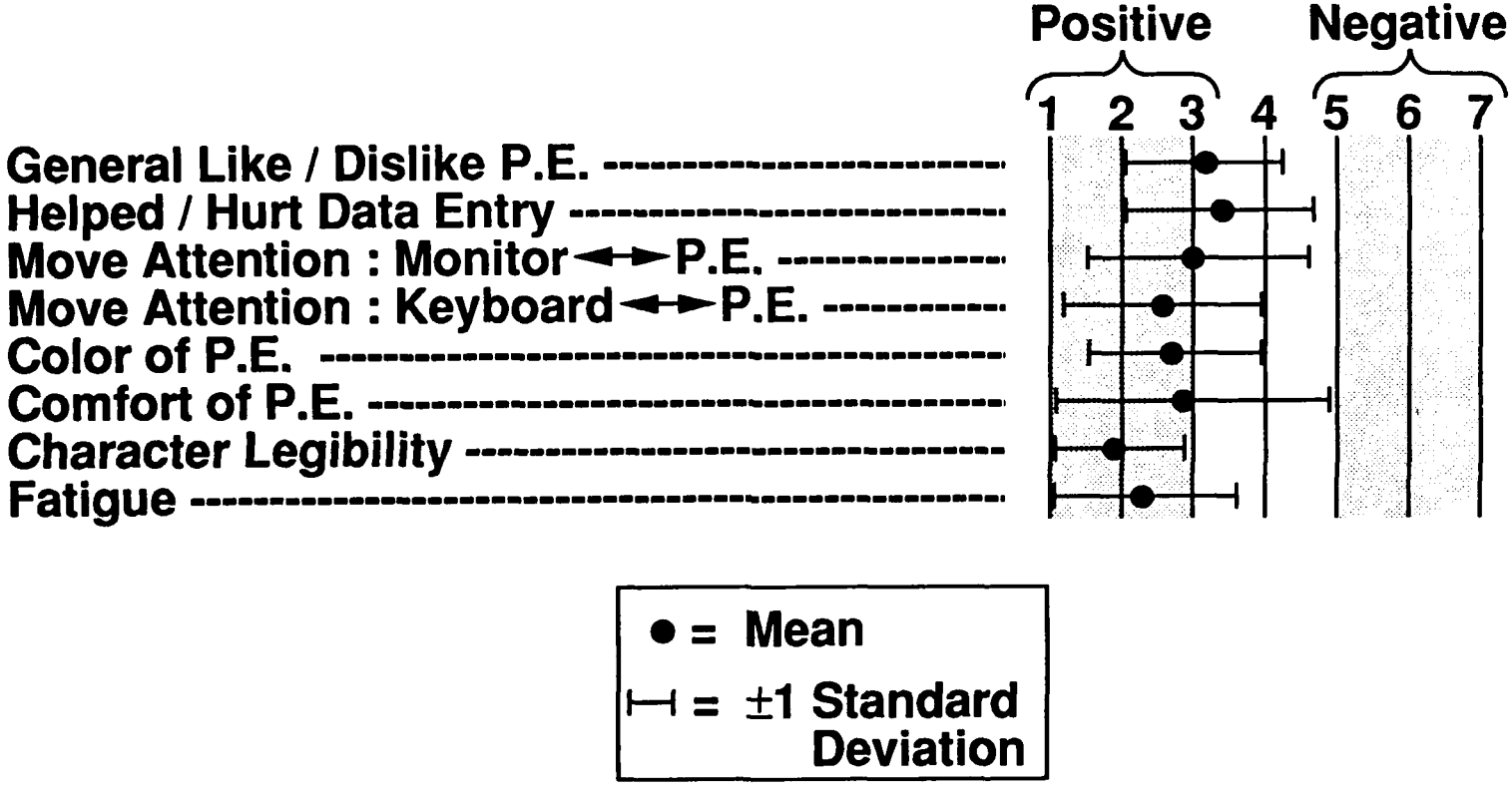


Figure 4-1. Summary of Subjective Ratings

As was expected, there were a variety of explanations for this rating, most of which were detailed in subsequent responses. There was about an even mix of favorable and unfavorable comments made by the subjects. Favorable ones included a reduced number of required eye movements and refocusing; unfavorable ones concerned difficulties getting used to the Private Eye (particularly to its head harness) and its use with bifocals.

