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A comparison of textual, symbolic, and pictorial presentation of information on an air-seeder display

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Abstract

This paper reports a study on the display of information on an air-seeder display in textual, symbolic, and pictorial forms. Seven parameters that are monitored most frequently by experienced air-seeder operators (i.e. fan rpm, tank levels, application rates, blockage, forward speed, tool pressure, and tool depth) were selected. Computer programs were developed to present this information in textual, symbolic, and pictorial modes. Twenty university students participated as subjects in the study. The interactive computer programs recorded the subjects' response time and whether the response was correct or wrong. The shortest response time was achieved with the pictorial display (2.46 s) while the average response time with symbolic and textual displays was 3.10 s and 3.03 s, respectively. Further analysis revealed that five of the subjects showed particularly poor performance with the symbolic display. For the remaining 15 subjects, the symbolic display resulted in a shorter response time compared to the textual display (2.21 s versus 2.64 s) and 50% reduction in the number of wrong responses. Results of the experiment also indicated that further practice resulted in significant reductions in response time and response error. However, these improvements were significantly larger for the symbolic display than either textual or pictorial displays. Pictorial and symbolic representations are superior to the textual representation of the information on an air-seeder display. However, careful design of the symbolic and pictorial displays is necessary in order to ensure fast and correct operator response.

Keywords: ergonomic design; human factors; information processing; operator-centered design; tractor operator.

Introduction

Agricultural machines are becoming increasingly complex. Operators are expected to make appropriate control adjustments based on information learned from watching both the machine and a large number of displays present at the operator's seat. Human factors principles need to be taken into account in designing these displays, otherwise the operator cannot efficiently and correctly interpret the displayed information. Stated in more general terms, design of machinery systems should always consider the abilities and limitations of the human operator. Operator-centered design will ensure optimal system efficiency as well as ensuring the well-being and comfort of the operator. Another trend related to the design of machines is increased emphasis on automation. Although it was initially assumed that automation would eliminate human operators, it is now recognized that automation changes the role of the human operator (Sarter et al. 1997). To be precise, human operators are often expected to assume more of a supervisory role in the presence of an automated system. Well-designed information displays are perhaps even of greater importance when the human operator is expected to fulfill this supervisory role. Although automation of agricultural machines has been pursued for several decades, most of the research in this area has focused only on the machinery modifications (Blackmore et al. 2002; Noguchi et al. 2002; Reid and Niebuhr 2001; Gray 2002). Very little attention has been paid to the usability of the system from the operator's point of view. In this study, the design of air-seeder displays is examined. When the appropriate information is displayed for the operator using effective means, the usability of the system is likely to improve. The concept of "situation awareness" can be used to determine whether the correct information is being displayed. Endsley (1988) defined situation awareness as "*the perception of the elements of the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future*." Using a tractor-machine system as an example, "Level 1" situation awareness is achieved when the operator perceives a change in the functioning of the tractor-machine system. If the operator also understands what the perceived change means, "Level 2" situation awareness has been achieved. To achieve the final level of situation awareness (i.e., "Level 3"), the operator must be able to anticipate the consequence of the perceived change in the near future. Previous research in Finland has shown that sprayer displays provided sufficient information to enable the operator to achieve "Levels 1 and 2" situation awareness, but not "Level 3" situation awareness (Nurkka 2006). This preliminary research suggests that current agricultural machinery systems warrant further review. The authors are not aware of any further published studies describing the usability of modern agricultural machines such as are currently being used in western Canada. An information display is a key component of modern air-seeder systems being used by Canadian farmers. The display is installed in the tractor cab and provides information to the operator about the working parameters of the air-seeder. In general terms, displays are used to convey relevant information about the inner workings of a system to the human operator. They are also used for providing advice, warning, or other instructions

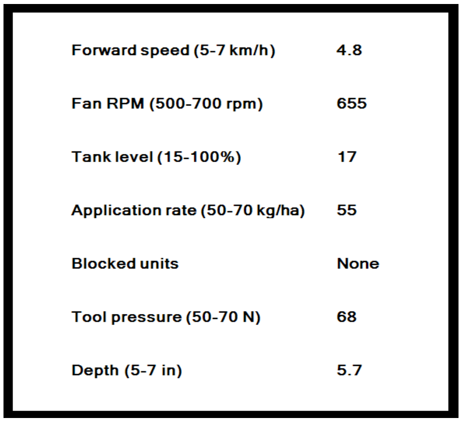

Fig 1. A snap shot of the textual air-seeder display.

