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Effects of Resolution and Field of View On Various Digital Kneeboard Tasks

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

//Signed//

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Effects of resolution and field of view on various digital kneeboard tasks

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ABSTRACT

As display technology moves forward, we are seeing the replacement of paper information in cockpits with digital information. Soon the stack of paper carried on the pilot's knee will be replaced with a digital kneeboard in which the information will not only be displayed, but also manipulated and changed. There are several options for viewing this information, including both a helmet-mounted display (HMD), a small display that rests on the knee (replacing its paper counterpart) or is mounted in the airframe. However, in either case the question arises as to what are the resolution and field-of-view requirements for optimal performance of various tasks. We examined the readability and task performance using the Antelope Technologies Rugged Handheld 01 display which has a resolution of 1024 x 768 (XGA), and the ADR model FG-8000 display with a resolution of 800 x 600 (SVGA). These two displays were used to manipulate the resolution variable as they were each used only in their native mode. Usability was tested with three different tasks at varying fields-of-view (FOV). The tasks required finding and reporting information displayed from: 1) aviation approach plates, 2) FalconView™ mission planning software, and 3) pseudo-checklists. For the checklist tasks we also manipulated font size to more precisely investigate readability. Results are discussed in terms of both FOV and resolution requirements for each of the tasks. Several recommendations are given for both display requirements as well as tests for examining usability of digital kneeboards.

Keywords: digital kneeboard, electronic flight bag, display, field of view, resolution

1. INTRODUCTION

As information processing and display technologies improve, there is a steady shift from the use of paper-based information to digital information. This shift is likely to continue into the cockpit, where charts, maps, checklists, etc. will be displayed digitally. In fact the commercial aviation community has already started to embrace digital kneeboards or electronic flight bags (EFBs) with several vendors supplying the commercial aviation world[1]. Such an arrangement frees the pilot from handling and securing stacks of important information before, during, and after flight. Traditionally, pilots have attached such stacks of paper to a "kneeboard" that was worn in the cockpit. In the future, the information may be displayed on a "digital kneeboard," a helmet-mounted display (HMD), or a display mounted to the airframe.

However, there are many potential human factors issues no matter how or where the information is displayed. To determine the advantages, disadvantages, and unique characteristics of such a display system, we studied the resolution and field-of-view (FOV) requirements for optimal readability and usability on three different tasks. Resolution was manipulated by use of two different displays: Antelope Technologies Rugged Handheld 01 display which has a resolution of 1024 x 768 (XGA), and the ADR model FG-8000 display with a resolution of 800 x 600 (SVGA). FOV was manipulated by varying the distance between the observer and the display, corresponding to 10, 15, 20, 25, 30, and 40-degree FOVs. In the third task, font size of textual information was also varied between 8, 10, and 12 point font.

We investigated three representative tasks that one might consider the first options for replacing paper with digital information. The first task required visually searching and reporting information displayed from aviation approach plates. The second task required searching and reporting information displayed on FalconView™ mission planning software. Finally, the third task required answering questions displayed in check-list format. We discuss each task in terms of the best resolution and FOV for optimal performance.

2. EXPERIMENT 1

2.1. Method

The purpose of the first experiment was to test observers on the readability of approach plates. Approach plates are flight information booklets that contain airport diagrams, approach and departure procedures, and other vital radar and instrument information. An example approach plate is seen in Figure 1[2].

