1993

Head-up displays : the effects of color and motion cues on attentional switching time

J. M. (Jean M.) Lynch
San Jose State University

Order Number 1356480

Head-up displays: The effects of color and motion cues on attentional switching time

Lynch, Jean Marie, M.A.

San Jose State University, 1993

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

HEAD-UP DISPLAYS:
THE EFFECTS OF COLOR AND MOTION CUES ON ATTENTIONAL SWITCHING TIME

A Thesis

Presented to

The Faculty of the Department of Psychology

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

by

Jean M. Lynch

December, 1993

APPROVED FOR THE DEPARTMENT OF PSYCHOLOGY

Dr. Kevin Jordan

10/21/93

Dr. Robert S. McCann

Dr. Robert Cooper

APPROVED FOR THE UNIVERSITY

ABSTRACT

HEAD-UP DISPLAYS: THE EFFECTS OF COLOR AND MOTION CUES ON ATTENTIONAL SWITCHING TIME

by Jean M. Lynch

Previous aviation display research (e.g., McCann, Foyle, & Johnston, 1993) has shown that transitioning between Head-Up Displays (HUDs) and the "out the window" view of the world involves a shift of attention which may delay processing of important world information during key decision points. The present study was designed to examine ways to reduce the costs of shifting attention.

During a simulated approach to a runway, a dual-decision task was used with the HUD being the same or a different color from the world and the world being in motion or being fixed relative to the HUD. The data indicated that the attentional shift and the resulting processing time increases were produced primarily by the motion of the outside world relative to the HUD; with no relative motion cues, attentional shift costs were reduced.

ACKNOWLEDGMENTS

This thesis was funded by NASA Cooperative Agreement NCC 2-327 to San Jose State University. I would like to thank my thesis committee for their invaluable contributions. To Drs. Kevin Jordan and Robert Cooper, thank for your guidance and patience. To Dr. Robert S. McCann, thank you for allowing me the opportunity to work with you. Your excitement for your work is contagious and inspiring. Also, many thanks to Daniel Delgado for programming, Cheryl Uyehara for designing the graphics, Maurice Standlee for help in recruiting subjects, and Roger Remington and Jim Johnston for lab space and equipment.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Head-Up Displays:
The Effects of Color and Motion Cues on Attentional Switching Time

Jean M. Lynch

San Jose State University

Running head: HEAD-UP DISPLAYS

Requests for reprints should be sent to Jean M. Lynch, Department of Psychology, San Jose State University, San Jose, California 95192.

Abstract

Previous aviation display research (e.g., McCann, Foyle, & Johnston, 1993) has shown that transitioning between Head-Up Displays (HUDs) and the "out the window" view of the world involves a shift of attention which may delay processing of important world information during key decision points. The present study was designed to examine ways to reduce the costs of shifting attention. During a simulated approach to a runway, a dual-decision task was used with the HUD being the same or a different color from the world and the world being in motion or being fixed relative to the HUD. The data indicated that the attentional shift and the resulting processing time increases were produced primarily by the motion of the outside world relative to the HUD; with no relative motion cues, attentional shift costs were reduced.

Head-Up Displays:

The Effects Of Color And Motion Cues On

Attention Switching Time

Head-up displays (HUDs) project aircraft flight data, such as altitude, speed, pitch, roll, and wind shear warnings, onto the windshield or a combiner glass so that a pilot can utilize needed flight information while viewing the outside world. HUD symbology is typically light green in color and focused at optical infinity. Since their introduction over 30 years ago, HUDs have been used in military jets, rotorcrafts, cargo carriers, and a few automobiles. Alaska Airlines is the first commercial airline to use the HUD, and others are soon to follow.

The growing popularity of HUDs is due to many factors. HUDs are widely considered to facilitate concurrent monitoring of the aircraft status and the external world (Larish & Wickens, 1991). The HUD allows takeoff guidance of departures with low runway visual ranges (RVRs) and landing during Category 3 conditions of only 700 feet RVR. The HUD also can display wind shear detection systems which not only detect wind shear, but also guide the pilot out of trouble while allowing continuous monitoring of the outside world (Johnson, 1988). Several experts have claimed that the HUD could have prevented up to 31% of the civil aviation accidents in the last thirty years (Nordwall, 1992; Velocci, 1992).

The HUD also facilitates flying during normal conditions. In several studies, vertical and lateral tracking, as well as approaches, were better with the HUD than with the conventional instruments (Boucek, Pfaff, & Smith, 1983; Fischer, Haines, & Price, 1980; Lauber, Bray, Harrison, Hemingway, & Scott, 1982).

Pilots like the HUD; one study reports that they prefer it to conventional instruments (Lauber et al., 1982). Additionally, pilots reported a lower subjective workload while using the HUD (Boucek et al., 1983). This may be because the HUD does not fly the airplane for the pilot, but aids in optimizing flight performance.

Although the HUD has many advantages, several performance problems have been associated with its use. The U.S. Air Force lost 73 HUD-equipped airplanes from 1980 to 1985. The pilots seem to have become disoriented and flew into the ground (Iavecchia, Iavecchia & Roscoe, 1988). Roscoe (1987) reported that about 30 percent of tactical pilots experienced disorientation while flying with the HUD, mostly while flying into and out of clouds.

Another problem which occurs with the HUD is that pilots fail to detect unexpected events (i.e., other airplanes were not seen on a runway which was to be landed on). In a study by Fischer, Haines, and Price (1980), it took subjects about two seconds longer to respond to unexpected events when using the HUD than without using the HUD. Two of the pilots who were using the HUD completely missed seeing the obstacles. In another study, Weintraub, Haines, and Randle (1985) found that only two out of eight of their pilots spotted unexpected obstructions. Lauber, Bray, Harrison, Hemingway, and Scott (1982) found that their subjects noticed runway obstructions, but it took them longer to respond than without the HUD.

Sources of HUD Problems

Accommodation. The problems caused by the HUD have several potential sources. Accommodation was first thought to be the main problem. Roscoe (1987) claimed that when using collimated virtual images, the lenses of the pilots' eyes relax to focus at their natural resting or dark focus. The visual scene then appears to be shrunken, and distant objects appear to be farther away than they actually are. The HUD is set up for the user to focus at optical infinity. This may cause distant objects, such as the runway, to seem to shrink in size and perhaps be out of focus (Iavecchia et al., 1988).

Weintraub, Haines, and Randle (1984) used 35-mm slides of actual approaches to runways in order to study accommodation in subjects. The slides were projected and collimated to appear the correct size, yet far away. The HUD was superimposed to appear at various optical distances. This allowed the researchers to study reaccommodation between the HUD and the slides. The subjects' task was to first check the HUD for airspeed and altitude information. If the information exceeded set limits, the subject was to abort the landing. If the airspeed and altitude were both within the legal limits, the subjects were to look on the runway for a symbol indicating whether the runway was open or closed. As soon as the subject had determined whether it was safe to land or a "go-around" was required, they were to signal their intent with a keypress on the joystick. The order of information processing was reversed by Weintraub, Haines, and Randle (1985) such that subjects first checked the runway and then the HUD. Across both studies, the results indicated that when subjects had to process both the HUD and the runway information, their response times were significantly longer than when subjects had to process just the HUD or just the runway.

