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HEAD-UP DISPLAYS: EFFECT OF INFORMATION LOCATION ON THE PROCESSING OF SUPERIMPOSED SYMBOLOGY

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by

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Abstract

Head-up display (HUD) symbology is a computer-generated image that presents aircraft status information. The image is superimposed on the terrain. Although the terrain and HUD information are simultaneously visible, the information they provide may not be available for concurrent cognitive processing. Accommodation has been investigated as a possible explanation for a lack of information integration. However, accommodation cannot adequately explain the problems encountered with HUD symbology use. A flight simulation was used to evaluate the influence of attentional segregation and attentive field size on information integration. A superimposed altitude indicator was presented at three distances from flight-relevant terrain information. Root mean squared error (RMSE) altitude and RMSE heading were measured. A performance decrement was observed when altitude and heading information were located near each other. Proximal placement did not result in information integration. Instead, it encouraged attentional tunneling. Performance was best in conditions that encouraged attentional or visual scanning.

Head-Up Displays: Effect of Information Location on the Processing of Superimposed Symbology

Aircraft status information has traditionally been presented on a panel-mounted display located beneath the windshield. The panel-mounted display format requires eye scanning movements between the external terrain and the instrument display panel. Scanning is associated with two notable drawbacks. First, the external terrain and vehicle information cannot be monitored simultaneously. Therefore, when vehicle status information is visually acquired, the external terrain cannot be perceived. Looking down at a panel can interfere with the ability to visually track targets in the terrain. Furthermore, failure to survey the surrounding environment continuously can contribute to controlled flights into the terrain. Second, reaccommodation is required when shifting between the terrain and the panel. Thus, additional time is lost with each shift between informational sources. The head-up display (HUD) has been designed to address the problems posed by the traditional panel-mounted display by minimizing concurrent accessibility problems and reducing the time required for scanning and reaccommodation.

HUD symbology is a computer-generated image. It generally contains frequently used aircraft status information such as altitude, speed, thrust, heading, climb rate, pitch, and roll indicators. The image is collimated and projected onto a combining glass located between the pilot and the windshield. Since information about the terrain and vehicle is concurrently available to the visual system, the need for scanning between the windshield and panel is reduced. Because the display is visually superimposed onto the external terrain at optical infinity, it is expected that the need for reaccommodation is eliminated. However, there has been debate about whether the superimposed symbology format has successfully minimized concurrent accessibility problems and reduced the need for scanning and reaccommodation.

Problems with HUD use

Fischer (1979) has suggested that external scenes are processed equally well regardless of the presence or absence of HUD symbology. However, other studies contradict this conclusion (Fischer, Haines & Price, 1980; Weintraub, Haines & Randle, 1985).

Fischer et al. (1980) reported that during a simulated landing, pilots took longer to respond to an unexpected airplane on the runway when using HUD symbology as compared to a panel-mounted display. In fact, two out of eight pilots failed to see the runway obstruction in the superimposed symbology condition and flew into it. Supporting these findings, Weintraub et al. (1985) presented a similar runway obstruction and reported that six out of eight pilots failed to see the jet on the runway when using HUD symbology. These results suggest that HUD presence can detract from the ability to process important information in the external scene. They suggest that information integration may not be occurring.

Problems with the use of HUD symbology have also been reported in actual aviation situations. The U.S. Air Force has reported incidents of experienced pilots losing awareness of pitch and roll angles and becoming disoriented to ground direction during flight. These events occurred even though all of the relevant information was displayed in the superimposed symbology that was located directly in the pilots' field of view (McNaughton, 1985). These incidents corroborate experimental findings and suggest that while concurrent visual availability is necessary for the concurrent use of visual information, it may not be sufficient.

Failures to detect unexpected events in the external scene with the use of superimposed symbology suggest that symbology presence may reduce the availability of information in the terrain. Furthermore, lack of vehicle state awareness despite the presence of superimposed vehicle state information suggests that HUD information may not be available if the external scene is being attended. Together these occurrences illustrate that information from the superimposed symbology and the external terrain may not be available for concurrent use. This suggests that the two sources of information may not be adequately integrated. This lack of integration has been attributed to both perceptual and cognitive processes. More precisely, differences of accommodation and the attentional segregation of objects have been investigated as possible explanations for the difficulties that are associated with the use of HUDs (Brickner, 1989; Foyle, Sanford, & McCann, 1991; Roscoe, 1984, 1987).

Accommodation

The assumption that collimated images draw eye focus to optical infinity has been integral in the prediction that pilots should be able to perceive HUD symbology and the external terrain simultaneously. However, empirical studies have shown that this assumption may not be true (Hull, Gill, & Roscoe, 1982; Norman & Ehrlich, 1986; Randle, Roscoe, & Petitt, 1980). Instead, there appears to be an intermediate resting focus between optical infinity and the combining screen. Accommodation tends to collapse toward this point (Iavecchia, Iavecchia & Roscoe, 1988; Roscoe, 1984, 1987). Worse yet, pilots often report focusing on the combining glass instead of optical infinity (Jarvi, 1981; Norton, 1981). This misaccommodation necessitates a shift in accommodation to perceive detailed terrain information that may be required for correct distance judgments. The inability to accommodate to the HUD information and the terrain simultaneously has been implicated in the performance problems with superimposed symbology (Roscoe, 1984).