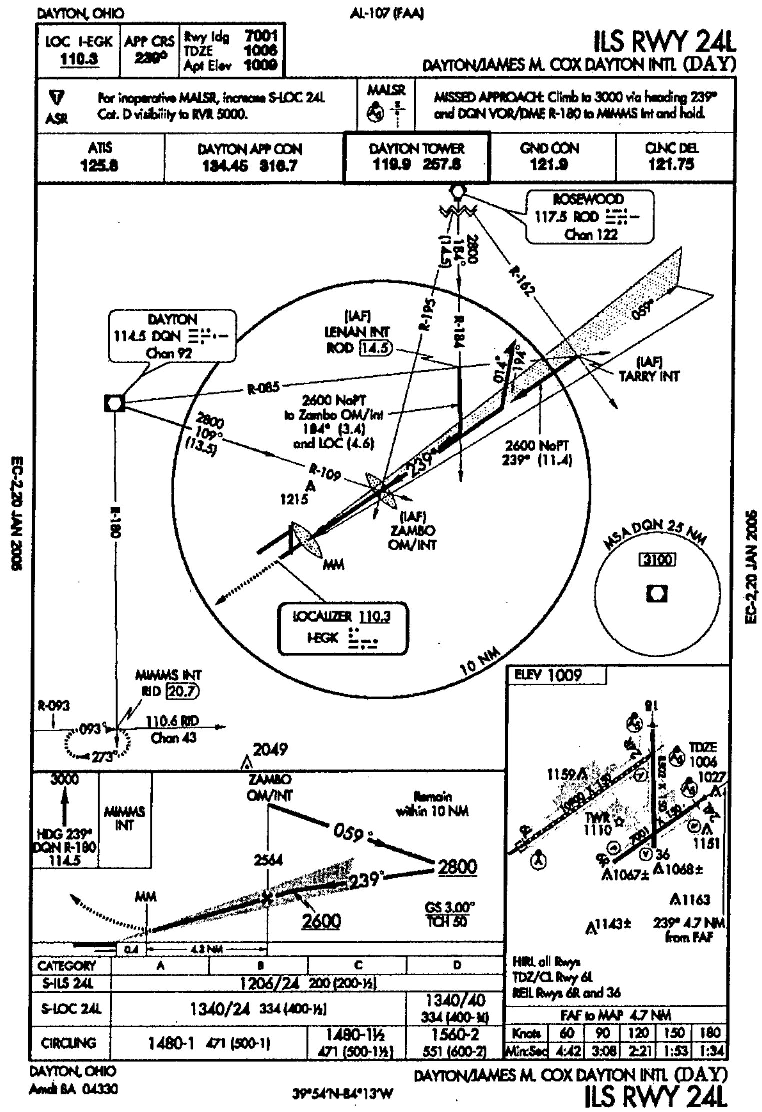

Figure 1. Example approach plate used in experiment

2.2. Participants

Twelve volunteers participated in the experiment, and all observers had normal or corrected-to-normal visual acuity.

2.3. Apparatus and Stimuli

Two displays were used in this experiment: the Antelope Technologies Rugged Handheld 01[3] (hereafter referred to as the Antelope) which has a resolution of 1024 x 768 (XGA), and the ADR model FG-8000[4] (hereafter referred to as the ADR) with a resolution of 800 x 600 (SVGA). Both systems utilized Microsoft® Windows operating systems.

Observers sat at the end of a table and faced the display. A chinrest mounted on the end of the table was used to keep the observer at the correct distance for each trial and centered their line of sight with the center of the display. On the table sat a movable display mount that allowed the experimenter to slide the display toward and away from the observer. By sliding the display at set distances for different trials, the experimenter was able to manipulate the field-of-view (FOV) of the observer. Several representative approach plates were chosen so that none were seen twice during the experiment.

2.4. Procedure

The main variables of interest were the field-of-view (FOV) and resolution requirements for display readability. Resolution was manipulated by changing which display the observer was viewing. The resolution of the Antelope display was 1024 x 768; the ADR's resolution was 800 x 600. FOV was manipulated by moving the display toward and away from the observer at specified distances. The FOVs used in this experiment were 10, 15, 20, 25, 30, and 40 degrees. The order in which different resolutions were presented was randomized across observers, and FOVs were randomly presented within each resolution.

Before beginning, each observer was briefed on the experimental task. Since the trials were not timed, we emphasized the need to answer as accurately as possible. Each task was generally broken into two sessions for each observer; one session per display. Each session took at most one hour to complete; many were completed in about half this time.