- "Please rate how the Private Eye affected your ability to enter data."

  A rating of 1 = helped it; a rating of 7 = had no effect; a rating of 7 = hurt it

  Mean Score: 3.4
  Standard Deviation: 1.3

The respondents were generally divided about the Private Eye's support to the entry of flight strip data. About half said it helped, several stating they did not have to keep moving their head and eyes as they did when using the printed paper source. Others said that using paper is a more familiar task, that it was harder to keep their place with the Private Eye.

- "Please rate how easy it was to move your attention between the PC Monitor and the Private Eye."

  A rating of 1 = easy to do; a rating of 7 = hard to do

  Mean Score: 3.0
  Standard Deviation: 1.4

Most of the subjects reported little difficulty in looking between the PC monitor and the Private Eye. Of the few who had problems, one said that because of his bifocals, he had to tilt his head to view the monitor.

- "Please rate how easy it was to move your attention between the keyboard and the Private Eye."

  A rating of 1 = easy to do; a rating of 7 = hard to do

  Mean Score: 2.6
  Standard Deviation: 1.4

Both the rating scores and the opinions were similar to the previous question. A few of the subjects had problems looking between the keyboard and the Private Eye, one saying that the Private Eye tended to obscure his vision of the keyboard. Problems were again reported when wearing bifocals. It is likely that the subjects' typing ability affected both questions 3 and 4, since a more skilled typist would tend to look between the Private Eye and the monitor or keyboard fewer times than would a less skilled typist. The one reported problem with the keyboard's being obscured might have been solved by slightly raising the Private Eye; thus, these two questions could also have been affected by the positioning of the Private Eye.

- "Please rate the color of the characters on the Private Eye."

  A rating of 1 = likes; a rating of 7 = disliked

  Mean Score: 2.8
  Standard Deviation: 1.2

About half of the subjects were noncommittal or indifferent about the Private Eye's red-on-black display. Of those with an opinion, four held positive attitudes toward the color, saying, for example, that the color did not interfere with the color of the monitor. Four subjects had negative opinions, preferring white, amber, or green characters. Based upon the subjects' subsequent explanations, it is likely that several of the ratings were not based solely upon color, but were also (positively) affected by the brightness and contrast of the Private Eye display.

- "Please rate the legibility of the characters on the Private Eye."

  A rating of 1 = legible; a rating of 7 = illegible

  Mean Score: 1.9
  Standard Deviation: 0.9

Although the legibility ratings were relatively high, there were complaints from many subjects that the spacing between adjacent words was too small. Several subjects said that it took a moment to focus their eye on the Private Eye, whereupon the legibility became acceptable. There was also confusion reported between the letters "U" vs. "V", "C" vs. "G", and between the letter "l" vs. the numeral "1". Character legibility is a function of the brightness and contrast of the characters, as well as the font style of the characters themselves. It is likely that the Private Eye's relatively high degree of brightness and contrast compensated for perceived deficiencies in the fonts, thus accounting for the generally positive ratings given to this question.

- "Please rate your fatigue during and after using the Private Eye."

  A rating of 1 = little fatigue; a rating of 7 = much fatigue

  Mean Score: 2.3
  Standard Deviation: 1.3

About 1/3 of the subjects reported some degree of fatigue after completing the study. Four of the subjects reported some eye fatigue, but it only ranged from slight to moderate; two others reported neck fatigue or discomfort related to wearing the head harness. Although the task was designed to require a rather unrealistically concentrated use of the Private Eye, it only lasted for about 20 minutes. If, as intended, the concentrated nature of this task compensated for its brief duration, it is possible that these ratings could be representative of a longer, more appropriate task.