However, other research has shown that there is no shift in accommodation when HUD symbology is used (Sheehy & Gish, 1991). Viewers accommodate to an appropriate distance, based on their normal dark resting focus. This accommodation is maintained even when information sources are placed 1.5 diopters apart, given that both sources of information are located at optical infinity. These results suggest that viewers may not be misaccommodating. Instead, reports of looking at the combining glass instead of out the window when using HUD information may reflect an attentional factor, rather than an accommodative factor.

Empirical studies in which HUD symbology and terrain information have been presented at the same optical distance dispute the accommodation explanation (Brickner, 1989; Foyle et al., 1991). These studies, using a computer graphics flight simulation with overlaid graphical HUD symbology, have shown that performance on an altitude maintenance task in which HUD information is utilized hinders performance on a tracking task in which terrain information must be processed. These results illustrate that performance problems persist in the absence of misaccommodation. Thus, factors other than misaccommodation contribute to the performance decrements that are associated with the use of superimposed symbology.

Attentional Segregation of Objects

Brickner (1989) and Foyle et al. (1991) have suggested that difficulty in integrating HUD and terrain information may be due to cognitive rather than optical segregation. Foyle et al. (1991) propose that there are two salient cues suggesting that the HUD symbology and terrain are separate, non-integrated sources of information: common fate and display format.

Common fate can provide important cues about the form of objects (Gibson, Gibson, Smith & Flock, 1959). For example, when a clearly discernible figure assembled of dots is viewed against a blank background, the figure is easily discernible. However, when it is placed in a field of dots, the figure seems to disappear. If the figure is moved, it seems to emerge from the field. Clearly, common fate can provide important information about figure or object boundaries. The relative motion between the figure and the field of dots also suggests that the two groups of dots exist on separate depth planes, thereby contributing to the establishment of a figure-ground relationship. Since the HUD symbology moves with the vehicle as the vehicle moves through the terrain, the HUD information and terrain may form a figure-ground relationship. This figure-ground relationship may cause the HUD symbology to be seen as a separate object that is superimposed over the terrain. Thus, the figure-ground relationship between the two sources of information may cause them to be seen as two segregated objects (Foyle et al., 1991).

Display format may also contribute to the lack of symbology-terrain integration. Terrain information is generally pictorial in nature, while HUD information is primarily digital. Furthermore, the superimposed symbology is composed of colors that may not be present in the terrain. The symbology may also have a different luminance level than objects in the terrain. When these display differences exist, integration problems may arise (Foyle et al., 1991). Therefore, the two sources of information may be perceived as separate objects due to attentional segregation (Brickner, 1989; Foyle et al., 1991).

When objects are attentionally segregated, it is more difficult to share attention between them. During the early stage of information processing, features are perceived in parallel. At this time, the figure-ground relationship is established (Treisman & Gelade, 1980). Once the figure-ground distinction has been determined, objects located in separate frames of reference do not seem to be processed simultaneously. For example, studies involving the detection of unexpected events in superimposed scenes have illustrated that people cognitively separate the scenes (Neisser & Becklen, 1975; Becklen & Cervone, 1983).

Neisser and Becklen (1975) found that subjects viewing a single scene were able to identify and respond to a target event in the scene. Subjects performing the same task with an unattended scene superimposed were slightly less accurate at identifying target events in the attended scene, but still performed well. However, subjects who were required to monitor and respond to target events in both scenes exhibited severely impaired performance. They were unable to attend to both of the superimposed scenes concurrently. Furthermore, when one scene was monitored, unexpected events in the unattended scene were frequently missed. Becklen and Cervone (1983) have investigated the possibility that a delay between the unexpected event and the opportunity to respond adversely affects the reporting of unexpected events. When response delay was controlled, it became apparent that forgetting was not a problem. Subjects who noticed the unexpected event remembered and reported it. The inability to report an unexpected event was the result of a failure to notice the event. These results indicate that it is difficult to integrate information from two cognitively dissociated sources.

Considering the problems that may arise from attentional segregation, it is understandable that Brickner (1989) and Foyle et al. (1991) reported a performance trade-off between heading and altitude performance when digital HUD symbology was presented in simulated flight tasks. The presence of HUD information improved altitude maintenance compared to the condition where the HUD symbology was absent. However, heading maintenance was impaired by the presence of HUD information. The performance trade-off was attributed to an inability to process HUD and terrain information concurrently.In these simulated flight tasks, the altitude information was located slightly above and to the left of the center of the display. Brickner (1989) used a slalom flight task. Therefore, the heading information, which was determined by the terrain, moved across the display as the simulated aircraft moved through the slalom course. Conversely, the heading information was located along the vertical center of the display in the task used by Foyle et al. (1991). In each task, the altitude information was displaced from the heading information; thus, the spatial displacement of the two information sources may have made it difficult to attend to both sources simultaneously. Moving the heading and altitude information closer together may place them within the same attentive field.