In both of the Weintraub et al. (1984, 1985) experiments, an eye tracker was used to measure when a shift of accommodation occurred during HUD use. They found that subjects did not wait for maximum reaccommodation in order to complete the task. They concluded that shifting attention from the HUD to the runway or vice versa seemed to be causing the HUD's problems, not the time required for reaccommodation.

Shifting Attention. Further evidence against the misaccommodation hypothesis comes from Brickner (1989). Brickner presented both the HUD and the "real world" scene on a two-dimensional screen, which created a situation where misaccommodation could not be a factor. Brickner had subjects fly a simulated helicopter through a slalom course. The task was to maintain a given altitude while maneuvering through the slalom course. Three display conditions were compared: environments with a grid on the ground, grid and texture on the buildings, and the grid and texture and a HUD with altitude information on it. He found that the presence of digital altitude information on a HUD facilitated performance in maintaining altitude but at the cost of diminished performance on tracking through the slalom course; i.e., the HUD led to a tradeoff between tracking performance and altitude performance.

Sanford (1992) replicated Brickner's performance tradeoff. She had her subjects fly a path defined by a series of pylons while maintaining an altitude of 100 ft. Sanford found that the presence of digital altitude information on a HUD significantly improved altitude maintenance. However, when the altitude indicator was close to the heading information, heading performance was decremented.

An Attentional Account

An alternative to the misaccommodation account of these performance problems is that the problems are attentional. Classical views of attention (i.e., Broadbent, 1982; Eriksen & St. James, 1986) liken attention to a spotlight. The spotlight theory claims that attention is allocated to a particular location in space and is distributed inside of the spotlight beam, but not distributed outside of the beam.

Whereas the spotlight theory claims that attention is focused on locations, object-based theories (i.e., Kahneman & Henik, 1977; Neisser, 1967) claim that attention is focused on objects. Object-based theories of attention claim that visual attention is allocated in two steps. First, the scene is preattentively segmented into separate objects. Attention is then focused on a particular object in order to analyze the "object's" features. Unlike the spotlight theories, the area in close proximity to the attended object is not itself attended to; rather, the attended object is attentionally selected from its surroundings. Empirical support for object-based models is increasing. For example, Baylis and Driver (1992) recently found that position judgments of parts of *one* object were quicker than position judgments of parts of *two* objects. The experimenters used identical stimuli for the two conditions, thereby controlling for spatial extent, yet found that judgments concerning different perceptual objects took longer than judgments concerning one perceptual object.

Further evidence suggests that attention can also be allocated to entire groups of objects when the group is defined by perceptual cues such as common fate, proximity, and color. Treisman (1982) found that searches within a group of objects were faster than searches across two groups of objects. Kahneman and Henik (1977) suggested that a preattentive process operates on perceptual units, such as groups of objects. Attention can then be focused on just part of a perceptual unit or over the whole perceptual unit. The claim is that instead of attention being allocated to just one object at a time, a group of similar objects could be attended to preattentively and then attention would be allocated to individual objects within the group.

There is evidence that when attention is allocated to one group, processing of objects in other groups in the visual field is restricted to low levels of analysis. Neisser and Becklen (1975) had subjects follow the action of one of two visually superimposed games. They found that when subjects were attending to one game, strange events in the unattended games were rarely noticed. This finding is similar to the Fischer et al. (1980) result noted earlier, where subjects attending to a superimposed HUD often failed to notice an unexpected airplane which was intruding onto the runway.

Wickens, Martin-Emerson, and Larish (1993) have described the HUD, and its symbology, as forming a near perceptual domain, and the outside world as forming a far perceptual domain. Domain grouping could therefore account for Brickner's (1989) and Sanford's (1992) findings. Suppose the HUD and the world form distinct domains. When the HUD was actively attended (i.e., the pilot was controlling altitude), path information, being part of the world, was not being processed; consequently, path performance suffered.

<u>The McCann, Foyle, and Johnston study</u>

One implication of the grouping-based models of the performance trade-off reported by Brickner and Sanford is that abrupt transitions from processing HUD information to processing world information (and vice versa) involve a shift of attention. McCann, Foyle, and Johnston (1993) recently tested this hypothesis in a dual-decision task that subjects performed during a simulated approach to a runway. The procedure was as follows. First, a three-letter cue appeared on either the HUD or the runway. After 250 ms, two sets of three symbols each appeared, one set on the HUD and the other on the surface of the runway. Each set consisted of a stop sign or diamond and two irrelevant shapes (a triangle and a rectangle). If one set contained a diamond and the other a stop sign, the trial was labeled incongruent. If both sets contained the same symbol (both were stop signs or diamonds), the trial was labeled congruent. If the cue spelled IFR (for instrument flight rules), the subject was instructed to attend to the HUD set of symbols and ignore the runway set. If the cue spelled VFR (for visual flight rules), then the subject was instructed to attend to the set of symbols on the runway and ignore the HUD set. The subjects' task was to search the attended set of symbols for the presence of the stop sign or diamond. This procedure yielded two kinds of trials: between-domain trials, where the cue was part of one domain (the HUD or the runway) and the relevant target was part of the other, and within-domain trials, where the cue and relevant target were part of the same domain.

Two results from McCann et al. (1993) are particularly relevant. First, between-domain trials took an average of 80 ms longer than within-domain trials. The 80-ms cost for between-domain trials was interpreted as an attentional shift between the two domains and was labeled a domain effect. Weintraub et al. (1984) claim that even this short amount of time can mean the difference between a near miss and a collision.

The second result was an interaction of congruency and type of trial (between-domain or within-domain), such that congruency effects were larger on between-domain trials than on within-domain trials. On between-domain trials, the target in the irrelevant domain interfered with processing the target in the relevant domain when the two targets were incongruent. The irrelevant target did not interfere as much with processing the relevant target on within-domain trials. This finding indicated that subjects were indeed ignoring information in the irrelevant domain on within-domain trials.

Perceptual Segregation

According to attention grouping theories, the domain effect obtained by McCann et al. (1993) is a product of the fact that the visual system parses the HUD as one perceptual group and the world as another. This parsing is presumably driven by the large number of perceptual cues that distinguish the two groups. Examples of such perceptual cues are relative motion, common fate, display format, and color. The next section reviews evidence that at least two of these cues, color and motion, can drive perceptual grouping.

Relative motion. If within a field of dots a few dots move in synchrony (i.e. they have a "common fate"), they are perceived as a unified object (Gibson, Gibson, Smith & Flock, 1959). Common fate may explain how the HUD can be attentionally segregated from the world: since the HUD does not move with the outside world, it is therefore viewed as being an object separate from the world.