- "Please rate the comfort of wearing the Private Eye."

  A rating of 1 = comfortable; a rating of 7 = uncomfortable

  Mean Score: 2.9
  Standard Deviation: 1.9

As noted above, ample time was given for the subjects to adjust the position of the Private Eye and its head harness. In spite of this, about half of the subjects had adverse, although not severe, comments. Most complained about the unbalanced headset which placed more pressure on one side of the head; one suggested some kind of counterbalance.

- "Did you notice flicker on the Private Eye? If yes, please rate how bothersome it was."

Five subjects noticed flicker, ghosting, or character movement on the Private Eye. Three perceived some movement of the Private Eye characters themselves, and a fourth felt the movement was due to refocusing his eye, not to the Private Eye. Also, two of these five subjects sometimes perceived ghosts or after-images on the display. The subjects rated their

perception of perceived flicker and its related phenomena from "not bothersome" (a rating of 1) to "very bothersome" (a rating of 7). The mean rating by these five subjects was 3.5 with a standard deviation of 2.1.

- "Did you have any problems judging how far away objects were from you (that is, your ability to judge close-up distances) when you were using the Private Eye? If yes, please describe them. When did they occur? Is there any way you can think of to deal with them?"

This question was intended to establish whether blocking one eye (and the resultant lack of "binocular parallax") impeded the subject's depth perception, and thus his/her task performance. Only 1 of the 17 subjects said he had a depth perception problem, and even this was relatively mild since he was able to compensate for it. Several subjects noted that they were able to look below the Private Eye and thus retain normal vision of the keyboard. Thus, the subjects were either able to appropriately locate the Private Eye or to use other depth perception cues than binocular parallax; the result was virtually no interference with depth perception.

- "Did you develop any special techniques for doing the task while you were wearing the Private Eye?"

This question was intended to enlarge upon any other special compensations that the subjects developed to deal with perceived display problems. About one third responded that they had developed some special "tricks" to help them perform the task, but most did not attempt any special techniques. Several noted that they carefully positioned the Private Eye so that they could more easily look at the monitor and/or the keyboard; one noted that he attempted to use only eye movements, not head movements, when looking at the keyboard. All three bifocal users found that using the top of the lens (the distance correction) was more suitable.

- "Do you have any other comments or suggestions about the Private Eye? Technical features? Application to this type of task? Application to any other type of task?"

Regarding the features of the Private Eye, a shortfall noted by two subjects was that field 8, the rightmost field, could not be properly displayed on the Private Eye and that the display should be wider; however, since only two reported this problem, perhaps the problem was caused by improper placement of the device. Another subject reiterated his problems using bifocals; a third complained that the Private Eye blocked part of the information on the PC monitor. One subject suggested that the typed input be "echoed" on the bottom line of the Private Eye as it is entered; another suggested that the brightness of the Private Eye's display be adjustable; a third said it should be capable of being flipped up, moving it out of the line of sight.

As expected, it was noted that the Private Eye is not suited to a concentrated data input task, particularly over an extended period of time; the paper was said to be an easier source of data for such a task.

A suggested application was a task in which the user is not able to stay in front of a fixed display. Another was a suggestion for an application requiring the display of slides or graphic data which change infrequently and/or would not have to be continuously monitored. One subject suggested the ability to see through the Private Eye, past the display information, similar to an aircraft's heads-up display. An application was also suggested in which information must be displayed to an individual in a darkened environment (e.g., on an instructor's display in a training simulator).

One subject first used his nondominant eye for the entire procedure, and subsequently repeated the Private Eye portion of the evaluation using his dominant eye. He reported that using the dominant eye seemed less irritating and made it easier to concentrate on the display with both eyes open. Although he perceived jitter during both sessions, it seemed less aggravating with the dominant eye.

4.2 PERFORMANCE DATA

The objective performance data was quantified in terms of the average number of characters per minute and number of incorrect fields per flight strip. It will be recalled that errors were not counted which were corrected by the subject before the field was entered; only uncorrected errors were recorded.