Attentive Field Size

As previously noted, problems with HUD use initially were attributed to accommodation (Randle et al., 1980; Roscoe, 1984). Further investigation has suggested that accommodation may not be an adequate explanation. The attentional segregation of objects may also contribute to the difficulties that have been encountered (Brickner, 1989; Foyle et al., 1991). However, it is possible that the attentional segregation may not be due to frame of reference cues such as common fate and display formats. Instead, the HUD information may be located outside the attentive field induced by maintaining heading.

LaBerge (1983) has suggested that attentive field size is variable. Task requirements affect processing strategies and, therefore, attentive field size. Furthermore, there may be a processing gradient: information closest to the center of the attentive field may be processed more efficiently than information that is more distant. Therefore, task parameters and information location may affect processing ability.

There is evidence that information location in displays may affect cognitive integration. Sojourner and Antin (1990) have reported that the relative location of information used in the performance of concurrent tasks significantly affects task performance. Sojourner and Antin (1990) presented a driving sequence that was videotaped from the driver's perspective. This scene included speed limit signs located on the right side of the road. During each trial a ball appeared in one of three screen locations: left, center, or right. These locations were equidistant from one another. HUD symbology, located in the center of the roadway, was used to present vehicle speed. Subjects memorized a driving route similar to that presented in the driving scene. Subjects verbally reported navigational errors and speed violations. They also pressed a button when the ball appeared on the screen. Subjects' navigational evaluation strategy probably involved a survey of cues located throughout the scene. Monitoring speed violations required attending to the speed limit signs located to the right of the road and the HUD symbology presenting speed information in the center of the screen.

Sojourner and Antin (1990) found that response times for targets on the right side of the screen were not reliably different from those for targets presented in the center of the display. However, target response times were faster when the target was presented in the center of the screen than when presented on the left side of the display. The equal target reaction times for center and right locations may be explained by the requirements of the speed monitoring task. This task required attending to the right side of the display, where speed limit information was presented, and the center of the display, which presented vehicle speed. Since it seems likely that center and right locations may have been attended more frequently than the left location, it is not surprising that targets located in the frequently attended areas were reported more quickly. Sojourner and Antin's (1990) results indicate that information location may affect dual task performance by influencing the ability to integrate information in displays.

Objectives

Given Sojourner and Antin's (1990) results, a test of the attentional segregation explanation can be performed by manipulating information location. In the present experiment, HUD symbology consisting of a digital speed indicator will be presented in one of three screen locations. The additional information that is generally provided in the HUD symbology, such as speed, thrust, heading, climb rate, pitch and roll, will be removed because the altitude indicator provides the information necessary to perform the flight task in this experiment. The superimposed symbology will be located in the lower portion of the screen near the heading information (the proximal condition), near the center of the screen at an intermediate distance from the heading information (the intermediate condition), or in the upper left corner of the screen far from the heading information (the distal condition). There will also be a control condition in which the HUD information will be absent.

The attentional segregation explanation maintains that the information sources will occupy separate frames of reference due to their differing display formats and directions of motion regardless of altitude indicator location. Therefore, the attentional segregation explanation predicts that more processing resources will be available for the performance of the heading task when the digital altitude indicator is absent than when it is present in any of the three locations. Consequently, heading performance will be better when the HUD symbology is absent than when it is present. Conversely, when HUD information is present an improvement in altitude performance at the expense of heading performance is expected. This is due to the shift in processing resources from the heading task to the altitude task. Altitude performance should be better when the digital altitude indicator is present in any of the three locations than when it is absent. If this performance trade-off is present when altitude information is directly superimposed over heading information, the attentional segregation explanation will be supported.

If a performance trade-off is absent when digital altitude information is placed near heading information, then the attentional segregation explanation will not be supported. If the trade-off can be eliminated by manipulating the relative location of the two sources of information, then the attentional segregation explanation may be called into question. The performance trade-offs that have been ascribed to attentional segregation may actually be attributable to the visual distance between the digital altitude indicator and the heading information in the terrain. As such, the heading information may be outside the attentive field when the HUD symbology is being monitored. The information sources may be too distant to be contained within a single attentive field.

If digital altitude indicator location does affect the ability to integrate information, then placing the information sources closer together should decrease the size of the performance trade-offs. Consequently, performance trade-offs should increase as the distance between information sources increases.

Method

Subjects

Fourteen right-handed adult male subjects with unaided normal or corrected to normal vision participated in this experiment. They were recruited and paid through the Bionetics Corporation. Subjects were treated in accordance with the ethics and guidelines set up by NASA Ames Research Center and the San Jose State University Human Subjects-Institutional Review Board.