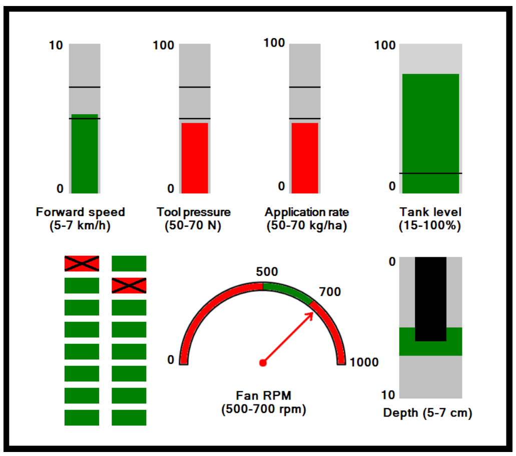

Fig 2. A snap shot of the symbolic air-seeder display.

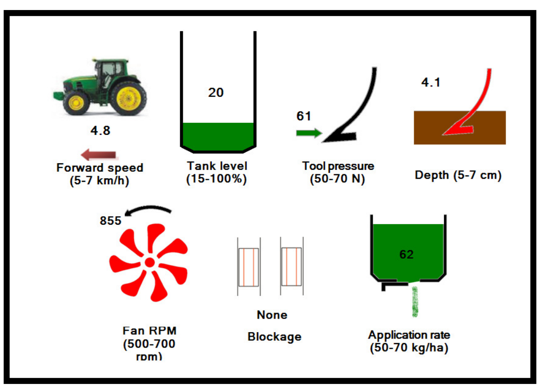

Fig 3. A snap shot of the pictorial air-seeder display

to the operator. Although non-visual displays, such as auditory and haptic devices, can be used, most of the displays in use today are visual. There is a vast literature on visual display design (e.g. Tufte, 1992) which provides guidelines for designing visual displays that convey the information most effectively so that the operator can identify and understand various pieces of information with minimal delay and effort. Visual displays can provide the relevant information in textual, symbolic, or pictorial form. Textual representation uses only textual characters to convey information using language or numbers. Symbolic representation relies on icons or similar symbols. The user is expected to learn the meaning of a given icon or symbol with appropriate training. In pictorial mode, on the other hand, the goal is to provide a graphical representation that is as close to the real parameter or system component as possible. With this approach, it is as if the user is viewing the actual system to obtain the desired information. For example, to show the level of liquid solution in a container in a chemical process, the display can show a number indicating the amount of solution (textual representation), it can use a symbol such as a dial indicator (symbolic), or it can show a pictorial representation that is very similar to the tank partially filled with solution (pictorial). Long and Kearns (1996) compared textual and symbolic (i.e. icon) formats for highway signs. They considered four different highway signs at two different driving speeds. Their results showed that the threshold size for accurate identification was significantly larger for the textual signs compared to the two sets of symbolic signs in almost all cases. Kline et al. (1990) compared textual and iconic presentation of four different highway signs for drivers of various ages. Their study showed that icons were visible at much longer distances compared to textual signs under both day and dusk conditions. In another study, Kline and Fuchs (1993) designed improved symbolic highway signs by low-pass filtering (i.e. blurring) of conventional symbolic signs. They studied visibility distance of textual, symbolic, and improved symbolic signs. Their results indicated that the symbolic signs are visible at distances that are on average twice larger than those for text signs. Furthermore, the visibility distances for the improved symbolic signs were significantly greater than those of the conventional symbolic signs. Shinar et al. (2003) studied the comprehension of traffic sign symbols in four different countries for various age groups. One of the conclusions of the study was that textual information should be added to the symbolic representation only if the symbolic representation is largely misinterpreted by the drivers. Smallman and John (2005) studied realistic displays that are gaining popularity for presenting geospatial data in a wide range of tasks including air-traffic control and military operations. Their study indicated that realistic displays often result in poor operator performance. Their examples show that interpretation of the state-of-the-art realistic visualizations may be wrong and that well-designed symbolic representations may be easier to interpret. Mouloua et al. (2003) suggested that icons and symbols can reduce the recognition time for operators of unmanned aerial vehicles. They also suggested that graphical display of information is more effective when they are filtered or enhanced properly and careful judgment is exercised in choosing their color. Hirst and Graham (1997) compared several combinations of visual and auditory displays for presenting collision warnings to automobile drivers. Their visual displays included two symbolic displays in the form of horizontal bars with different designs as well as a pictorial display. Each of these visual presentations was accompanied by some form of simultaneous auditory warning. The results of their experiments that were carried out in a simulated environment indicated that the symbolic display in the form of a color-coded horizontal bar was superior to the pictorial display in terms of both the braking reaction time as well as the number of collisions. This form of visual presentation also received the most favorable subjective feedback from the participants in the experiment. The objective of this study is to compare the effectiveness of textual, symbolic, and pictorial representations of the information displayed for air seeder systems in terms of response time and number of response errors.