Movement filter. The construct of a movement filter in the visual system may also be responsible for the perceptual system grouping the HUD separately from the world. McLeod, Driver, Dienes, and Crisp (1991) found that attentional segregation could be produced by differential motion cues. They had their subjects search for a moving X in a field of stationary Xs and moving or stationary Os. The reaction times were not affected by the total number of X's and O's in the search field, so the researchers concluded that the subjects attentionally grouped the moving objects. As usually defined, common fate requires the objects to be moving in the same direction in order to be grouped, but this study found that all of the moving objects were attentionally segregated from all of the stationary objects regardless of their direction of movement. McLeod et al. (1991) also found that when the task involved search for a target that could be either moving or stationary, search was more difficult than when the search was performed on just stationary or moving targets. They concluded that this was due to attention being directed to two components of the visual array instead of just one.

McLeod et al.'s (1991) findings are consistent with Treisman's (1982) findings that visual search across groups is serial in nature, while search within a group is parallel. If all of the moving stimuli are grouped and the non-moving stimuli are grouped, then they will be perceived as two separate groups which must be searched serially. This provides a natural account of the slowdown in response time in the McCann et al. (1993) study on between-domain trials compared to within-domain trials.

Display format and color. Perceptual segregation between the HUD and the outside world may also be based on differences in display format and color. The terrain is pictorial and three-dimensional while the HUD is mostly digital, two-dimensional, and light green. The HUD changes much less often and much less quickly than the outside world, and because of this, the pilot is more likely to fixate on it. Even the apparent motion of the HUD display (i.e., numbers changing) may cause attentional segregation (Larish et al., 1991).

In support of these conjectures, Kramer, Tham, and Yeh (1991) and Baylis and Driver (1992) found that common color leads to grouping during selective attention tasks. Both studies used an Eriksen flanks paradigm which required subjects to search for a target which is surrounded by distractors. The distractors can have various characteristics, such as color, motion, and shape, which are the same or different from the target. Both Kramer et al. (1991) and Baylis and Driver (1992) found that proximal distractors that were the same color as the target caused more response competition than proximal distractors of a different color. The metaphor of attention as a spotlight or zoom lens was not supported by their results since attention was drawn to distal similar-colored objects over the proximal different-colored objects. They also found that the stronger the near distractors grouped with the target, the less the far distractors could be grouped. There seemed to be competition for attentional resources in grouping.

The Present Study

Existing evidence suggests that the color and motion cues can lead to perceptual grouping. There are therefore three possible sources of attentional segregation between the

HUD and the world: (1) color is driving segregation, (2) motion is driving segregation, or (3) both color and motion are needed to drive segregation. A study is mandated to distinguish among these hypotheses.

Accordingly, the present study used the same task as McCann et al. (1993) to compare domain effects under a variety of perceptual conditions. The HUD was either the same color as the world or a different color from the world. The world was either moving (i.e., the display had the appearance of an ongoing approach to a runway) or the world and the HUD were both fixed. The factorial combination of the two levels of HUD color (same or different from the world) and two levels of relative motion (world in motion or world fixed) resulted in four perceptual conditions.

The predictions are as follows. If color is the sole determiner of domain segregation, then the domain effect reported by McCann et al. (1993) should be reduced when the color cue is removed (i.e., when both the HUD and world are the same color). If motion is the sole determiner of domain segregation, then the domain effect should be reduced only when the motion cue is removed (i.e., when the world is fixed). If domain segregation requires both color and motion cues, the domain effect should be reduced when *either* cue is removed and when both cues are removed.

The present experiment also hypothesizes that domain effects will be reduced because the between-domain trials will get faster. Without the relative motion and color cues, the HUD and runway should not segregate into two domains and the search will proceed with one larger domain. Attention shifting will therefore no longer occur on between-domain trials.

Method

Subjects

Forty-eight college students participated in the experiment as partial fulfillment of a course requirement or for pay.

Apparatus

An IBM personal computer with a 14-inch NEC Multi Sync monitor was used to simulate real-time, three-dimensional approaches to a runway. The display consisted of a runway and a HUD. The complete HUD measured 11.5 cm wide by 9 cm tall and consisted of an aircraft reference symbol, two sets of pitch lines and four boxes (see Figure 1). The HUD and the world were either both brownish-yellow, or the HUD was blue and the world was brownish-yellow. A blue horizon line bisected the screen. The runway was viewed as it would appear at a 3-degree glideslope. The far end of the runway was at the horizon and measured 1-cm wide while the near end of the runway appeared at the bottom of the screen and measured 26-cm wide. There was a broken line down the middle of the runway. The flight simulation program showed a fixed HUD for all of the trials, and the runway was either fixed

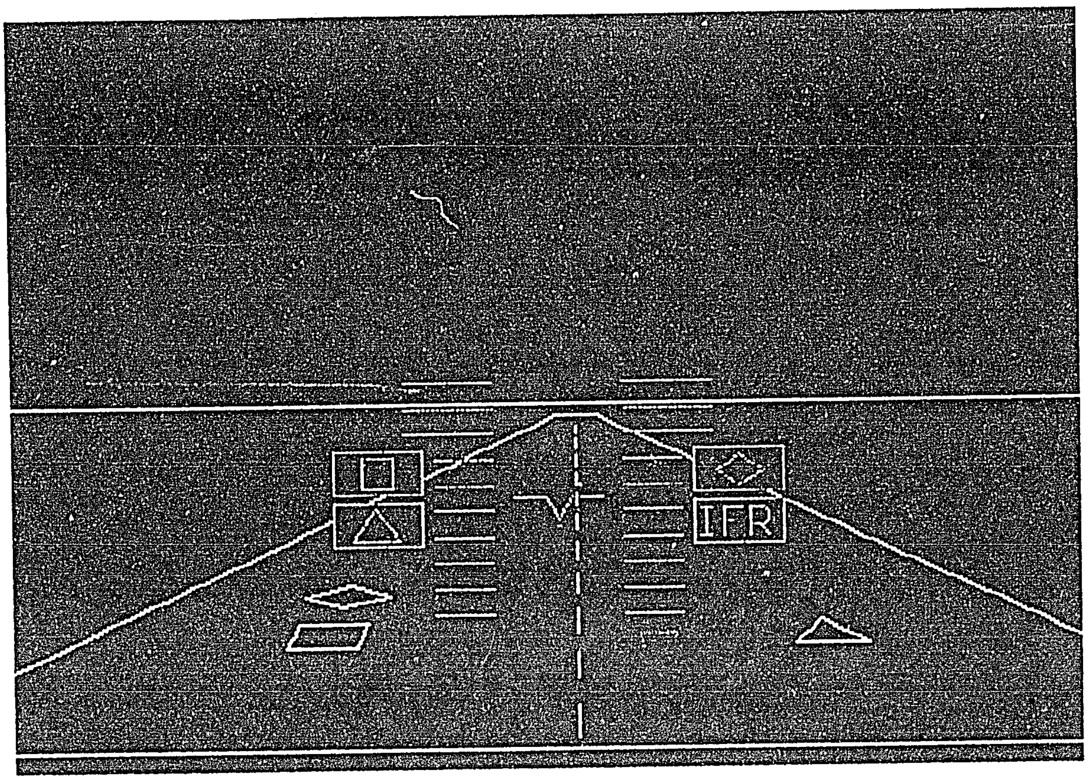


Figure 1. Schematic representation of flight simulation with the starting position on the HUD.

with respect to the "aircraft" or it moved consistent with the pilots view of a runway just prior to touchdown (see Figures 2 & 3).