Observers received a brief instruction and answer sheet and were allowed to view and answer questions about two sample approach plates before beginning the trials. For each resolution and FOV, there were 6 trials consisting of two approach plates per trial. For each approach plate, observers had to visually search and then record answers to five questions. Questions referred to information on each plate, such as "What runway is this approach plate for?" and "What are the coordinates for the given airfield?" These questions were standardized for each trial. After answering the five questions for each of the two approach plates, the FOV was changed and the observer continued with the next two approach plates. After completing the first six trials, the questionnaire was issued, the display was changed, and the observer continued with six more trials. After completing the trials for each display, observers answered a brief subjective questionnaire.

2.5. Results

A full factorial analysis of variance (ANOVA) was conducted on the percent correct values, using resolution and FOV as the main effects. The analysis revealed significant main effects of resolution $F(1,132) = 4.67$, $p = .0324$, and FOV $F(5,132) = 87.00$, $p < .0001$. The interaction of resolution and FOV was nonsignificant at the .05 level. A post hoc analysis on FOV using Tukey's HSD test at the .05 alpha level revealed no significant differences between the FOVs: (20, 25, 30, and 40), but there were significant differences between that group and 10 and 15 degrees FOV as well as between 10 and 15 degrees FOV. The main effect of resolution is shown in Figure 2, and the main effect of FOV in Figure 3.

2.6. Discussion

As shown in Figure 2, observers performed better using the lower resolution. However there was no significant interaction of resolution and FOV for this task. One noticeable difference between the two displays used was that the ADR had a much higher luminance output over the Antelope. We did not account for this by making the two displays equally luminous and the differences between the two are seen in Table 1.

