

2005

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Mathard, E. K., & Wickens, C. D. (2005). An Evaluation of Scanning of Integrated Hazard Displays as a Function of Size and Event Detection Performance. *2005 International Symposium on Aviation Psychology*, 517-522.
https://corescholar.libraries.wright.edu/isap_2005/81

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AN EVALUATION OF SCANNING OF INTEGRATED HAZARD DISPLAYS AS A FUNCTION OF SIZE AND EVENT DETECTION PERFORMANCE

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The present study was designed to assess the influence of display enlargement on pilot scanning patterns and event detection performance. Nineteen pilots monitored an integrated hazard display for changes in the altitude or heading of traffic aircraft and weather systems. Analyses revealed that event detection accuracy and response time were unaffected by display size, suggesting pilots compensated for display enlargements by strategically widening scanning patterns. While eye movement data revealed that attention was allocated to the peripheral display regions regardless of display size, individuals who were poor at detecting events were less likely to attend to these display areas. The results suggest that the attention allocation patterns of pilots are adaptive and flexible and that such flexibility leads to higher performance in attentional tasks.

Introduction

With continuing advances in the technological capabilities of aviation displays, designers are now able to implement large scale displays that portray a top-down view of the environmental hazards that exist within a large region of the airspace. The integrated hazard display represents one example of these advanced displays.

The integrated hazard display depicts traffic, terrain, and weather hazards in a single, unified panel. This integrated display layout allows the pilot to easily monitor the dynamic airspace for changes in the lateral and vertical behavior of traffic aircraft and weather systems. This monitoring task requires that the pilot identify changes in the movement or location of a hazard from one moment to the next. Unfortunately, observers have been shown to be poor at change detection, reflecting instead a tendency toward “change blindness” (Carpenter, 2001; Rensink, 2002; Simons, 2000). Change blindness refers to the inability that observers have in detecting changes that occur beyond the focus of attention (Levin & Simons, 1997; Muthard & Wickens, 2002; Pringle, Irwin, Kramer, & Atchley, 2001; Rensink, O’Regan, & Clark), particularly as events occur at locations that are increasingly more distant from the fovea (Pringle et al., 2001).

Any enlargement to a display augments the area that must be scanned and increases the proportion of the display that is located within the observer’s periphery. Thus, it reasons that such changes to display size may also hinder change detection, as more effort must be used to access peripherally located information. Wickens (1992) proposes a model of information access effort that describes this

relationship. In this model, the effort required to access information is proposed to increase nonlinearly with eye movements and head movements of increasing magnitudes. Consequently, small displays, which can be monitored effortlessly with short saccades, do not induce large scanning costs. Conversely, when larger displays exceed twenty degrees of visual angle, observers must begin to use head movements to access peripheral information (Bahill, Adler, & Stark, 1975), which become increasingly effortful as they increase in magnitude (Wickens, 1992).

Two models have been proposed to examine the potential surveillance strategies that pilots might employ in response to display enlargement. The first model is supported by the presented research on attentional effort and is termed the *effort conservation* model. Under this model, pilots do not invest the effort needed to access the most peripherally located information. As a result, detection performance for the most peripheral changes suffers proportionally more with display enlargements. In fact, under an extreme effort conservation model, the ratio of performance decrement with display enlargement should be equal to the ratio of the sizes of the displays. The second model of *strategic compensation* postulates that the pilot realizes that peripheral events will go unnoticed if the display perimeter is not monitored. As a result, the pilot strategically adapts and enlarges his scanning area, despite the extra resources that must be deployed to do so. For pilots strategically compensating for display size, surveillance performance would not differ across display sizes.

While understanding the potential hindrance that display enlargement may pose to attention-based

tasks is important, only a handful of studies have explicitly examined this relationship. Enoch (1959) asked participants to search for a Landolt C, which was presented on aerial maps that ranged in size from 3 to 51 degrees of visual angle. Enoch's work indicated that display enlargement resulted in shorter fixations and longer saccades. Fixation length was reduced because fixations to the most peripherally located display regions were difficult to maintain for extended time periods and because additional search time was needed to make longer saccades to reach these regions. Enoch (1959) also reported that the concentration of fixations in search was located in the center of the maps, particularly for displays of larger size. Kroft and Wickens (2003) also examined search for hazards on sectional charts. While Enoch (1959) reported disadvantage to larger displays, Kroft and Wickens (2003) determined that search was inhibited by small displays, largely because of the reduced legibility of symbols and text. While this pair of studies provides some indication of the influence that display size may have on performance, both examine the task of goal-directed search rather than surveillance.