Apparatus

An IRIS 3130 Silicon Graphics computer was used to present the flight simulation program and to collect data. The program was viewed on a 19 inch Silicon Graphics color monitor from a distance of 65 cm. The flight simulation was controlled with a spring-centered joystick built into the right arm of the subjects' chair.

The flight simulation program provided a rotorcraft simulation that was flown through a virtual environment. The rotorcraft simulation did not pitch up or down when climbing or descending. This restriction was instituted so that the heading information in the virtual environment would be visually available at all times. The virtual environment contained a blue sky that met a green ground at the horizon. A white grid was superimposed on the ground. The eight paths which subjects followed were each marked by brown pyramid-shaped objects that were 12 ft x 12 ft at the base and 6 ft high. The pyramids were located 33 ft apart on the ground. These measurements represent the size and distance of the objects within the scale of the virtual environment. Each path consisted of nine segments that were four pyramids in length. The segments were joined at 60°, 90° or 120° angles which turned either right or left. The turn directions alternated between right and left, forming a zig-zag pattern. The order of angle placement was randomly assigned with the restriction that each angle was used three times in each path.

A digital speed indicator was presented in one of three locations: proximal, intermediate, or distal. The altitude indicator was a rectangle 0.8 cm x 0.4 cm on the display. The boundary of the rectangle was white, while the interior was a translucent blue. The digital information was presented in white 12-point Chicago font. Directly above the box, the word "altitude" was presented in white capital 12-point Chicago font. In the proximal condition, the altitude indicator was centered along the width of the screen. The upper left corner of the indicator was located 18.5 cm from the left edge of the screen and 17.5 cm from the top of the screen. The upper left corner of the intermediate altitude indicator was located 13.0 cm from the left edge of the screen and 10.0 cm from the top of the screen. In the distal condition the upper left corner of the altitude indicator was 7.5 cm from the left edge of the screen and 2.5 cm from the top of the screen. These locations, as shown in Figure 1, were equidistant from one another.

Random vertical and horizontal turbulence was introduced in all trials. The joystick sampling, data collection and graphics were updated at 12 Hz.

Design

A two-way within-subjects design with repeated measures was utilized. The variables of interest were HUD location and replication. There were four levels of HUD location: proximal, intermediate, distal, and absent. There were 20 replications of the four conditions. The first four replications served as practice trials. The remaining sixteen