Stimuli

The stimuli were presented on a CRT screen. The "out the window view" consisted of a horizon line and a runway which was viewed at a three degree glideslope. The runway was formed by a trapezoidal box measuring 23 cm at the near end and 1 cm at the far end with a broken line running down the middle. Superimposed on the "out the window view", was the HUD which consisted of four boxes (1.9 cm wide by 1.1 cm high) placed 0.6 cm apart vertically and 5.4 cm apart horizontally. Across the HUD were a set of pitch lines, and in the middle an airplane symbol. The HUD was fixed to the center of the screen and obscured the farther half of the runway.

When the color cue was present, the HUD was blue and the world was yellow; when it was absent, both HUD and runway were yellow. When the motion cue was present, the HUD remained fixed in the center of the screen while the runway moved forward on the screen, as it would during a final approach to a runway. Pitch and yaw buffeting was added to further simulate a real descent. When the motion cue was absent, the "out the window" scene remained fixed behind the stationary HUD for the trial duration.

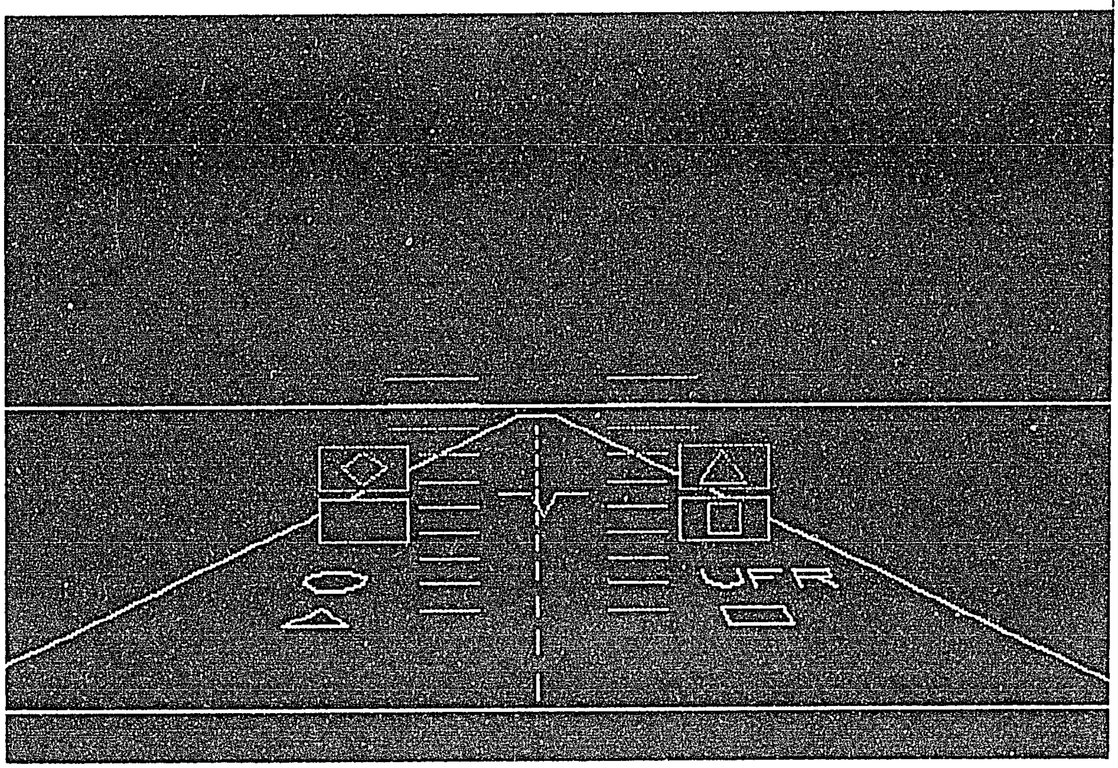


Figure 2. Schematic representation of flight simulation with the starting position on the runway.

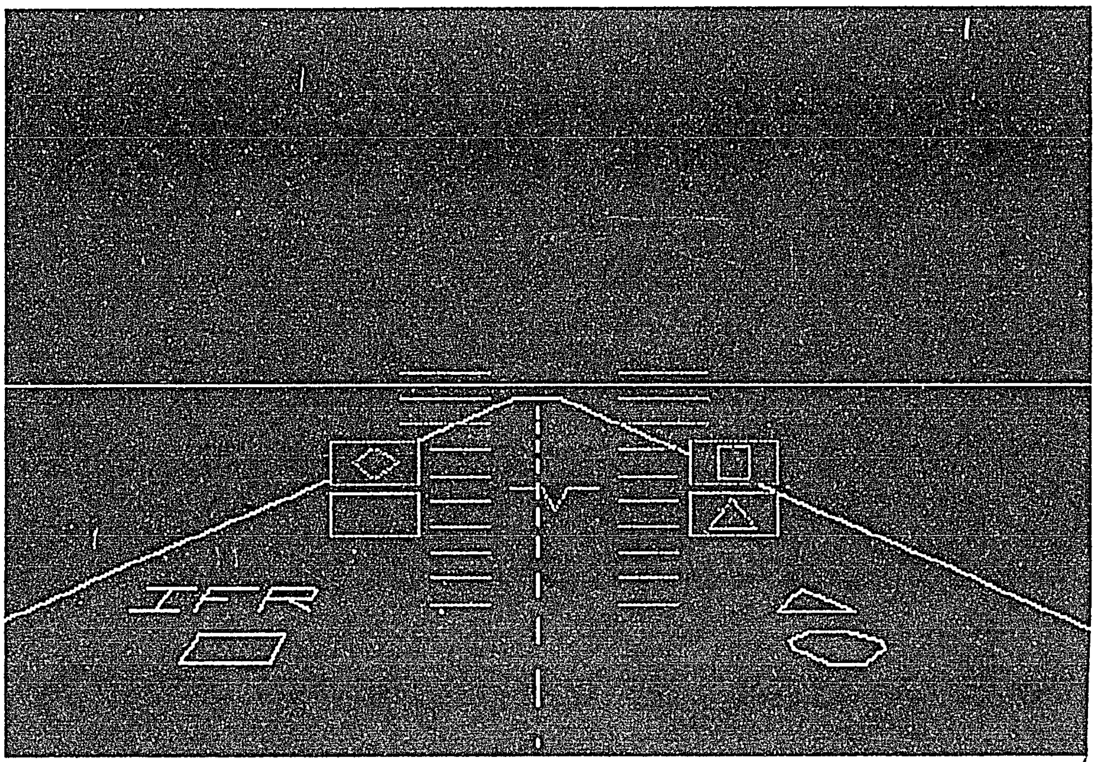


Figure 3. Schematic representation of flight simulation with the starting position on the runway. Note that the airplane has moved further down the runway than in figure 2 and the runway symbols have also moved.