The present study seeks to examine the influence of display enlargement on the task of hazard surveillance within the context of the proposed effort conservation and strategic compensation models. In a low fidelity simulation, pilots were asked to monitor an integrated hazard display for changes in the altitude, airspeed, and trajectory of traffic aircraft and weather systems, while also flying the aircraft. Change detection performance was assessed as a function of event location and display size. Eye movement data was also collected as a measure of surveillance. To the extent that pilots employed an effort conservation strategy, change detection performance should be reduced with display enlargements, particularly for the most peripheral changes. Scanning to the display perimeter should also be reduced. If pilots were able to strategically compensate for display enlargement by widening scanning patterns, however, the proportion of fixations in the outer display regions and change detection performance should not be affected by size.

Methods

Subjects

Nineteen pilots from the University of Illinois, Institute of Aviation participated in the study. These pilots ranged in age from 19 to 23 years ($M = 21$ years) and all were male. Participants had an average of 226 flight hours of experience. Six pilots had

private licenses while the remaining thirteen were instrument certified.

Display

Pilots were shown an integrated hazard display that depicted traffic aircraft and weather systems overlain on a topographical map, as shown in Figure 1. The topographical map was based on the National Oceanic and Atmospheric Administrations (NOAA) sectional aeronautical chart. Traffic aircraft were depicted with small aircraft icons and digital data tags that included the aircraft's call sign, altitude, heading, and airspeed. Weather systems were portrayed as a series of concentric circles. The altitude of weather tops were shown with data tags located in the center of each weather system.

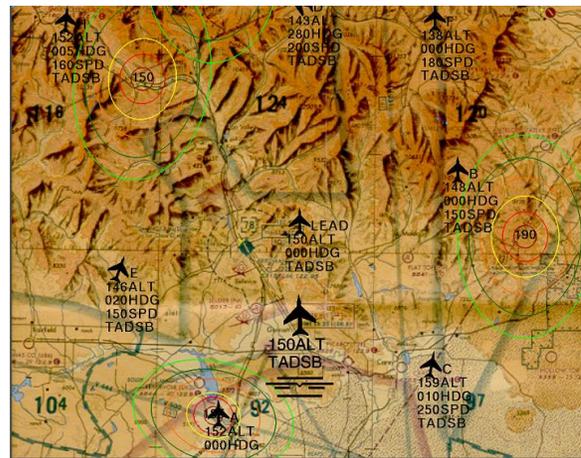


Figure 1. *Integrated hazard display. Ownship is located in the center of the display.*

Ownship was depicted with a large aircraft icon and was always located in the center of the display. Ownship remained stationary at this location and traffic aircraft and weather moved relative to ownship. An attitude directional indicator, which depicted only pitch, was located directly below ownship to assist in altitude control.

The integrated hazard display was presented in three sizes. The small display measured 8.9 by 6.4 cm and encompassed 10 by 7 degrees of visual angle. The medium and large displays measured 19.1 by 14.0 cm (20° by 15°) and 34.3 by 25.4 cm (36° by 27°), respectively. With all changes to display size, the text and icons located within the display also changed proportionately.

Procedure

Participants were asked to complete two tasks, namely flight control and hazard surveillance. In the flight control task, pilots were asked to maintain a target flight level of 15,000 feet and a north-up heading. Vertical and lateral maneuvers were made with a two-axis joystick. While altitude information could be determined from the digital readout in ownship's data tag and from the attitude directional indicator, heading information could only be deduced from the orientation of the aircraft icon representing ownship. Participants were also asked to maintain a separation of 5,000 feet from a lead aircraft by increasing and decreasing their airspeed. The target separation distance of 5,000 feet was depicted in a scale that was located on the bottom right-hand corner of the display.

While performing the flight control task, pilots were also asked to monitor the airspace for changes in the heading, altitude, or airspeed of traffic aircraft and weather systems. These hazard changes occurred randomly every 15 to 75 seconds. Pilots were asked to identify changes with a key press and verbal description of the change (e.g., "Aircraft C changed heading"). While altitude and airspeed events could only be detected by noting the changes in the hazard's digital data tag, heading changes could be detected by viewing the heading information located within the data tag or by noting a change in the movement of the hazard. Participants completed one practice trial and six experimental trials. Each trial lasted six minutes and the experimental session lasted for about one hour.

Experimental Design

Display size was counterbalanced and manipulated as a within-subjects variable. For the task of flight control, measures included lateral and vertical root mean squared (RMS) error and mean absolute error in tracking the target separation distance from the lead aircraft. Change detection performance was evaluated with measures of response time and accuracy. Surveillance performance was also assessed through measures of percent dwell time and mean dwell duration to three designated display regions.