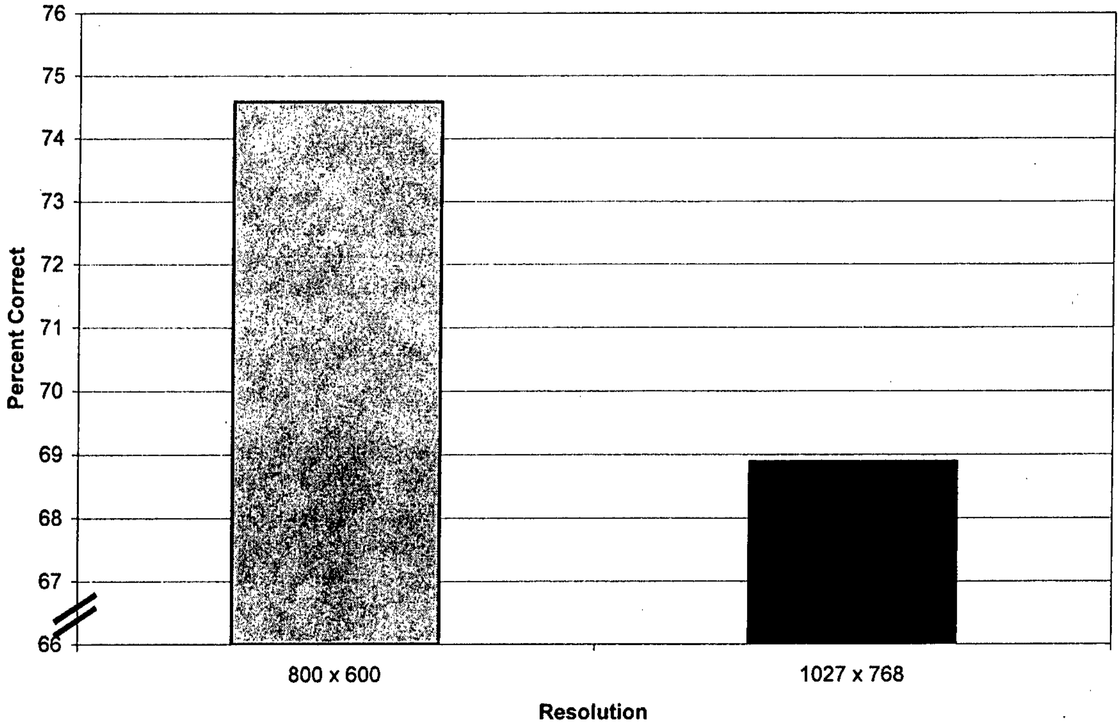

Figure 2. Percent Correct by Resolution for Approach Plates

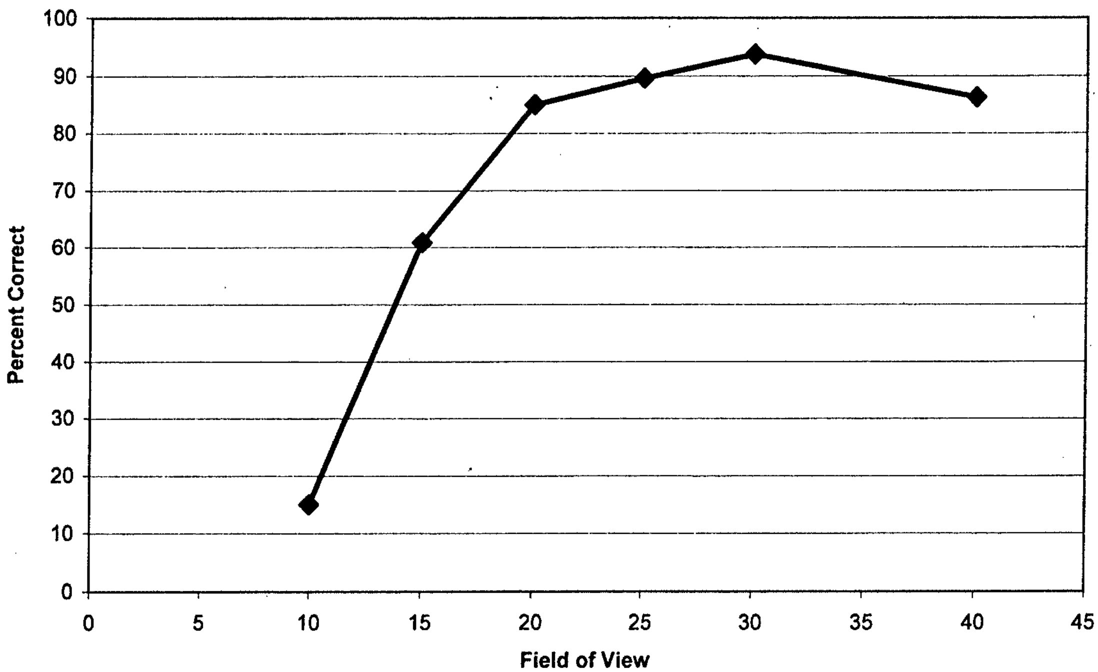

Figure 3. Percent Correct by Field of View for Approach Plates

Antelope				ADR			
Color	**u'**	**v'**	**cd/m²**	**Color**	**u'**	**v'**	**cd/m²**
Black	0.2025	0.4521	3.55	Black	0.1963	0.4544	4.13
White	0.2071	0.4801	88	White	0.2041	0.4798	268.48
Green	0.1476	0.5477	54.42	Green	0.1376	0.5461	155.37
Yellow	0.2276	0.5411	77.03	Yellow	0.2271	0.5402	215.5
Red	0.3872	0.5145	24.6	Red	0.4068	0.5208	70.78
Magenta	0.2718	0.4000	35.25	Magenta	0.2715	0.4021	103.76
Blue	0.1448	0.2872	13.33	Blue	0.1374	0.2925	40.44
Cyan	0.1444	0.4664	65.62	Cyan	0.1361	0.4647	191.35
Green	0.1476	0.5477	54.42	Green	0.1376	0.5461	155.37

Table 1. Chromaticity and Luminance Values for the Displays

As shown in Figure 3, once the display size subtended at least 20 degrees FOV, further increases in display size did not lead to significant increases in performance. We can conclude from this study that, at least for this task, a FOV of 20 degrees or greater is required for best performance.

Subjectively, observers did report that they liked using the lower resolution display (ADR) over the higher resolution (Antelope). The performance difference for this task may be due to the higher contrast ratio that may be achieved using the ADR. Further, as the approach plates were in .pdf form we had no control over the fonts in the display. One issue that arose was the fact that the fonts were anti-aliased and on the higher resolution display (Antelope) these were much harder to read. Future evaluations of approach plates will need to take this into account as font size and formats can cause great variability in the readability of a display [5].