The experimental stimuli consisted of two three-letter cues, IFR (instrument flight rules) and VFR (visual flight rules), two potentially relevant targets (each either a stop sign or a diamond) and four distractors (two on the HUD, two on the runway). The HUD stimuli appeared in the four boxes and the runway stimuli appeared to lie flat on the runway, in four locations directly below the HUD. Both the HUD and the runway contained a potentially relevant target and two distractors, but only one domain contained the cue. The relevant target could occur in three different boxes on the HUD or in three different locations on the runway (see Figure 1). The cue appeared in either one of the two bottom HUD boxes or in one of the two top runway locations. The determination of which target was relevant and which was irrelevant was controlled by the identity of the cue (IFR: HUD target relevant, runway target irrelevant; VFR: runway target relevant, HUD target irrelevant). The two potentially relevant targets were either congruent (both diamonds or both stop signs) or incongruent (a diamond and a stop sign). The distractors were a triangle and a rectangle, and were always embedded in both the HUD and the runway.

Design

A 2(cue domain) x 2(relative motion) x 2(HUD color) x 2(relevant target domain) x 2(congruency) mixed factorial design was used. Starting from when the cue appeared, reaction time to indicate the decision to abort or continue the landing was the primary dependent variable.

Cue domain (HUD or runway) was a between-subject variable and the rest were within subject variables. Half of the 48 subjects were instructed to search for the cue on the HUD while the other half searched for the cue on the runway.

The HUD was blue for four blocks of trials and brownish-yellow, the same color as the world, for the other four blocks. The runway moved for half of the blocks or was fixed to the position of the "aircraft" for the other half of blocks. The factorial combination of the relative motion and HUD color conditions resulted in four grouping conditions, defined by the factorial combination of motion (world moving verses world stationary) and color (same verses different).

Each subject participated in a total of eight blocks of trials, consisting of two blocks for each of the four grouping conditions. Each of the two blocks was presented consecutively. Within each group of two blocks, there were 144 trials resulting from the factorial combination of two levels of congruency (congruent verses incongruent), two levels of relevant target domain (relevant target part of the HUD or relevant target part of the runway), three levels of relevant symbol position and 12 replications. The factorial combination of cue domain and relevant target domain yielded two kinds of trials. *Between-domain* trials required the subjects to process information in both domains (the HUD *and* the outside world), while *within-domain* trials required the subject to process information in just one of the domains (the HUD *or* the outside world). Half of the trials were congruent and the other half incongruent.

Procedure

Each subject participated in one session which averaged about one hour. The subjects were instructed to play the role of a first officer in a commercial airliner. Their task was to decide whether to continue or abort a landing using information from the HUD and/or the runway. Subjects viewed the HUD and runway for an initial period of 1.5 s. The cue then appeared, followed 250 ms later by the two sets of three symbols. The cue always occurred where the subject was told to look for it, on either the HUD or the runway. Subjects were instructed to use the cue to determine where to search for the relevant symbol. If the cue spelled IFR, they were to scan the HUD to determine the relevant target. If the subject saw VFR, they were instructed to scan the runway. If the target in the domain indicated by the cue (i.e., the relevant target) was a stop sign, they were to signal their intent to abort the landing by pressing the key labeled "2" on the key pad. If the relevant target was a diamond, they were to signal their intent to continue the landing by pressing the 8 key.

The display was presented until the subject responded or until after 12 s had elapsed. When the subject responded correctly, the screen went blank and the next trial started automatically after 1 s. If the response was incorrect, the screen would clear and a blue box with the word "error" appeared for 1 s and then the next trial began. If the subject failed to respond, a "no response" message appeared for 1 s and then the next trial would begin. Each trial on which there was no response or an incorrect response was discarded and not repeated.

Results and Discussion

The two dependent variables analyzed in the present study were median reaction time (RT) and error rate. Mean RTs were not used since the distributions of the raw reaction times were highly positively skewed. The median RT, standard deviation, and error rates for each cell in the design are presented in Table 1. The median RTs varied from a low of 1323 ms to a high of 1463 ms. The error rates varied from a low of 1.4% to a high of 9.3%.

Analysis of Reaction Time Data

A 2(HUD color) x 2(relative motion) x 2(cue domain) x 2(relevant target domain) x 2(congruency) mixed analysis of variance was conducted on median RTs for correct trials. Cue domain was a between subjects variable.

Analysis of Cue and Relevant Target Domain. The ANOVA revealed a main effect of relevant target domain, $F(1,46)=4.66$, $p<.05$, such that reaction times were faster for trials where the relevant target was part of the HUD domain

Table 1

Median RTs(SD) and percent error rates.

Relative motion, different colors

			Cue Domain: HUD	Cue Domain: World
Relevant Target Domain	HUD	Congruent	1326(244), 2.1	1453(330), 5.3
		Incongruent	1323(244), 3.0	1448(287), 8.6
	World	Congruent	1424(254), 1.4	1363(230), 3.2
		Incongruent	1429(280), 6.5	1406(295), 6.3

Relative motion, same colors

			Cue Domain: HUD	Cue Domain: World
Relevant Target Domain	HUD	Congruent	1327(224), 4.3	1440(185), 2.8
		Incongruent	1371(326), 7.2	1427(181), 7.9
	World	Congruent	1451(320), 5.3	1345(152), 2.8
		Incongruent	1456(309), 6.9	1379(179), 5.0

No relative motion, different colors

			Cue Domain: HUD	Cue Domain: World
Relevant Target Domain	HUD	Congruent	1350(196), 2.8	1421(263), 4.7
		Incongruent	1335(210), 3.1	1401(260), 5.3
	World	Congruent	1419(201), 3.7	1390(248), 4.6
		Incongruent	1438(243), 7.8	1394(215), 5.6

No relative motion, same colors

			Cue Domain: HUD	Cue Domain: World
Relevant Target Domain	HUD	Congruent	1378(275), 4.2	1413(211), 5.0
		Incongruent	1383(294), 4.5	1407(216), 5.7
	World	Congruent	1442(305), 3.6	1463(361), 3.5
		Incongruent	1460(297), 9.3	1394(194), 7.1

than part of the runway domain (see Figure 4). It was easier to search for the relevant target when the relevant target was on the HUD than when it was on the runway. More importantly, the cue domain by relevant target domain interaction was highly significant, $F(1,46)=22.85$, $p<.001$. Subjects were slower on between-domain trials, where they were required to process information in both domains than on within-domain trials, where processing was confined to only one domain. The resulting cross-over pattern between cue domain and relevant target domain replicates the pattern reported by McCann et al. (1993), and is taken as the signature of attention shifting between domains.