Results

Change Detection Performance

On average, pilots detected 12.2% of changes with a latency of 18.0 s. Change detection accuracy and response time were both evaluated in a one-way

repeated measures ANOVA as a function of display size. These analyses revealed no significant effect of display size on either accuracy ($p > 0.10$, $\phi = 0.48$) or response time ($p > 0.10$, $\phi = 0.26$). Independent of display size, the influence of change eccentricity on detection performance was also assessed by evaluating by accuracy and response time as a function of the distance of the event from ownship, which was assumed to be the focus of attention. This analysis yielded a significant correlation between change eccentricity and detection accuracy ($r = -0.49$, $p < 0.01$). Thus, detection accuracy was significantly reduced as the change occurred at an increasingly greater distance from ownship, independent of the relevance of the event to ownship's safety.

Given that display size had no effect on surveillance performance, the analyses suggest that performance was degraded as changes occurred further from the center of the display. However, display enlargements, which served to further increase the distance between the center of the display and the display perimeter, did not amplify this effect. This latter finding suggests that pilots were *strategically compensating* for display enlargement by widening their scanning patterns. This can be confirmed by examining the eye movement data.

Eye Movement Data

Eye movement data was collected and assessed as a function of percent dwell time and mean dwell duration in three designated display regions, as shown in Figure 2. The *ownship* display region included ownship, a lead aircraft, and the attitude directional indicator. The *midrange* display region included the area immediately surrounding the ownship region. The most peripherally located region was the *outer* display area, and included the area of the map around the display perimeter.

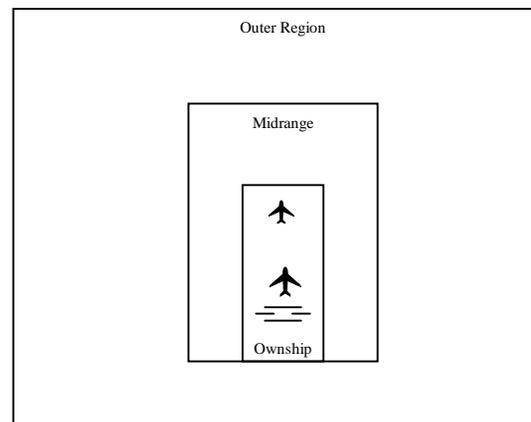


Figure 2. Display regions or areas of interest.

Using a median split, pilots were also grouped into high and low change detection performers. While head movement data was collected, participants rarely used head movements to access information located on the display. Consequently, these data will not be discussed.

Percent dwell time and mean dwell duration were assessed in Display Size X Display Region X Change Detection Performance mixed ANOVAs. Percent dwell time analyses revealed a significant main effect of display region, with participants allocating the greatest proportion of attention to the ownship region ($F(2, 20) = 56.13, p < 0.001$). Interestingly, the outer region received a significantly greater proportion of attention than the midrange region, and this effect increased with display enlargement from the small to medium display ($F(4, 40) = 4.12, p = 0.007$). There was also a shift in attention away from the midrange region to the ownship region from the small to medium display, suggesting that pilots needed to foveate the ownship area to gain flight control information when the display was enlarged. Interestingly, there was no significant effect on percent dwell time for display enlargement from the medium to large display, suggesting that pilots strategically compensated for display size in their scanning patterns. These relationships are depicted in Figure 3.

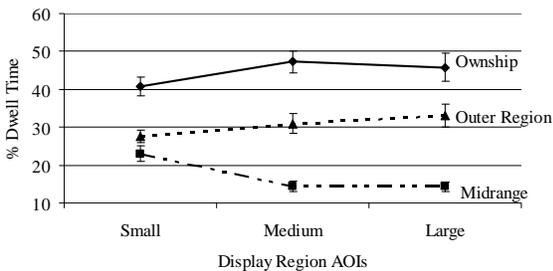


Figure 3. Significant interaction of display region and display size.

While a significant proportion of attention was allocated to the outer display region, this region was also the largest in area. Thus, when percent dwell time was normalized by a measure of percent/cm², this measure declined monotonically from the ownship region of the display to the midrange and outer regions ($F(2, 20) = 274.0, p < 0.001$). Thus, while the outer region received more total attention than the midrange region, the allocation was more sparsely distributed across display area. These findings support the performance analyses that revealed a decrease in change detection accuracy for events in the more eccentric outer display region.

Mean dwell duration in each of the three regions was also examined to determine if the differences found in percent dwell time were due to more scans or longer fixations within each display region. The mean dwell duration data, examined as a function of display size and display region are plotted in Figure 4. The analyses revealed a significant main effect of display region ($F(2, 20) = 132.8, p < 0.001$), with dwells in the ownship region lasting more than three times the length of those in the midrange and outer display regions. This finding reflects the need to access information about flight control from this region.