3. EXPERIMENT 2

3.1. Method

The purpose of the second experiment was to have observers read and navigate using the FalconView™ 3.2.0 software[6]. FalconView™ is a mission planning and mission analysis program that provides for the viewing of digital maps at varying scales. For this experiment, observers were also afforded the use of a three-button mouse to allow scrolling and zooming.

3.2. Participants

Twelve volunteers participated in the experiment, and all observers had normal or corrected-to-normal visual acuity.

3.3. Apparatus and Stimuli

The apparatus was the same as in Experiment 1. The stimulus used was the FalconView™ software.

3.4. Procedure

Observers received a brief instruction and answer sheet and were allowed to view and answer sample questions about the information displayed in FalconView™. During this time they were able to learn how to use the mouse to navigate in the environment. On each trial, a question directed observers to specific coordinates and asked about geographical and textual information, such as "What island is located at the coordinates N 35° – E 024°?" and "What sea is this island located in?" Observers used a three-button mouse to scroll to different geographical regions and zoom in and out at varying scales. Coordinate information was displayed at the bottom of the screen.

Each of the 12 observers answered five questions for each of the six FOVs. After the first 30 questions, the display was changed, a questionnaire was completed, and observers continued with the next 30 questions. All answers were recorded by the observer on the answer sheet provided.

3.5. Results

A full factorial analysis of variance (ANOVA) was conducted on the percent correct values, using resolution and FOV as the main effects. The analysis revealed significant main effects of resolution $F(1,11) = 14.86$, $p = .0027$, and FOV $F(5,55) = 11.74$, $p < .0001$, and the interaction of resolution and FOV $F(5,55) = 5.04$, $p = .0007$. A post hoc analysis on FOV using Tukey's HSD test at the .05 alpha level revealed a significant difference between 10 degrees FOV and the remaining FOVs (i.e., 15, 20, 25, 30, and 40). The interaction between resolution and FOV is shown in Figure 4.

Observers in their subjective ratings preferred the 800 x 600 resolution as they did in the first experiment. Overall they said it was easier to read and would use this display over a paper map if given the choice.