The reason for the overall processing advantage when the relevant target was on the HUD is not clear. Perhaps it was easier for subjects to perform the task when the relevant target was on the HUD because the HUD was always stationary. Since the HUD did not move on any of the trials, the subjects had more practice finding it. The runway symbols, on the other hand, were moving towards the subject on half of the trials and thus were not always in a fixed location.

Impact of Relative Motion Cues. As shown in Figure 5, the magnitude of the crossover interaction between cue domain and relevant target domain was clearly influenced by the motion variable, such that the pattern was less pronounced when the world was frozen. This observation was supported by the presence of a significant three-way interaction between

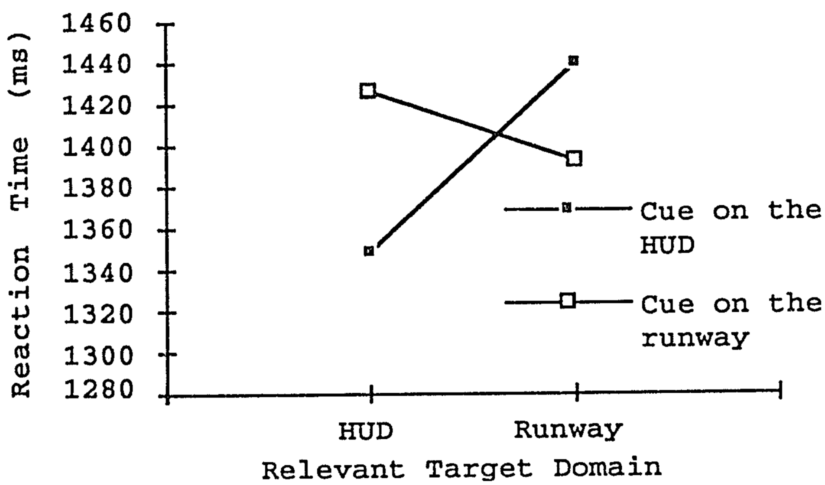
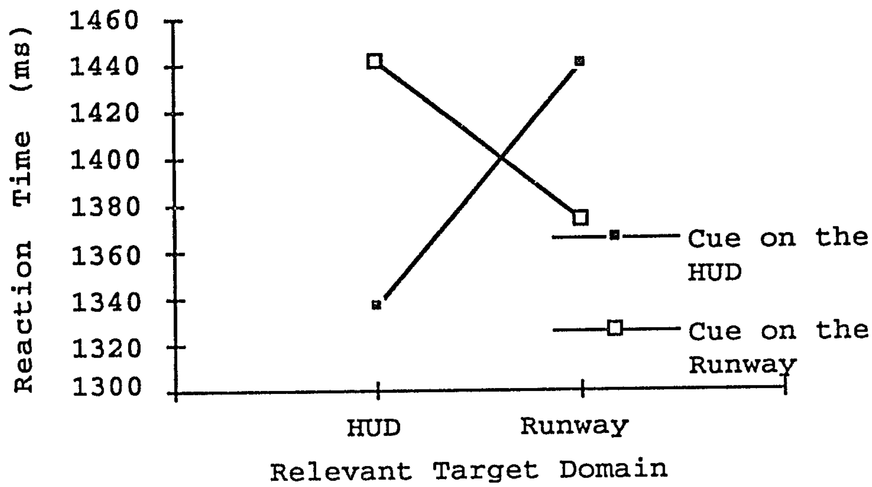
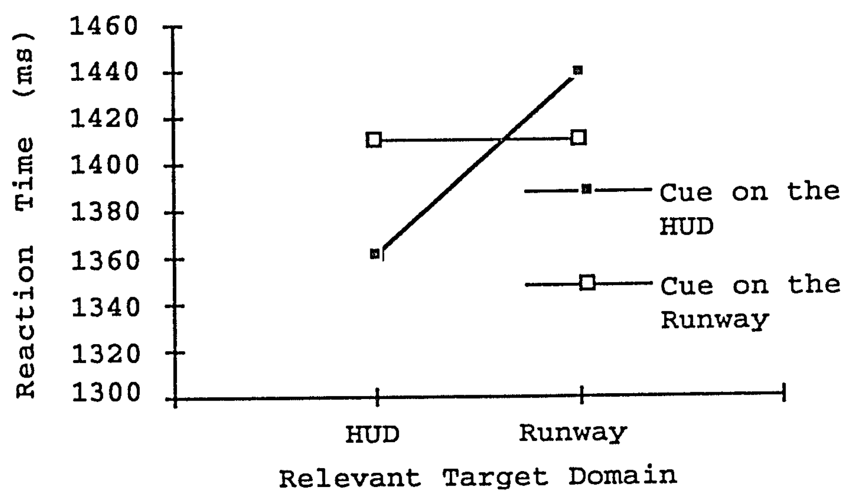


Figure 4. Cue domain by relevant target domain interaction.

a.



b.



<u>Figure 5</u> a. World in Motion

b. World Fixed

cue domain, relevant target domain, and motion, $F(1,46)=8.75$, $p<.01$. The advantage for within-domain trials over between-domain trials was reduced without the relative motion cue segregating the HUD from the runway. Logically, the reduction of the advantage of the within-domain trials over between-domain trials could be due to two possibilities. Our prediction, of course, was that the between-domain trials would be made faster. The second logically possibility, however, is that within-domain trials were slowed. The data reveal that both effects contributed. Within-domain trials increased from an average RT of 1355 ms during motion trials to 1386 ms during no motion trials. Between-domain trials were reduced from 1441 ms during motion trials to 1426 ms when there was no motion.

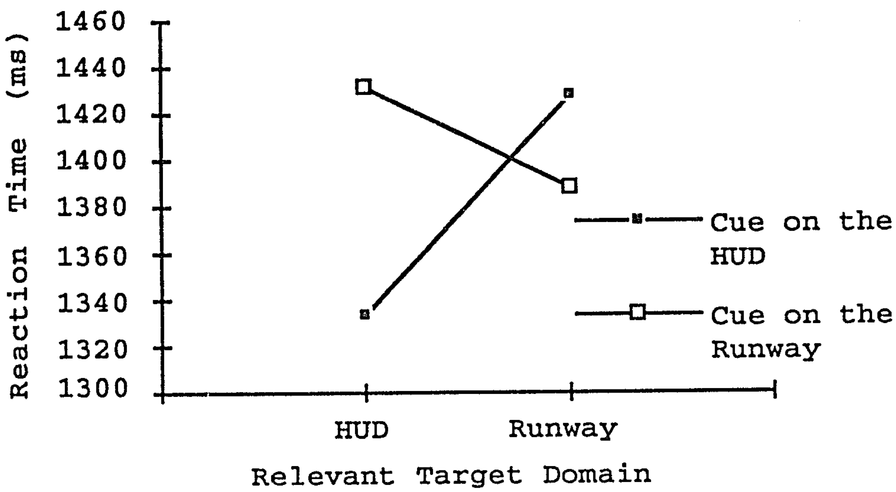
How might we account for these effects? For the within-domain trials, relative motion segregated the HUD and runway into two separate objects, yet the search was restricted to only one object. The search therefore proceeded efficiently. Without the relative motion, the within-domain trials were more difficult since the HUD and runway were not segregated into two objects and therefore the search proceeded with one larger object.