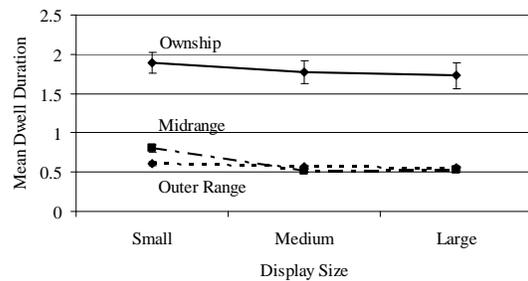


Figure 4. Mean dwell duration as a function of display size in each of the three display regions.

Analyses also indicated that dwell duration for the midrange and outer display regions did not significantly differ, at least for displays that were medium or large in size. Thus, the difference in percent dwell time for the midrange and outer display regions was *not* due to a difference in dwell duration, but rather can be attributed to a greater number of visits. These findings provide additional support for the *strategic compensation* model of surveillance, suggesting that pilots fixated the outer region more frequently and with longer scans than the midrange area.

Finally, surveillance was assessed as a function of change detection performance. These analyses indicated that good performers allocated a greater proportion of attention to the outer display region, while attention for the low performers was more solely concentrated to the ownship region ($F(2, 20) = 5.84, p = 0.01$). This difference strengthened when displays were enlarged from small to medium ($F(4, 40) = 2.14, p = 0.09$), though the interaction was only marginally significant. High performers were also found to have shorter dwells than low performers, though only for the ownship region ($F(2, 20) = 3.73, p = 0.04$). Thus, these data suggest that high performers were particularly skillful at allocating attention away from the ownship region to the more peripheral regions of the display. This *strategic compensation* was particularly apparent with the medium and large displays.

Discussion

The present study was designed to examine two strategies of surveillance in response to display enlargement. The first model, *effort conservation*, posited that pilots would be unable to sustain extended surveillance patterns, opting instead to conserve scanning effort by concentrating on the central portions of the display (Enoch, 1959). Some evidence for the effort conservation approach was found in the eye movement behavior of the poor change detection performers, who spent too long focusing on the proximal tracking task and failed to allocate attention to the outer display regions to detect distant events, particularly for large displays. Despite this evidence, change detection performance for the group as a whole was unaffected by display enlargement, suggesting instead that pilots adopted the strategic compensation model.

The *strategic compensation* model posited that pilots would adapt to enlargements in display size by widening their scanning patterns to monitor even the most peripherally located display regions. Evidence for the strategic compensation model was found in the scanning data for both high performers and that of the overall participant group. The overall analyses indicated that, while the outer region received the smallest proportion of attention per square centimeter of display area, this proportion did not decrease with display enlargement. In fact, for the high performers, this proportion *increased* when the display size was enlarged from small to medium. Thus, pilots were able to widen their scanning patterns without a performance cost (Teichner & Mocharnuk, 1979).

A final form of strategic compensation was evidenced in the elevated values of percent dwell time and mean dwell duration for the midrange region in the small display. It is our belief that, when the display was presented in the small format, pilots were able to fixate in the middle display region while maintaining the ownship region within the useful field of view. Thus, with the small display pilots might have chosen a strategy to fixate more often in the middle region, knowing that by doing so, they did not need to temporarily abandon the flight control task.

While the strategic compensation strategy used by pilots sustained change detection performance across display sizes, it likely did not come without cost. Any widening of the scanning pattern with an enlargement in display size would also produce an increased demand for resources (Recarte & Nunes, 2002). To the extent that the scanning task becomes more difficult because the display becomes

excessively or concurrent tasks are added, the pilot may turn to an effort conservation approach to cope with the increased demands. This may primarily occur when display size is increased to such a large degree as to induce head movements, though this threshold was not examined in the present study. Additionally, pilots represent a population who has been thoroughly schooled on the importance of scanning displays and instruments, despite the extra effort that must be employed to do so. Consequently, care should be taken in extending these data to other domains whose operators do not share this characteristic.

Conclusions

Despite the increase in effort associated with monitoring large displays, pilots demonstrate adaptiveness by widening and enlarging scan patterns in order to access information needed for safe flight. At a practical level, the results suggest that displays of this sort can be enlarged up to thirty degrees of visual angle without much *performance* cost, though workload will be increased. Care should also be taken to ensure such an enlargement will not simultaneously hinder additional tasks supported by the display.

Acknowledgments

This work was supported by a grant from the NASA Ames Research Center (NASA NAG 2-1535), for which Dr. David C. Foyle served as the technical monitor. The authors also wish to acknowledge Sharon Yeakel and Roger Marsh for their programming efforts.

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