Figure 4-2 shows the average number of character/minute entered on each of the 22 successive flight strips, including the time to detect and correct errors. The figure indicates that the average input rate for paper was higher then for the Private Eye on nearly every flight strip. Of more interest is the additional indication from this figure that performance on both printed material and Private Eye depended to a great extent on the particular strip being entered. For example, the rate of entry from both sources was lower on flight strip 7 and 19 and relatively higher on strips 9 through 13.

The Private Eye had an average input rate of 76.6 characters/minute for all flight strips with a standard deviation of 26.2; the overall rate was 80.1 characters/minute for the paper material with a standard deviation of 22.7. Because of this substantial variability under both conditions, this 3.5 character/minute difference between the means of the two sources was not statistically significant.

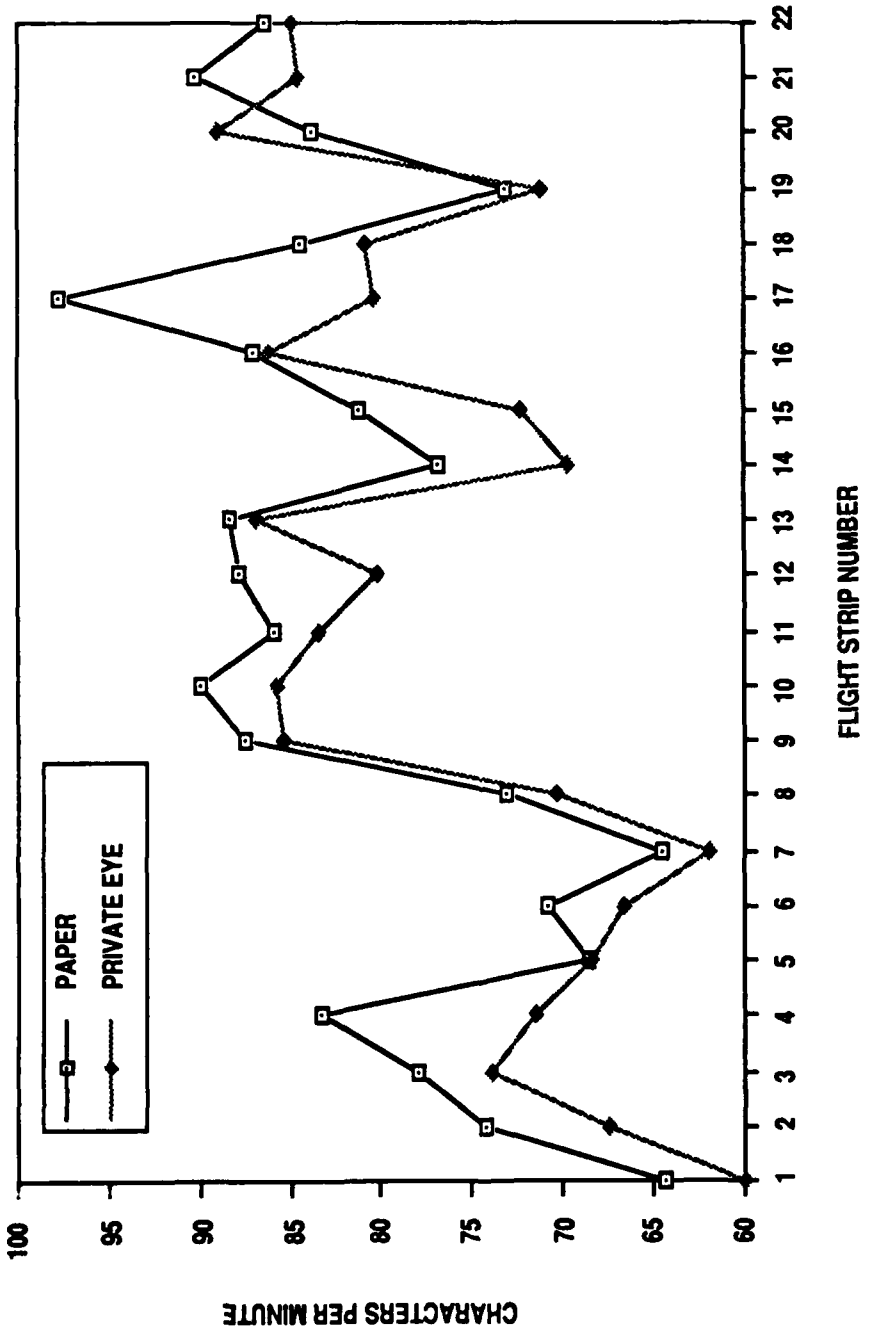


Figure 4-2. Key Entry Rates from Private Eye and from Paper

Of the roughly 22,000 keystrokes made by all subjects under each condition, there was a total of 95 errors when using the Private Eye and a total of 70 errors when using the paper. Most of the errors in both conditions involved hitting an incorrect character; the next most frequent error was the insertion of an additional character; the third most frequent error was skipping a character. Apparently the flight strips were roughly equivalent in difficulty since no flight strips appeared to be consistently more error prone than others.

4.3 RELATIONSHIP TO SUBJECTS' CHARACTERISTICS

Subjects were divided into two groups, those who gave more favorable ratings (three or more questions with ratings of 1) and those who gave less favorable ratings (three or more questions with ratings of 5 or above). There was no apparent relationship between subjects' tendency to give favorable or unfavorable ratings and their needs for corrective lenses nor their amount of reported keyboard experience.

SECTION 5

DISCUSSION

5.1 SUBJECTIVE DATA, OVERALL

It is widely accepted that rating scales are susceptible to several biases due to people's "built-in" attitudes and characteristics. One of these biases which may have been a factor in this evaluation is called the bias of "central tendency" or the predisposition to avoid extreme statements, positive or negative, tending to force ratings toward the midpoint of the scale.