For the between-domain trials, relative motion segregated the HUD and the runway into two separate objects, and the search took place over two objects. Without the relative motion cue, the between-domain trials were faster since the HUD and runway were not segregated into two objects and therefore the search was restricted within one object.

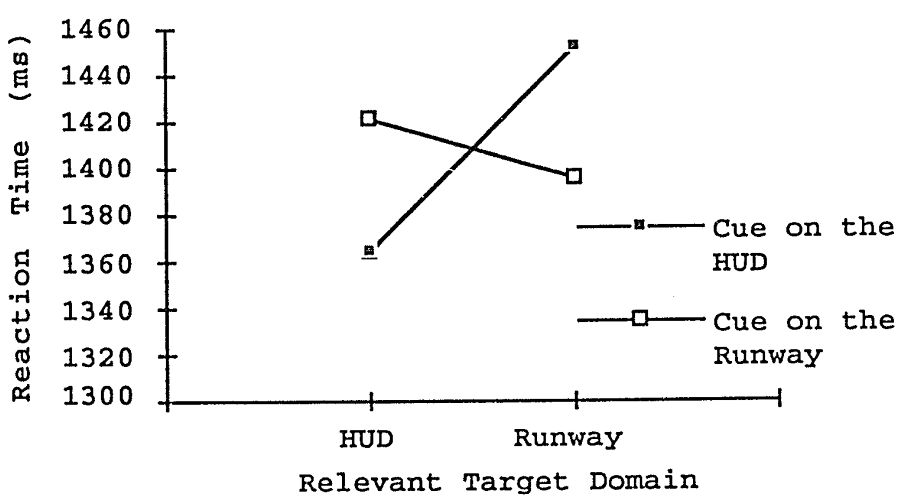
One additional aspect of the data is noteworthy. For the between-domain trials, the removal of the relative motion cue had a different effect depending on which domain contained the cue (HUD or runway). When the cue was located on the runway, the loss of motion cues reduced the domain effect from 69 ms to 0 ms, $\underline{F}(1,23)=27.85$, $\underline{p}<.001$ (see Figure 5). On the other hand, when the cue was located on the HUD, the domain effect was only reduced from 103 ms to 78 ms and was not significant, $\underline{F}(1,23)<1$.

Impact of HUD Color. As shown in Figure 6, there was little indication that the color variable had any impact on the magnitude of the cross-over interaction over and above the impact of the motion variable. In support of this observation, there was no main effect due to color, and the critical three-way interaction between color, cue domain and target domain was not significant, $\underline{F}(1,46)<1$ (see Figure 6). Thus we can conclude that unlike motion, color did not influence perceptual grouping, and hence the size of the domain effect.

Although the studies by Kramer, Tham, and Yeh (1991) and Baylis and Driver (1992) suggest that the HUD and world may be segregated perceptually by their color and spatial layout, only color and not other aspects of display format were a.



b.



Relevant Target Location

<u>Figure 6.</u> a. HUD color different from the world

b. HUD color same as the world

manipulated. In the current study, the displays of the HUD and runway symbols were different in that the HUD symbols were upright and framed while the runway symbols were flat on the runway and unframed. Color alone was not strong enough of an effect in this application.

In summary, the data suggest that motion was the significant factor in producing the attentional domain effect (based on perceptual grouping). I conclude that when the world was in motion, the HUD and world were attentionally segregated into two domains, whereas when the world was fixed, the HUD and the world were not attentionally segregated as effectively. Whether the world and the HUD were the same color or not had no additional effects.

Analysis of Error Rates.

A 2(HUD color) x 2(relative motion) x 2(cue domain) x 2(relevant target) x 2 (congruency) mixed analysis of variance were conducted on the error rates, with cue domain the between subjects variable. The main effect of congruency was significant, $F(1,46)=40.37$, $p<.001$, and the cue domain by relevant target domain interaction was significant, $F(1,46)=10.31$, $p<.01$. More errors occurred on incongruent trials (i.e., when the two potentially relevant symbols were different) and the congruency effect was more pronounced on between-domain trials, which required the subject to use both the HUD and the runway, than on within-domain trials, where no switching between domains was required. Other significant effects included a relevant target domain by congruency interaction, $F(1,46)=4.66$, $p<.05$, and a cue domain by relevant target domain by congruency interaction, $F(1,46)=4.48$, $p<.05$ (see Figure 7). The two-way interaction can be understood as follows. When the relevant target was part of the HUD domain, incongruent trials produced slightly more errors than congruent trials (3.89% for congruent vs. 5.66% for incongruent trials). However, when the relevant target was part of the runway domain, the difference in error rates between congruent and incongruent trials was considerably larger (3.52% for congruent vs. 6.79% for incongruent trials). The three-way interaction of cue domain by relevant target domain by congruency revealed that congruency had little effect on trials where processing was confined to the HUD domain; otherwise, it had a substantial effect. In other words, when processing was confined to the HUD, the presence of an incongruent symbol on the runway did not increase the error rate. However, on trials where processing was logically confined to the runway, incongruent information on the HUD still caused interference.

Speed-Accuracy Tradeoff. There is no evidence of a speed-accuracy tradeoff. In general, the faster the reaction times, the lower the error rates.

Congruency Effects for both Reaction Time and Error Analysis. It is important that the congruency main effect was not significant in the overall analysis of median RT,

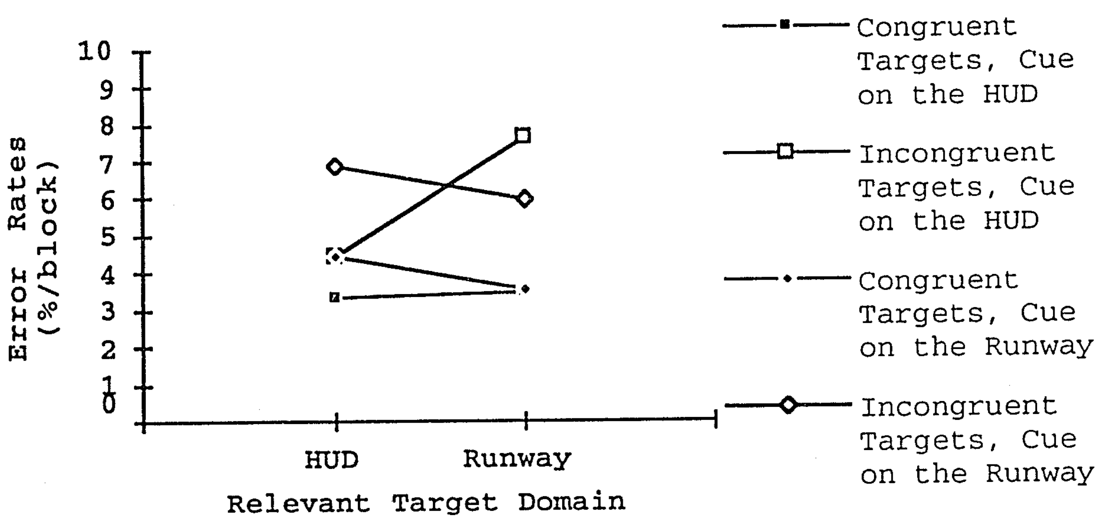


Figure 7 Congruency by cue domain by relevant target domain

since this would have suggested that the subjects were not following the directions. For example, if the subjects just looked at the two potentially relevant targets and ignored the cue, then incongruent trials would have taken longer than the congruent trials.