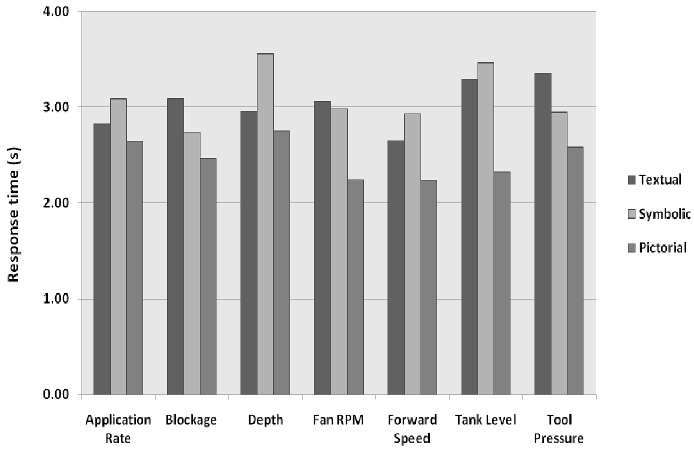

Fig 4. Average response time of the 20 subjects for each of the seven parameters and each of the three displays

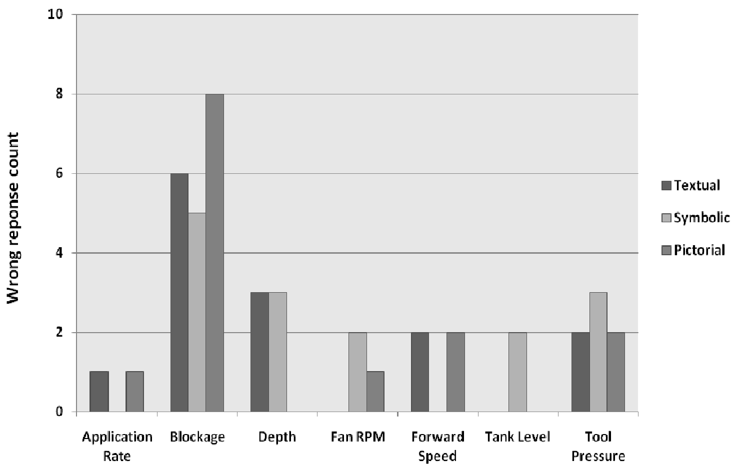

Fig 5. Total number of wrong responses for all 20 subjects for different parameters and display modes.

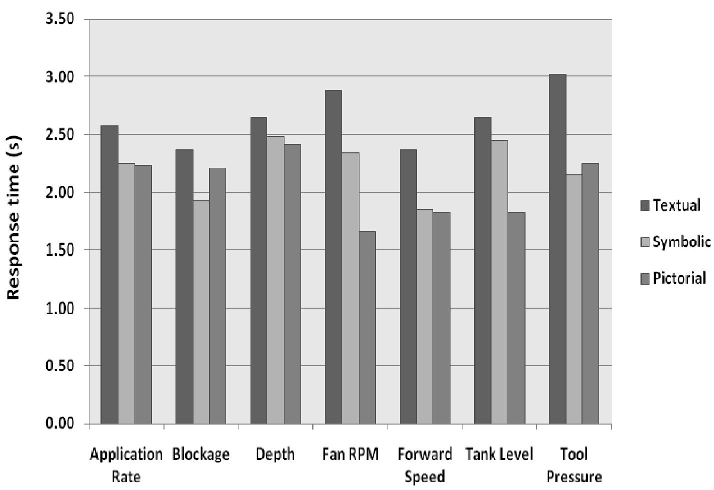

Fig 6. Average response time for 15 subjects that had higher performance.