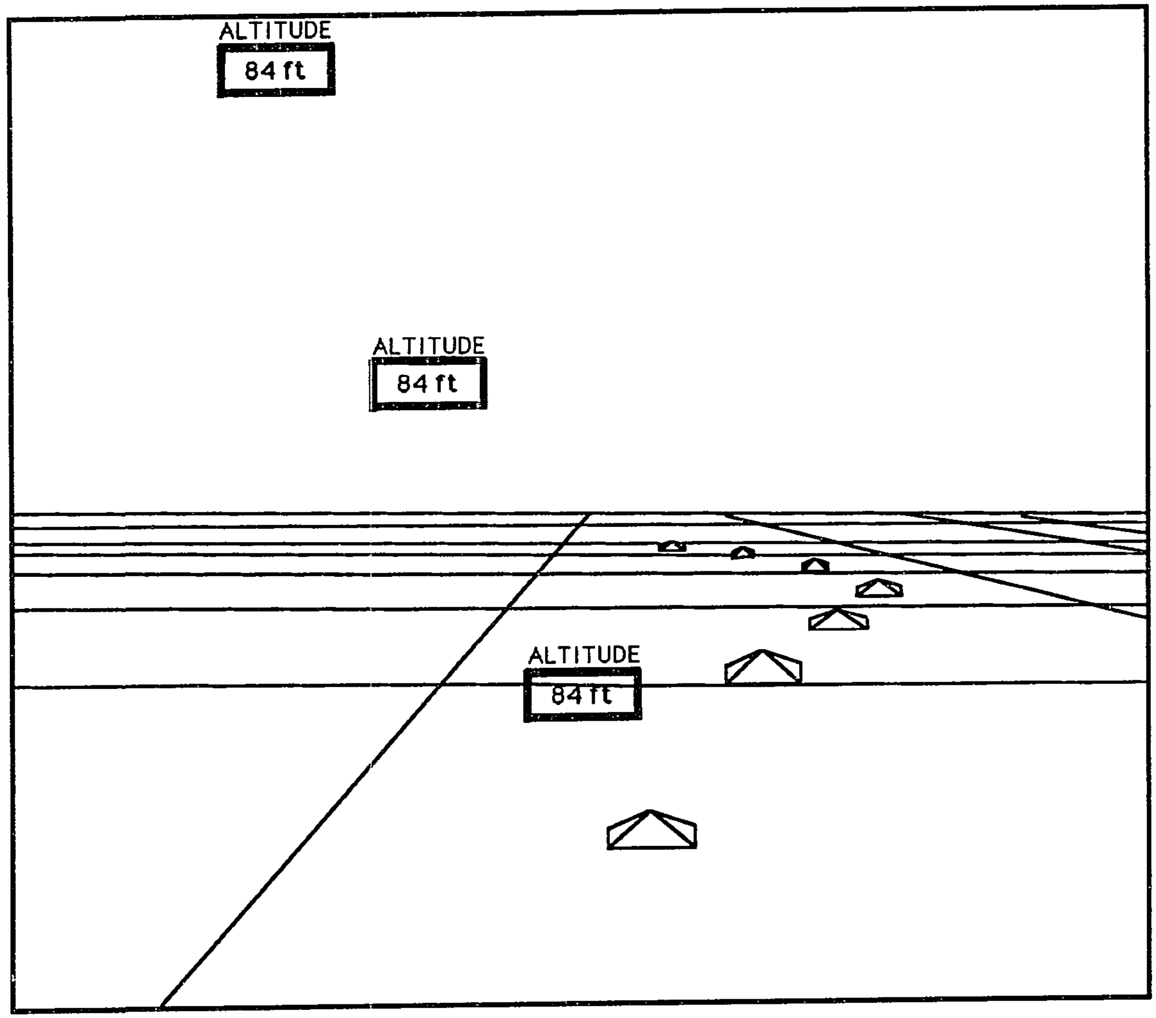

Figure 1. Schematic representation of flight simulation with HUD symbology displaying three altitude locations.

replications served as experimental trials. The replications were blocked. Each location was presented once in each replication. However, the order of presentation within each block was randomly assigned. There was a total of 80 trials. One of eight paths was randomly assigned to each trial, with the restriction that each path was used ten times for each subject. The dependent measures were root mean squared error (RMSE) altitude and RMSE heading. Altitude errors were determined by measuring subjects' distance from the correct altitude as they flew through the virtual environment. Heading errors were determined by measuring subjects' distance from the closest straight line segment in the path as they flew through the virtual environment. The RMSE was calculated with the following formula where e represents error and n represents the number of data points:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} {e_i}^2}{n}} \, .$$

Procedure

Each subject participated in one 2.5 hr session. Subjects were verbally instructed to fly directly over the path and maintain an altitude of 100 ft as accurately as possible. The experimenter demonstrated the flight task. The subjects were familiarized with each of the four experimental conditions during the sixteen practice trials. Once the experimental trials began, each subject completed sixteen replications of the four conditions.

Results

In order to maintain a familywise error rate of $\underline{p} < .05$, a Scheffe test was used to establish a modified critical $\underline{F}$ value of 2.84. This criterion was applied to the two-way 4 (locations of altitude information: lower, center, upper and absent) x 16 (replications) x 14 (subjects) within-subjects analyses of variance with repeated measures and the planned comparisons which were performed in both the RMSE altitude and RMSE heading performance data.

Altitude Performance

HUD location had a reliable main effect on altitude performance, $F(3,13) = 10.61$, $p < .0001$. An omega-squared analysis estimated that HUD symbology location accounted for 67% of the total variance in altitude performance. Replication did not produce a main effect, nor did it interact with HUD information location.

Several planned comparisons were conducted. Initially, the three HUD symbology present conditions, proximal, intermediate and distal, were combined and compared to the HUD symbology absent condition. This analysis revealed that altitude performance was reliably better when altitude information was presented than when it was absent, $F(1,13) = 13.09$, $p < .003$.

Another planned comparison investigated the difference between the HUD information absent and proximal conditions. Altitude performance was reliably better when the HUD symbology was present in the proximal location than when it was absent, $F(1,13) = 10.07$, $p < .007$.

A planned comparison of the proximal and intermediate locations revealed that there was no reliable difference in altitude performance when the altitude indicator was located in the intermediate or proximal location $F(1,13) = .30$, $p < .59$.

A subsequent planned comparison was conducted to further evaluate attentive field size. The proximal and intermediate conditions were combined and then compared to the distal condition. There was no reliable difference between the HUD symbology present conditions regardless of location, $F(1,13) = 2.73$, $p < .12$. Altitude performance was equivalent in each of the HUD information present conditions.

Heading Performance

HUD location produced a reliable main effect on heading performance, $F(3,13) = 12.27$, $p < .0001$. An omega-squared analysis estimated that HUD symbology location accounted for 44% of the total variance in heading performance. Replication did not reliably affect performance when the conservative criterion produced by the Scheffe test was applied. However, replication did produce marginally significant heading results, $F(1,15) = 2.03$, $p < .02$. The marginal reliability of replication was attributable to a simple practice effect. Replication did not interact with HUD information location.

Several planned comparisons were conducted. Initially, the three HUD symbology present conditions, proximal, intermediate and distal, were combined and compared to the HUD symbology absent condition. This analysis revealed that HUD symbology did not reliably affect overall heading performance, $F(1,13) = 3.40$, $p < .09$.

Another planned comparison investigated the difference between the HUD information absent and proximal conditions. Heading performance was reliably better when the HUD symbology was absent than when it was present in the proximal condition, $F(1,13) = 16.51$, $p < .001$.

A planned comparison of the proximal and intermediate locations revealed that heading performance was better when the altitude indicator was located in the intermediate condition, $F(1,13) = 33.18$, $p < .0001$.