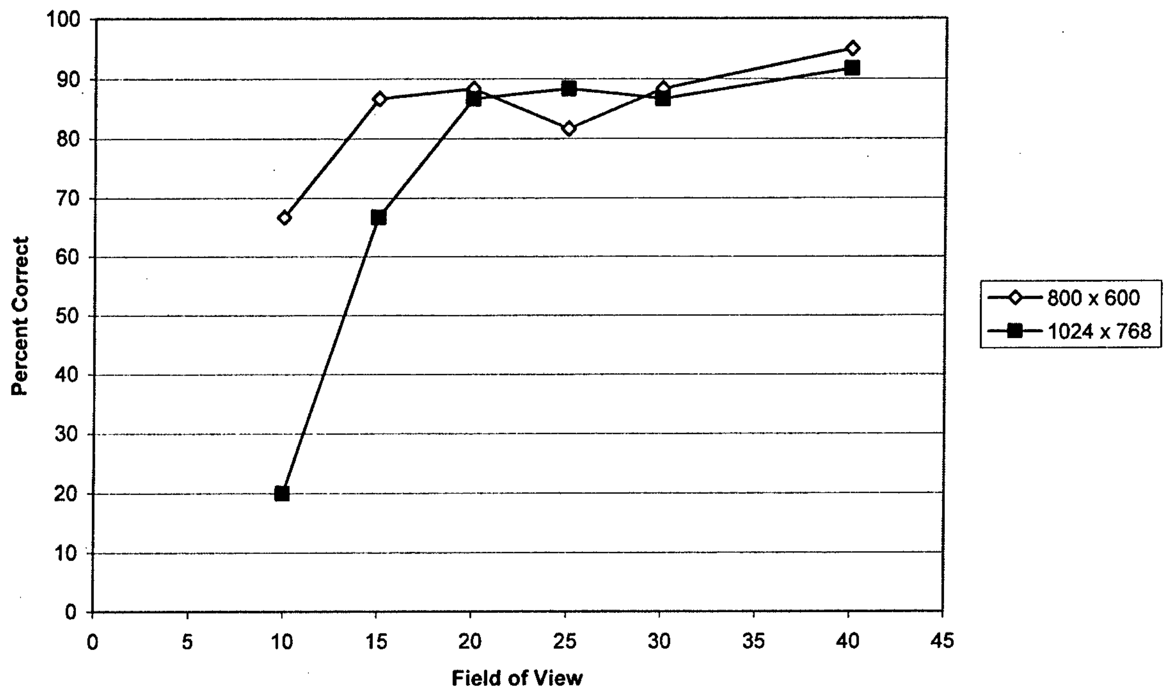

Figure 4. Percent Correct by Field of View and Resolution for FalconView

3.6. Discussion

As can be seen in Figure 4, the significant interaction is caused by the poorer performance by observers with the 1024 x 768 display at both the 10 and 15 degree FOVs. Once the FOV is 20 degrees or greater there is very little difference in performance between the two resolutions. We conclude that for this task, as was with the previous, a FOV of 20 degrees or greater is needed for optimal performance.

4. EXPERIMENT 3

4.1. Method

For the third task, observers were tested on the readability of pseudo-checklists, meant to simulate a checklist one might find in the cockpit. The checklists were simply long lists of questions such as "Who is the current president of the U.S.?" or "In what year did Neil Armstrong walk on the moon?" Some questions referred to a board placed three feet to the right of the observer on which rows and columns of numbers, shapes, letters, colors, etc. were drawn, as shown in Figure 5. These questions were also meant to have obvious answers, such as "What shape is below the letter D?" and "What color is the triangle?"

4.2. Participants

Twelve volunteers participated in the experiment, and all observers had normal or corrected-to-normal visual acuity.

4.3. Apparatus and Stimuli

The apparatus was the same as in Experiment 2. The stimulus used is seen below in Figure 5.