The subjects' overall ratings of the Private Eye ranged from slightly favorable to neutral, as indicated by their ratings and their stated opinions. Many of the ratings were toward the positive end of the rating scale, falling mostly between 2.8 and 4.2. The first question indicated a generally neutral attitude toward the device. More detailed questions indicated slightly positive attitudes toward the Private Eye's legibility and color and more neutral attitudes for the suitability of the Private Eye to the task, since the application was not optimized.

5.2 SUBJECTIVE DATA, INDIVIDUAL ISSUES

Depth Perception. The Private Eye blocks the visual field of one eye, thus limiting binocular parallax cues to stereoscopic vision. In spite of this blockage, it did not impede the task chosen for this study. There was not a substantial requirement for stereopsis when looking at the keyboard or PC monitor, and it is likely that single eye vision would suffice even if the subjects had not learned to look around the Private Eye. However,

other applications may depend upon binocular parallax to a greater extent. If these applications also limit other cues, stereoscopic perception may be reduced. Each application of the device thus must be evaluated with this limitation in mind, particularly if it involves a safety risk. To retain binocular parallax cues while keeping the Private Eye conveniently available, it is suggested that the device be able to be flipped up, totally out of the line of sight.

Color/Contrast. The red color of the display did not cause consistent objections from the subjects, although some preferred other colors perhaps because they are accustomed to them. The contrast and brightness of the display seemed quite good, but a possible enhancement would be to make the brightness adjustable.

Fatigue. There seems to be little reported fatigue in the eye used to view the Private Eye. Although the Private Eye was only used for about 20 minutes, this time limitation might be somewhat offset by the concentrated nature of the task. These results might thus be generalized to a longer but less concentrated task; substantial eye fatigue may not occur up to a period of several hours if the Private Eye is not continuously viewed. Most of the fatigue seemed to result from the head harness and/or the need to keep the head steady while viewing the Private Eye, in spite of the fact that the device was worn for only a short time. The vendor has redesigned this harness, and the new design may compensate for some of these reported problems.