A subsequent planned comparison was conducted to further evaluate attentive field size. The intermediate and distal location conditions were combined and then compared to the proximal condition. This analysis illustrated that larger errors were observed in the proximal condition than in the intermediate and distal conditions, $F(1,13) = 41.36$, $p < .0001$.

One post hoc comparison was conducted on the heading performance data. The absent, intermediate and distal conditions were combined and then compared to the proximal condition. This analysis illustrated that a heading performance decrement was present in the proximal altitude indicator location condition compared to the absent, intermediate and distal conditions, $F(1,13) = 36.34$, $p < .0001$.

Discussion

Altitude performance improved reliably, regardless of location, when an altitude indicator was presented in the HUD symbology. Altitude performance was equal in each of the HUD symbology present conditions. A decrement in heading performance was observed in the proximal condition. Heading performance was equal in the absent, intermediate and distal conditions. A performance trade-off was present in the proximal condition.

As predicted, the presence of a superimposed altitude indicator reliably improved altitude performance compared to performance when the indicator was absent. Figure 2 illustrates that while altitude performance was improved by the presence of the HUD symbology, altitude performance was unaffected by symbology location.

Conversely, heading performance was affected by location. As shown in Figure 3, heading performance was impaired when the HUD information was located near the heading information. Surprisingly, heading performance was equal across the HUD symbology absent, intermediate and distal conditions.

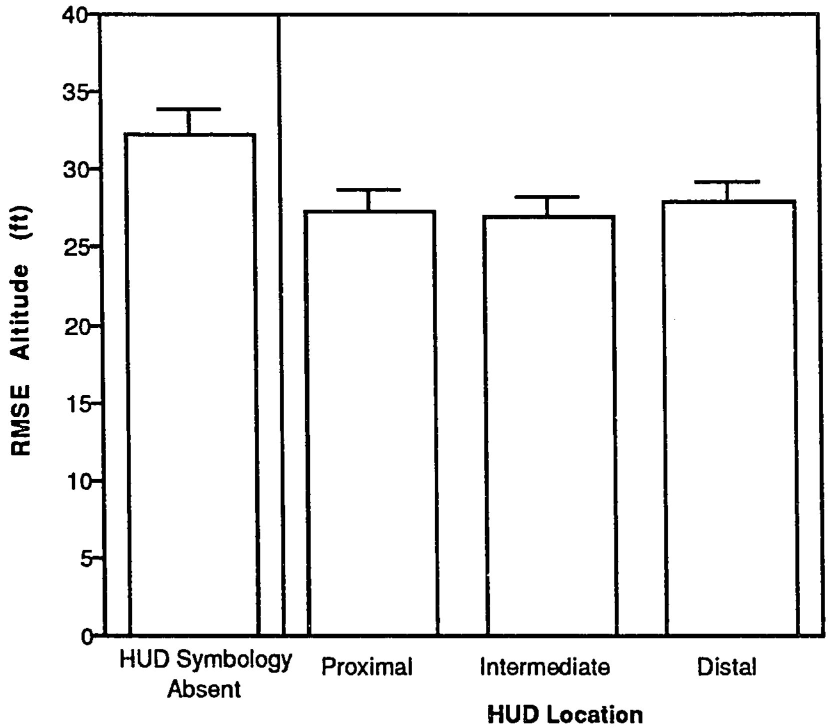

Figure 2. Effect of HUD symbology on altitude performance.

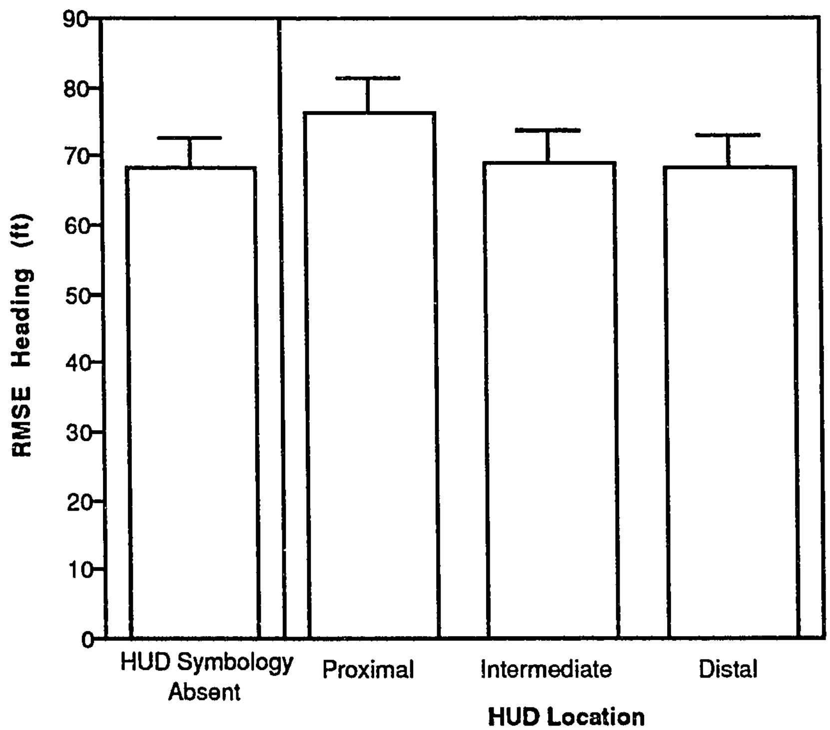

Figure 3. Effect of HUD symbology on heading performance.