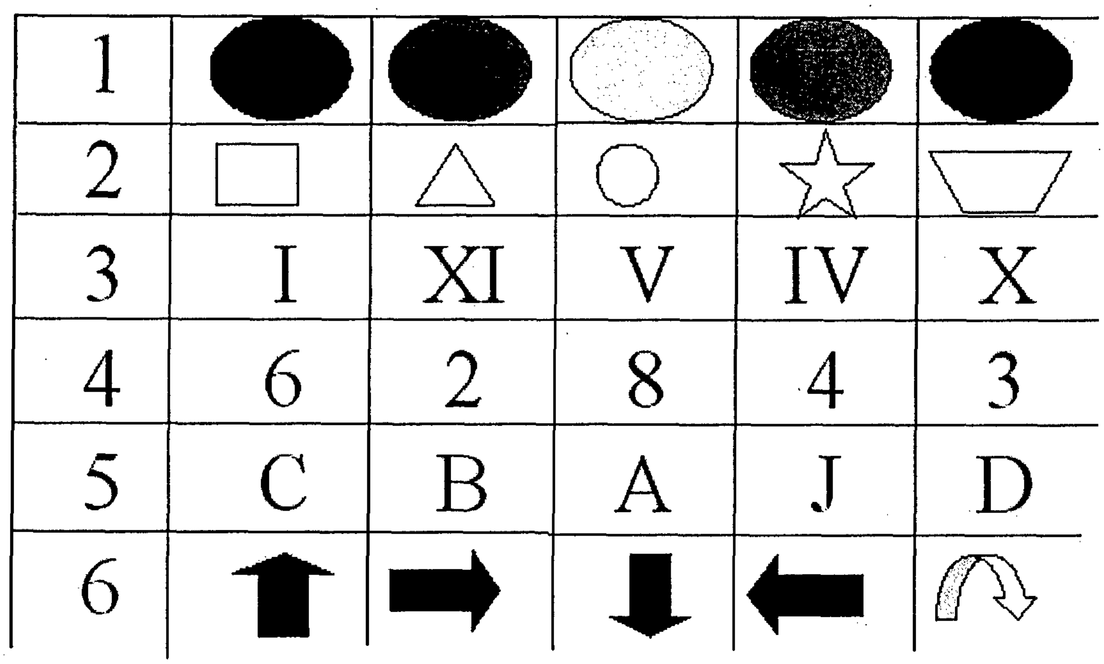

Figure 5. Stimulus for Checklists

4.4. Procedure

For the pseudo-checklist task, it should be noted that not only were the resolution and FOV manipulated, but text size also varied. Text sizes were 8, 10, or 12-point font; the font type used was Arial. The checklist questions were presented in Microsoft® WordPad. The order in which observers viewed the font sizes was randomly balanced.

Observers were given brief instructions and an answer sheet. A mouse was also provided to allow for scrolling through the checklist screens. Each of the 12 observers answered a total of 360 questions, broken into two sessions consisting of 180 questions. Each session used only one of the displays. There were 10 questions per font size for a total of 30 questions per FOV.

Questions were designed to elicit obvious responses, such as "Write today's date" and "What is the sum of 46 and 14?" Three out of every ten questions asked the observer to read information off of a board located approximately three feet to the right. The board contained shapes, colors, numbers, etc. Example questions referring to the board include "What is the shape below the orange circle?" and "What number is above the letter B?"

4.5. Results

A full factorial analysis of variance (ANOVA) was conducted on the percent correct values, using resolution, FOV, and font size as the main effects. The analysis revealed significant main effects of resolution $F(1,396) = 150.4$, $p <.0001$, FOV $F(5,396) = 145.36$, $p < .0001$, font size $F(2, 396) = 19.09$, $p < .0001$, the interaction of resolution and FOV $F(5,396) = 108.8$, $p < .0001$, the interaction of resolution and font size $F(2,396) = 12.13$, $p < .0001$, the interaction of font size and FOV $F(10,296) = 10.28$, $p < .0001$, and the interaction of resolution, FOV, and font size $F(10,396) = 6.20$, $p < .0001$. A post hoc analysis on FOV using Tukey's HSD test at the .05 alpha level revealed no significant differences between any of the FOVs and significant differences between all three of the font sizes. The interaction between resolution, FOV, and font size is shown in Figure 6. As in the last two experiments, observers again preferred the 800 x 600 display.