Display Artifacts. A few of the subjects noticed some vibration in the device, or some movement or "ghosting" of the images, but these subjects rated the perceived effects as not particularly objectionable. Perception of some artifacts by a minority of observers is not an unusual occurrance in display evaluations. Since these phenomena were not consistently reported by all subjects, they might be due to some individual

characteristic of the subject or perhaps to some other display artifact. In a conversation with E. Peli (Tufts and Harvard Universities), he noted a similar, transient artifact with the Private Eye when subjects moved their heads. The track in the present study did not require head or eye movement, but it is possible that these few subjects tended to move around more than the others, thus accounting for the reported phenomena. It is suggested that these effects be investigated further.

Font. The character font for the display must be carefully chosen. Differences in pixel aspect ratios result in slight changes in the height/ width ratio of characters when displayed on the Private Eye. For example, standard PC monitor text appears smaller on the Private Eye. Although a new font was designed for this experiment (18 point Times font), the result was tall thin characters and narrow blanks between words. Although zeros and the "Os" were deleted from the study, confusion related to the font design still occurred fairly frequently. It is suggested that font(s) be specifically designed for the Private Eye to overcome this limitation (e.g., Lincoln-MITRE font).

Device Adjustment. The Private Eye must be very carefully adjusted, and the users must be carefully instructed in how to best perform these adjustments. They must be given both the time and information to locate the head harness and the display in the most comfortable and workable position. It is possible that the subject who reported difficulty in seeing all of the Private Eye did not have the device positioned close enough to his eye. Similarly, those bifocal wearers who experienced difficulties might have avoided their problems had they positioned the device and/or adjusted the focus to allow them to consistently use either the top of their glasses (with the device focused for distance viewing) or the bottom of their glasses (with the device focused for close up). Ease of adjustment should be a prime concern in the redesign of the head harness.

5.3 PERFORMANCE DATA

There was not a substantial difference in the subjects' performance between entering data from the Private Eye and entering it from the paper source material, although the average performance was usually poorer when using the Private Eye. Even if the input rate had been statistically different under the two conditions, the obtained difference of only 3.5 character/minute would be trivial for nearly any technical application of the device. Likewise, when comparing errors under the two conditions, a total difference of 15 errors by all 17 subjects entering the total amount of information on all 22 flight strips could be considered to be a relatively trivial difference.

It is possible that there are some learning effects in using the Private Eye. Subjects might have become more used to the device and more proficient with it had they used it for longer periods of time over several days. However, this evaluation was intended to be relatively brief and to use as many subjects as possible. A systematic examination of learning was thus not feasible.

5.4 GENERAL CONCLUSION

The Private Eye was slightly slower and more error prone than was the paper material in this simulated air traffic control task. It is thus not an optimum device for continuous, concentrated data entry. However, in spite of its performance restrictions, subjects generally felt it was acceptable.

To summarize, this evaluation identified no intrinsic limitations in the usability of the Private Eye. Possible applications should capitalize on the portable nature of the display and its privacy aspects, displaying data not requiring continuous reading. Attention must also be given to the appropriate choice of an input device (e.g., voice recognition). Given such applications, this type of wearable display could have significant advantages.

Appendix A

The following were used as stimulus material from both the Private Eye and the presented material. They are reproduced here in the same size and font as they appeared on the paper