When heading and altitude performance were evaluated jointly, it became clear that only one performance trade-off was present. Presenting the altitude indicator near the heading information did not hinder altitude performance relative to the other HUD symbology present conditions. However, it did cause a reliable decrement in heading performance. The results of this experiment do not clearly support either the attentional segregation or the attentive field size argument. Instead, aspects of each argument seem to be affirmed.

Evaluation of Hypotheses

Improved altitude performance in the HUD symbology present conditions was predicted by the attentional segregation argument. More importantly, as shown in Figure 2, altitude performance was equivalent regardless of location in each of the symbology present conditions. This result supports the attentional segregation argument and would seem to call the attentive field size argument into question. However, altitude and heading performance must be considered together before any theoretical conclusions may be reached.

The attentional segregation argument contended that more cognitive resources would be available to process the heading information when the HUD symbology was absent than when it was present in any of the three location conditions. Hence, it predicted that heading performance should have been impaired in each of the HUD symbology present conditions compared to the HUD symbology absent condition. This hypothesis was not supported. Figure 3 illustrates that heading performance in the intermediate and distal HUD information present conditions was not reliably different than the HUD symbology absent condition. Consequently, the attentional segregation argument cannot be fully endorsed. In fact, the heading performance decrement which appears when the HUD symbology is placed near the heading information strongly suggests that attentive field size played an important role in the integration and utilization of heading and altitude information.

The presence of a performance trade-off in the proximal HUD symbology condition combined with the absence of trade-offs in the middle and distal HUD symbology conditions clearly indicates that the proximal altitude indicator location and heading information were included in a single attentive field. Furthermore, the equivalent performance in the middle and distal HUD information conditions suggests that exclusion from an attentive field may affect objects similarly.

It is interesting to note that if the presence of attentive fields is overlooked, the attentional segregation argument cannot be fully supported. While the altitude performance was consistent with the attentional segregation predictions, the equivalent heading performance in the middle, distal and absent HUD symbology conditions cannot be explained by the attentional segregation approach. When both the altitude and heading information were present, the attentional segregation approach clearly predicted that heading performance should have suffered as compared to the HUD symbology absent heading performance. Since the available cognitive resources should have been divided between the two sources of information, a performance trade-off should have been observed. This did not occur; therefore, the attentional segregation argument cannot completely explain the overall pattern of results.

However, the attentional segregation argument precisely explains the pattern of results obtained when the heading and altitude information were contained within a single attentive field. When performance in the HUD symbology proximal condition is compared to performance in the HUD symbology absent condition, it is clear that improved altitude performance was associated with a decrement in heading performance. Altitude performance was reliably better in the proximal HUD information condition compared to the HUD information absent condition. Meanwhile, heading performance was reliably impaired in the proximal HUD information condition compared to the HUD information absent condition, just as the attentional segregation approach predicted. The attentive field and attentional segregation approaches have converged in an unpredicted manner.

General Discussion

The manner in which the attentive field and attentional segregation approaches have come together to affect performance contradicts the hypotheses which were set forth. It was hypothesized that placing information within an attentive field would facilitate information integration. In contrast, placing the altitude and heading information close enough together to be located within a single attentive field seems to have encouraged subjects to focus their attention on one source of information, thereby neglecting the other. This occurrence, in which one source of information receives cognitive attention while the other perceptually available information is ignored, is called attentional tunneling.

There is no evidence that information integration was occurring in the proximal condition. In fact, there was no evidence that information integration was occurring in any of the HUD symbology present conditions. Instead, an attentional scanning strategy seems to have been adopted. However, placing separate information sources in close proximity seems to have discouraged attentional scanning. Conversely, placing two sources of information in different frames of reference within the same attentive field seems to have encouraged attentional tunneling. Apparently, attention was focused on one piece of information, thereby reducing the efficiency with which the remaining information could be utilized.

It is possible that an attentional scanning strategy may have been adopted because the altitude and heading information were located in separate frames of reference. Neisser and Becklen (1975), Becklen and Cervone (1983) and Foyle et. al (1991) have suggested that placing information in different frames of reference interferes with the integration of information. However, it is important to note that superimposing digital symbology over pictorial terrain information, thereby placing the information in separate frames of reference, did not inhibit the use of information from both sources when attentional scanning was clearly required. More precisely, when heading and altitude information were too distant to be contained within a single attentive field, attentional scanning was necessary in order to obtain information from both sources. Scanning improved performance. When attentional scanning was required, in the intermediate and distal HUD symbology conditions, altitude performance improved and heading performance was unimpaired. In conditions where attentional scanning was encouraged, both sources of information were processed effectively. Information provided by the altitude indicator was utilized without any associated decrement in heading performance.