The immediate application of this research is to select displays to be used in a tractor-air seeder (TAS) simulator currently under development in the Agricultural Ergonomics Laboratory in the Department of Biosystems Engineering at the University of Manitoba. Ultimately, with the use of the simulator, it will be possible to study the usability of both existing and proposed display designs.

Results

The average response time for all 20 subjects is shown in Fig. 4. The figure shows the average response time for each of seven parameters and for each of the three displays (n = 60; 3 replicates for each of 20 subjects). For all seven parameters, the fastest response was achieved with the pictorial display. The average response time for all seven parameters was 2.46 s for the pictorial display, 3.03 s for the textual display, and 3.10 s for the symbolic display. In terms of the number of wrong responses, a total of 15 wrong responses occurred with the symbolic display and a total of 14 wrong responses were recorded with each of the textual and pictorial displays. Figure 5 shows the breakdown of the number of wrong responses for each of the parameters and each of the three displays.Further analysis of the data showed that five of the subjects had significantly poorer performance compared to the other subjects. These subjects were identified as having a response time that was more than two standard deviations larger than the average standard deviation of all subjects. These five subjects also had poorer performance in terms of the number of wrong responses. Out of the total of 43 wrong responses from all 20 subjects, 26 of them (i.e. 60%) were committed by these 5 subjects. Therefore, the performance of the remaining 15 subjects was analyzed separately (Figs. 6 and 7). After removing the 5 outlier subjects, the performance of the remaining 15 subjects is much different from the average response of all 20 subjects. For the new set of 15 subjects, the average reaction times are 2.64, 2.21, and 2.06 s for textual, symbolic, and pictorial displays, respectively. In other words, the average response time was shorter for the symbolic display than for the textual display. An analysis of variance showed that the differences between pictorial, symbolic, and textual displays were significant at the 5% confidence level. Furthermore, after removing the 5 outlier subjects, the total number of wrong responses for the remaining 15 subjects for pictorial, symbolic, and textual displays was 5, 4, and 8, respectively. In other words, pictorial and symbolic displays resulted in a significant reduction in the number of wrong responses compared with the textual display. Overall, the pictorial display resulted in the fastest response for five of the parameters (i.e., application rate, depth, fan rpm, forward speed, and tank level) whereas the symbolic display resulted in the fastest response time for the other two parameters (i.e., tool pressure and blockage).

Discussion

There are two major observations that can be identified in the results of this study. First, the pictorial display was the best of the three. It resulted in the lowest response time and a small number of wrong responses. Unfortunately, we were unable to find previously published studies that compare pictorial, textual, and symbolic displays in terms of response time and/or response accuracy. Therefore, we cannot compare our results with those of other studies. The second observation is related to the symbolic display.

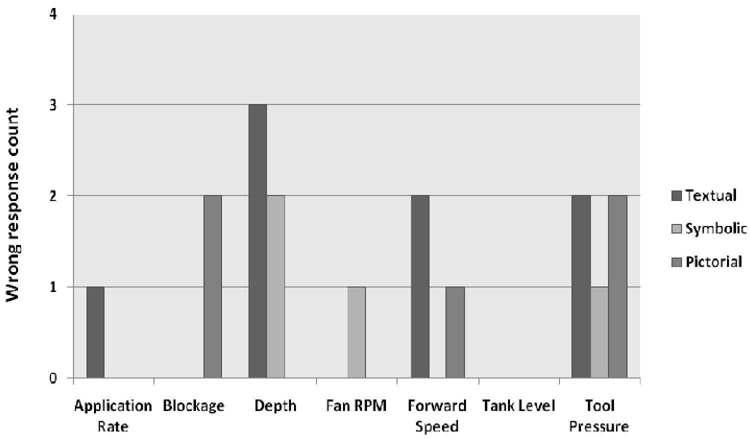

Fig 7. Total number of wrong responses for 15 subjects that had higher performance.