1 - HUSKY11 2 - B2/F 3 - 325 6 - P1525 7 - 415 8 - PSM

9 - PSM MPV IR711 ART172316

9a - REQ IR ENTRY AT MPV

1 - PUFF76 2 - F11/P 3 - 325 6 - P1855 7 - 211 8 - RME

9 - RME UCA ALB V2 GDM V431

9a - EMERGENCY

1 - CRANE32 2 - HS25/F 3 - 445 6 - P1135 7 - 115 8 - SCH

9 - SCH ALB EEN V93 CUN PSM

1 - KH34 2 - F117/P 3 - 425 6 - P1242 7 - 155 8 - PBG

9 - PBG PLB ALB AR216 ENE BGR

9a - AR WITH KEEPER63

1 - M14987 2 - C135/A 3 - 465 6 - P2244 7 - 225 8 - LFI

9 - LFI SAV CEW VPS

1 - A19372 2 - A4/A 3 - 465 6 - P1355 7 - 335 8 - MYR

9 - MYR VAN D1+11 MYR

9a - GAMECACK MIA

1 - VM5264 2 - CH53E 3 - 395 6 - P1715 7 - 225 8 - NHZ

9 - NHZ J29 ALB J75 JFK PAX

1 - SABER9 2 - T39/F 3 - 355 6 - P1335 7 - 175 8 - SSC

9 - SSC FLI VAN SSC

1 - PUFF37 2 - SR71 3 - 785 6 - P1123 7 - 435 8 - IAG

9 - IAG SYR ART SYR IAG

9a - REFUEL AT 1545

1 - TIGER87 2 - EA6B 3 - 485 6 - P1224 7 - 325 8 - PSM

9 - PSM CAN PLB191111 PBG

9a - TRAINING FLIGHT

1 - HUSKY29 2 - C5A 3 - 385 6 - P2352 7 - 255 8 - RME

9 - RME UCA ALB V2 GDM V431

9a - REQ IR ENTRY AT ALB

1 - KH15 2 - E3A 3 - 295 6 - P2112 7 - 345 8 - SCH

9 - SCH ALB EEN V93 CAN PSM

9a - SPECIAL

1 - A29461 2 - E3A 3 - 465 6 - P1111 7 - 285 8 - PBG

9 - PBG PLB ALB AR216 ENE BGR

9a - AR WITH KEEPER63

1 - VM3251 2 - C5A/P 3 - 322 6 - P1255 7 - 115 8 - LFI

9 - LFI SAV CEW VPS

1 - M17769 2 - F16/F 3 - 265 6 - P1537 7 - 295 8 - MYR

9 - MYR JFK PWL HFD BED

9a - REQ RNAV AT YSC

1 - SABER52 2 - A6 3 - 285 6 - P1649 7 - 245 8 - SSC

9 - SSC SSC144515 V56 SSC

9a - TRAINING FLIGHT

1 - TIGER43 2 - C141/F 3 - 355 6 - P2137 7 - 335 8 - IAG

9 - IAG SYR ART SYR IAG

9a - D1+11 STAR LIFTER

1 - HUSKY67 2 - KC135Q 3 - 315 6 - P1215 7 - 225 8 - PSM

9 - PSM MPV IR715 ART PSM

9a - REFUEL BLACKHAWK

1 - PUFF22 2 - B52/A 3 - 427 6 - P2247 7 - 85 8 - RME

9 - RME UCA ALB V2 GDM V431

1 - CRANE12 2 - S64 3 - 215 6 - P2357 7 - 65 8 - SCH

9 - SCH ALB EEN V93 CAN PSM

9a - D1+12 SKYCRANE

1 - KH25 2 - F18/F 3 - 345 6 - P2214 7 - 225 8 - NHZ

9 - NHZ J29 ALB J75 JFK PAX

9a - TRAINING FLIGHT

1 - A11687 2 - A10 3 - 225 6 - P1821 7 - 85 8 - PBG

9 - PBG PLB ALB AR216 ENE BGR

9a - AR WITH KEEPER63

(rev 2.5)

Name : _____ Date: _____
Interviewer: _____ Start Time: _____
Stop Time: ____

BACKGROUND DATA

Subject's job title (e.g., MTS, secretary etc): _____
Year in which Bachelors degree was received: _____

Subject's dominant eye: ___right ___left
Subject's eye used for Private Eye: ___right ___left

Subject's vision:

Normally wears glasses: ___yes ___no
Normally wears contact lenses: ___yes ___no
If yes, glasses/contact lenses needed for:
close up___
distance___
both (bifocals) ___
astigmatism ____
Glasses/contact lenses worn during study: ___yes ___no

Subject's estimated hours per week that he/she uses any type of keyboard (typewriter, PC, etc.):

__ less than 1, __1-2, __ 3-4 , __ 4-8,
__ 8-12, __ 12-16, __ 16-24, __ 24-30, __ over 30

OBSERVER'S COMMENTS

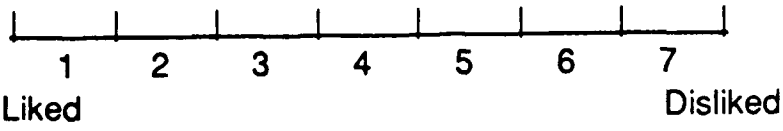
The observer should note below any of the subject's comments (verbatim) or any observations of behaviors which are relevant to his/her opinion or use of the Private Eye.

INTERVIEW

Interview Procedure: Interviewer reads each question to subject, asks him/her to make a rating (1 of 7 numbers only), and then asks why that rating was given.

---

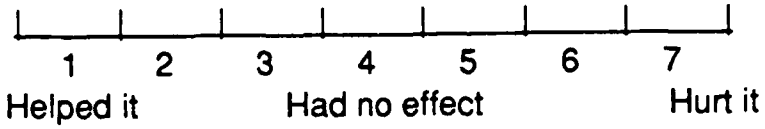
1) In general, how did you like the Private Eye.



Please explain

---

2) Please rate how the Private Eye affected your ability to enter data



Please explain:

3) Please rate how easy it was to move your attention between the PC Monitor and the Private Eye.

1 2 3 4 5 6 7

Easy to do Hard to do

Please explain:

---

4) Please rate how easy it was to move your attention between the keyboard and the Private Eye.

1 2 3 4 5 6 7

Easy to do Hard to do

Please explain:

---

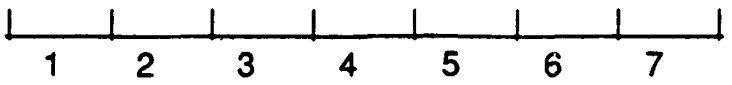
5) Please rate the color of the characters on the Private Eye

1 2 3 4 5 6 7

Liked Disliked

Please explain.

6) Please rate the legibility of the characters on the Private Eye

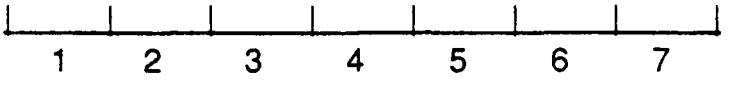


Legible Illegible

Please explain.

---

7) Please rate your fatigue during and after using the Private Eye

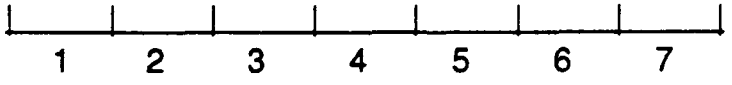


Little fatigue Much fatigue

Please explain:

---

8) Did you notice flicker on the Private Eye? If yes, please rate how bothersome it was.

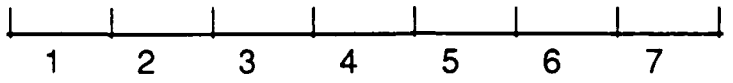


Not bothersome Very bothersome

Please explain:

---

9) Please rate the comfort of wearing the Private Eye



Comfortable Uncomfortable

Please explain:

---

10) Did you have any problems judging how far away objects were from you (that is, your ability to judge close-up distances) when you were using the Private Eye?

-If yes, please describe them:

-When did they occur?

-Is there way you can think of to deal with them?

---

11) Did you develop any special techniques for doing the task while you were wearing the Private Eye?

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12) Do you have any <u>other</u> comments or suggestions about the Private Eye?

-Technical features?

-Application to this type of task?

-Application to any other type of task?