Apparently, it may not be necessary to facilitate information integration by placing information sources in the same display format and frame of reference. Alternatively, altering the HUD design to encourage attentional scanning may reduce or alleviate the performance problems which have been encountered with the use of superimposed symbology.

Placing information in separate frames of reference only posed a performance problem when both sources of information were located within a single attentive field, in the proximal HUD symbology condition. It seems that placing the information in separate attentive fields encourages attentional scanning. Conversely, placing information in a single attentive field discourages attentional scanning, thereby contributing to an attentional tunneling problem.

Practical Implications

It appears that superimposing digital flight information in a separate frame of reference from terrain information may not cause performance problems unless the HUD symbology relevant to the task being performed is located near the task-relevant information in the external terrain. However, this situation may occur in aviation situations, especially during runway approaches when the runway should be located near the center of the pilots' field of view along with some superimposed symbology. Therefore, this study reaffirms the need to investigate methods of alleviating attentional tunneling and encouraging attentional scanning.

Clearly, the digital symbology display format and placing symbology in a separate frame of reference from the terrain information did not hinder performance when attentional scanning was required. These results imply that there may be no need to facilitate the integration of HUD and terrain information. Alternatively, placing attentional scanning cues in the superimposed symbology may adequately alleviate the problems encountered due to attentional tunneling. The attentional scanning cues should encourage the pilots to survey the other sources of relevant information periodically. Extrapolating from the results of this study, it seems possible that such a design alteration might reduce the performance problems which have been associated with the use of superimposed symbology.

Larish and Wickens (1991) have also suggested that encouraging attentional scanning may be the most efficient way to improve performance with HUD symbology. They have suggested scenario-specific cues for the segments of flight during which pilots' should be surveying the terrain. For example, they suggest presenting flashing flare bars in the symbology when a decision height is reached for landing.

Since it is especially important for pilots to maintain constant situational awareness in a rotorcraft aviation environment, more frequent and less situationally-specific attentional scanning cues might be useful. For example, an icon might be presented in the symbology periodically to remind the pilots' to survey the terrain.

Future Research

It is important to note that only one piece of HUD information was presented in this experiment. Consequently, the results may not be completely representative of flight performance in aviation situations where full HUD symbology is presented. Furthermore, the complexity of the full symbology should be taken into consideration when investigating any alteration of or addition to the HUD design. Display complexity may alter attentional scanning strategies. Additionally, attentional scanning strategies may be affected by flight variables such as turbulence levels. Each of these issues should be considered in future research.

Conclusion

The results of this study indicate that further investigation of a design change which could effectively encourage attentional scanning might be useful. Such a design change might reduce the attentional segregation problems which have been encountered with superimposed symbology due to differences in information location.

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Appendix A. Signed Approval Forms

APPROVED BY THE MASTER'S THESIS COMMITTEE

Kevin Jordan, Ph.D.
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Research Psychologist, NASA Ames Research Center

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May 27, 1992

TO: Beverly Sanford, MA candidate

FROM: Kevin Jordan, MA Coordinator

RE: Design and analysis review

Drs. Hawkins and Nishita have read your thesis proposal for the Design and Analysis Committee. Their comments are enclosed. Based on their comments, the thesis proposal is approved. As you can see, both reviewers are enthusiastic in their approval. Dr. Nishita has a few comments included in the manuscript, so I forward his copy to you.

Based on this committee's approval, the collection of data for your thesis is approved contingent on documentation of compliance with university policy regarding the use of human subjects in research. University policy requires approval of your project by the Human Subjects Institutional Review Board. Please provide me with a file copy documenting such approval as soon as you receive it. After that copy is part of your file, you may begin collecting data.

Congratulations on your progress to date! We look forward to the continuation of your fine performance in the program.

cc:

Cooper
Foyle (NASA-ARC; forward to Jordan)
Hawkins
Jordan
Nishita
file

Office of the Academic Vice President • *Associate Academic Vice President* • *Graduate Studies and Research*
One Washington Square • San José, California 95192-0025 • 408/924-2480

To: Beverly D. Sanford, Psychology
568 N. White Road
San Jose, CA 95127

From: Serena W. Stanford
AAVP, Graduate Studies and Research

Date: March 27, 1992

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

"Heads-Up Displays: Effects of Information Location on the Processing of Super Imposed Symbology"

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to any and all data that may be collected from the subjects. The Board's approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Dr. Serena Stanford immediately. Injury includes but is not limited to bodily harm, psychological trauma and release of potentially damaging personal information.

Please also be advised that each subject needs to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate or withdrawal will not affect any services the subject is receiving or will receive at the institution in which the research is being conducted.

If you have questions, please contact me at 408-924-2480.

CC: Kevin Jordan, Ph.D.