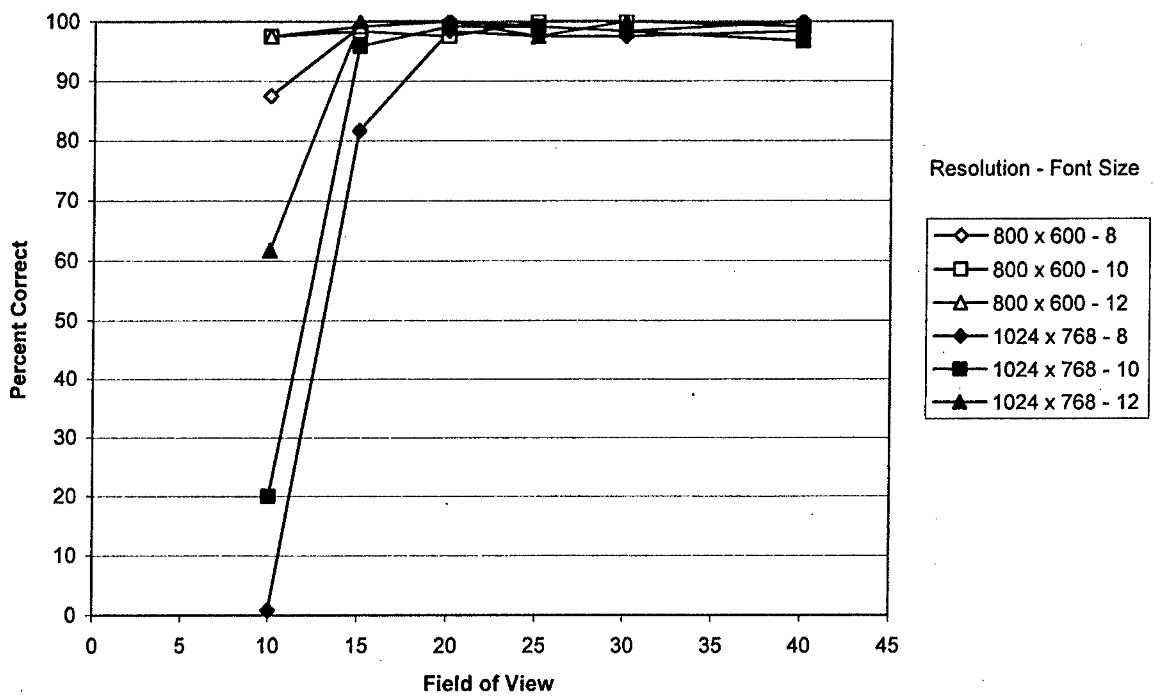

Figure 6. Percent Correct by Resolution, FOV, and Font Size

4.6. Discussion

Overall the results of this experiment concur with the previous two. The addition of font size to the experiment allowed us to determine what font size may be too small given resolution and FOV. As seen in Figure 6, as in the previous experiments, a FOV of 20 degrees or greater gives rise to the best performance by the observers. It is interesting to note that in those cases there is very little effect of font size. However, as can be seen in the graph, small font sizes (i.e., 8 point font) can cause a dramatic decrease in performance as observed in the data for the 15 degree FOV.

CONCLUSIONS AND FUTURE RESEARCH

We conducted three experiments designed to look at the effects of resolution and FOV on tasks that would be representative of a "digital kneeboard." For each task (approach plates, FalconView™, and checklists) we found that overall performance leveled out to its best at 20 degrees FOV. Any increases in FOV did not significantly improve performance. In terms of resolution, overall observers performed better with the lower resolution display. However, as mentioned earlier in experiment 1, this may be due to the fact that the lower resolution display (ADR) had on average a significantly higher luminance output over the higher resolution display (Antelope). It must be noted though that at the FOVs with the best performance (i.e., 20 degrees and up) there was very little performance difference between the displays as seen if Figures 4 and 6. Overall we conclude, based on these three tasks, that a FOV of at least 20 degrees is needed for best performance.

These studies have also led to several questions that we are pursuing for future research. Namely, what is the performance difference in resolution if the luminance outputs are matched? The reason we had chosen two different displays was to use each in its native resolutions and thus control any pixel spreading artifacts. However, a simple legibility study with controlled luminance would allow us to look at the effects of display brightness on reading. Also, one issue that arose was how to navigate around the environment. For approach plates and checklists, observers simply had to read the display. However, for the FalconView™ task, observers needed to navigate around the displayed maps, and some said that they felt this hindered their performance as they were not used to the task. In an actual aircraft cockpit this would be a significant issue and needs to be further addressed.

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REFERENCES

1. Chandra, D.C., Yeh, M., Riley, V., & Mangold, S.J. (2003). "Human Factors Considerations in the Design and Evaluation of Electonic Flight Bags (EFBs)", Department of Transportation DOT-VNTSC-FAA-03-07, Office of Aviation Research, Washington, DC.
2. Digital Terminal Procedures: http://www.naco.faa.gov/index.asp?xml=naco/online/d_tpp
3. Antelope Technologies Rugged Handheld 01: http://www.antelopetech.com/en/index.aspx?view=iproducts_RuggedHandheld.htm
4. ADR model FG-8000: http://www.adrsoft.com/Electronic_Flight_Bag/EFB_Brochures_and_Information_Guides.htm
5. Bernard, M.L., Chaparro, B.S., Mills, M.M., & Halcomb, C.G., (2003). "Comparing the effects of text size and format on the readability of computer-displayed Times New Roman and Arial text", International Journal of Human-Computer Studies, **59**, 823-835.
6. FalconView™ 3.2.0: http://www.falconview.org/