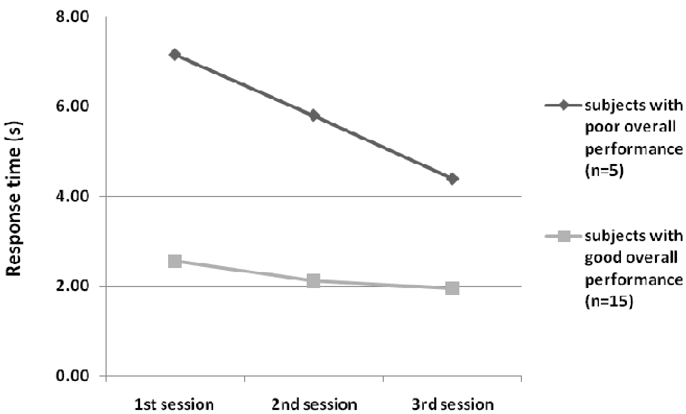

Fig 8. Improvement in the response time with session number for subjects with good and poor performance for the symbolic display.

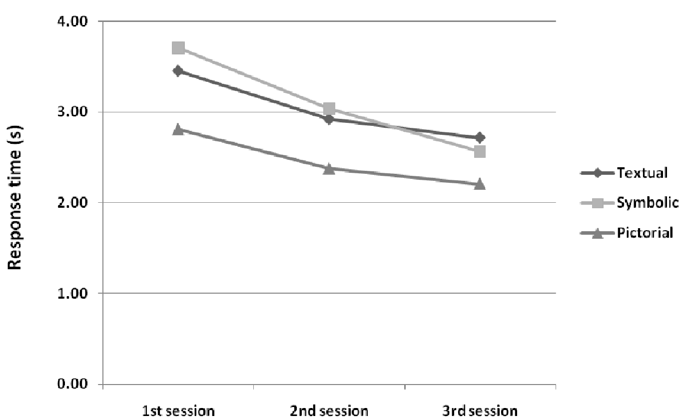

Fig 9. Change in operator response time with session number.

Even though the symbolic display resulted in the longest response time and largest number of errors when considering all 20 subjects, further analysis showed that this was due to the particularly poor performance of a small number of subjects. Disregarding those subjects, the response time with the symbolic display was superior to the response time with the textual display and very close to that of the pictorial display. In terms of the response accuracy, the symbolic display was superior to both the textual and pictorial displays. In order to understand why five of the subjects performed differently compared to the rest of the subjects, the change in the response time with the session number was plotted for the symbolic display (Fig. 8). The performance of the five subjects with poor overall performance improved significantly for the second and third sessions. Although these subjects performed better with the textual display than with the symbolic display during the three experimental replicates, it is likely that their performance with the symbolic display would have continued to improve with further use. With sufficient experience, performance with the symbolic display may have surpassed performance with the textual display. Figures 9 and 10 show the change in operators' response time and error for all 20 subjects. These graphs can be interpreted as the learning graphs for these three display modes. Performance improvement is greater with the symbolic display compared to the textual and pictorial displays. This is true for both the response time as well as response errors. Therefore, it is reasonable to expect that with more practice, operators' performance with the symbolic display will greatly improve.

Materials and methods

Subjects

The study was conducted in the Agricultural Ergonomics Laboratory in the Department of Biosystems Engineering at the University of Manitoba. Twenty students (11 male and 9 female) were recruited as the study subjects. Previous studies (i.e. Whisenand and Emurian 1996; Caird et al. 2008) have used a similar number of subjects. The subjects were asked to sign a consent form before the start of the experiment. The study had been approved by the Education/Nursing Research Ethics Board of the University of Manitoba. Upon completion of the experiment, each subject was provided with an honorarium.

Displays

Typical air-seeder displays provide information about various aspects of the air seeder unit. Some information is of secondary importance and not regularly monitored by the operator. We selected seven parameters that are most frequently monitored during field operation: 1) fan rpm, 2) tank levels, 3) application rates, 4) blockage, 5) forward speed, 6) tool pressure, and 7) tool depth. For the experiments described in this paper, a "desirable range" was selected for each of the parameters. The desirable range for each parameter was included next to the parameter name on the display so that the test subjects would not be required to memorize this information. For example, the desirable range for ground speed was considered to be 5-7 km/h. These ranges were chosen arbitrarily and do not represent the actual ranges of the corresponding parameter in the field. The following three displays were designed to show these seven parameters:

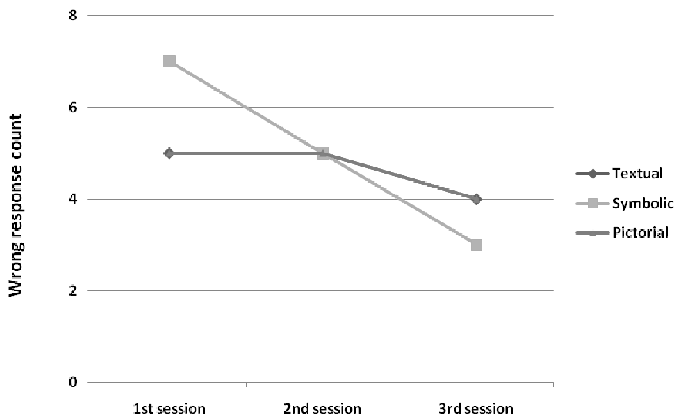

Fig 10. Change in the number of wrong responses with session number. Note that the graphs for pictorial and textual displays are on top of each other.

- Textual display: On this display, all the information was provided using simple text, with no graphics. A picture of the textual display is shown in Fig. 1.
- Symbolic display: All seven parameters were presented using symbols (Fig. 2). The symbols included four vertical bars for forward speed, tool pressure, application rate, and tank level. For the seeding-depth parameter, an upside-down vertical bar was used and for fan rpm a dial symbol was used. The blockage was shown using an array of green squares. Every time a blockage occurred, the corresponding square turned red and a black cross appeared on the square to indicate the blockage. In designing the symbolic display, commonly accepted design rules such as those provided by O'Hare and Stenhouse (2008) and Letho and Buck (2007) were followed to ensure that the symbols were easy to learn. Green color was used in all symbols when the parameter was within the desirable range. When the value of the parameter was outside the range, a red color was used instead.
- Pictorial display: In this display, all seven parameters were presented using pictures or drawings (Fig. 3). Pictures were designed so that the operator can easily understand and respond to the parameters. Similar to the symbolic display, colors green and red were extensively used to indicate when the value of a parameter was within or outside the desirable range. The actual numeric value was displayed next to each picture.

Experimental procedure

The three displays explained above were implemented in Microsoft Visual Basic. A program was developed for each of the displays. Each session consisted of seven questions, one regarding each of the seven parameters. The order of the questions changed on a random basis. Once the operator started the program, a screen appeared showing a question regarding one of the parameters. The question always asked whether the value of the specific parameter was "OK". For example, the question about the fan rpm was: "Is the fan rpm OK on the next screen?" The operators could spend as much time as needed reading the question. When they understood the question, they clicked on a button to show the air-seeder display. The value of each of the parameters changed by the program on a random basis every time the air-seeder display was shown. Then the operator had to respond as quickly as possible on one of the two buttons: "YES" or "NO". For example, if the question was regarding the fan rpm and the value shown on the display was outside the desirable range, the operator had to choose the "NO" button. The program automatically ended after the operator had responded to seven questions. The computer program saved the questions, the operator's answers as well as the response delays. The response delay was computed as the time between when the air-seeder display was shown and the time when the operator clicked on one of the response buttons (i.e., "YES" or "NO"). Before the subjects started the experiment, they were given a description of the experimental procedure. The three different air-seeder displays were shown to the subject and all seven parameters were explained. Subjects were instructed on how to work and interact with the program. Because the workings of the program were very simple, generally subjects were able to work with the program very quickly. The subjects were allowed to work with each of the three displays for two or three times or until they were confident with all three displays. After that, each subject completed three sessions with each of the three displays (i.e., nine sessions in total).

Conclusions

This study investigated different modes of presenting information on an air-seeder display. Pictorial presentation resulted in the fastest response. Symbolic display resulted in faster response than textual display for most of the subjects, however, 25% of the subjects in this study showed difficulty learning the symbolic display. They performed much worse with the symbolic display than with either the pictorial or textual display. With more experience, their performance with the symbolic display showed improvement. Relatively poor performance of some of the subjects with the symbolic display may be attributed to non-optimal design of the display. For example, three of the symbols had exactly the same shape and were located adjacent to each other. For these symbols, the subjects had to either memorize the location of each of the three parameters or read the labels each time they wanted to read one of them. Our analysis showed that in the last session, the symbolic display resulted in faster response time compared to the textual display. Moreover, in the last session, the symbolic display resulted in the smallest number of wrong responses.

Acknowledgments

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