However, congruency was significant in the error analysis. More errors were made when the two potentially relevant targets were different than when they were the same (see Figure 7). This may have occurred because when the subjects were searching for the cue, they processed the target within the same domain whether it was relevant or not. Treisman (1982) claimed that searches within groups are conducted in parallel and searches across groups are conducted serially, so when searching for the cue, the potentially relevant target should be perceived also. Therefore, when processing the VFR cue on the HUD, a potentially relevant target (i.e., a stop sign) on the HUD may also have been processed. This could then interfere with processing the correct relevant target (i.e., a diamond) on the runway. Also, trials where processing was logically confined to the runway showed more of a congruency effect than trials where processing was logically confined to the HUD. In other words, it was apparently harder to ignore symbols on the HUD when processing was supposed to be confined to the runway than it was to ignore symbols on the runway when processing was supposed to be confined to the HUD.

Conclusions

There were two major results in the present study. First, whenever the cue (IFR/VFR) and the relevant target occupied different domains, response times increased relative to trials where all relevant information was confined to one domain or the other. McCann et al. (1993) interpreted this between-domain increase in RT as an attentional shift cost.

The second important finding was that when there was no motion in the outside view of the world relative to the HUD, the domain effect was reduced. On within-domain trials (when just the HUD domain or just the runway domain was processed), RTs were faster for trials with the world in motion than for trials with the world fixed (see Figure 5). This suggests that when the world was in motion, the HUD and the world were easily segregated. On the other hand, during the world-fixed condition, the HUD and the world were not segregated by motion. Thus, segregation between the HUD and the world was less complete, resulting in within-domain trials taking longer and between-domain trials (both the HUD and runway domains were used) taking less time.

Additional Findings

The present experiment hypothesized that when the HUD and runway displays were made more similar perceptually, the between-domain trials would get faster. This hypothesis was based on the idea that the between-domain trial penalty was entirely due to attention shifting between domains. However, when the domains were made more similar by taking away the motion cue, not only did between-domain trials get faster, within-domain trials got slower. It would appear therefore, that part of the domain effect is due to a facilitation of within-domain processing when segregation is working. That is, when the HUD and runway were easily discernible (the runway was moving as the HUD was fixed), within-domain trials were easier to process because half of the display could be effectively ignored. When the HUD and runway were both fixed, it was more difficult to ignore half of the display.

Another unexpected finding was revealed in the error analysis by the interactions of cue domain, relevant target domain and congruency. Subjects were less affected by inconsistent information on the runway when attending to the HUD than vice versa. This may have been because (1) the HUD was upright while the runway symbols were tilted, (2) the HUD symbols were framed while the runway symbols were not, or (3) because the HUD appeared in front of the runway. Future studies will control for the first two possibilities by having the runway display with its symbols upright and framed, as though they were projected onto billboards.

The third possibility, that the HUD appeared to be in front of the runway, may have affected the performance on within-domain trials. Fewer errors were committed while using the HUD only than the runway only in within-domain trials in the three-way interaction of cue domain, relevant target domain and congruency in the error analysis. This is consistent with the results of a recent study by Andersen and Kramer (1993). They found that objects which appeared to lie in front of a target were harder to ignore than objects which appeared to lie behind the target. Even though the present experiment was conducted on a two-dimensional screen, the HUD still appeared to lie in front of the runway (see Figure 1). Therefore, following Andersen and Kramer, the natural tendency may have been to focus on the HUD more than on the runway. The logic for why the natural tendency to focus on the HUD would produce the three-way interaction in the error analysis would be as follows. When the cue was on the HUD the perception that the HUD was closer to the observer than the runway made it easy to focus on the HUD and to ignore the runway. Therefore, the presence of an incongruent target on the runway had little influence on processing the relevant target on the HUD. Similarly, when the relevant target was on the runway, the perception that the HUD was closer to the observer made it hard to focus attention on the runway and away from the HUD. Therefore, the presence of an incongruent target on the HUD had a large effect on processing a relevant target on the runway.

If attention was drawn more naturally to the HUD domain than to the runway domain, it may also explain the asymmetry of the domain effect. That is, removal of the motion cue did not impact the size of the domain effect significantly when the cue was located on the HUD, but motion cue removal did significantly reduce the domain effect when the cue was located on the runway. Suppose, once again, the natural tendency to attend to the HUD domain made it easier to focus on the HUD than on the runway. Therefore, even without the motion cues, subjects were still able to focus attention on the HUD. When the cue was part of the HUD domain and the target part of the runway domain, this resulted in a shift cost.

The situation when the cue was on the runway would be quite different. As long as motion cues were available, there was enough perceptual support to overcome the natural tendency to focus on the HUD, so subjects successfully focused attention on the runway. Once again, this produced a within-domain processing advantage. On the other hand, the attention-drawing power of the HUD made it difficult to allocate attention *exclusively* to the runway domain, so attention ended up being divided between the domains. The persistence of attention on the HUD domain meant that HUD symbology interfered with processing on trials where all processing was supposed to be confined to the runway (thereby slowing within-domain trials), and conversely, reduced the necessity to shift attention when the relevant target was on the HUD (thereby speeding between-domain trials). The domain effect was thereby abolished.

Implications for HUD design. This study was conducted to examine ways to reduce the costs of shifting attention in HUD usage. Two grouping cues, relative motion and HUD color, were included in our design to see if either or both contributed to the segregation of the HUD and world. Relative motion was found to be the contributing factor in the domain effect.

The findings of this study could be implemented in current aircraft by removing the differential motion between HUD symbology and world during landings. Current HUDs have a flight path marker (a small circle with "wings") to indicate the plane's location, a guidance cue (a small, empty circle) to indicate where the plane should be, and a non-conformal runway outline. When the flight path marker is properly positioned, the circle is filled.

The differential motion between the HUD and world could be removed by having the HUD landing symbology conformal to the world. This could be done by placing a pictorial representation of the actual runway over the real runway with digital information on the runway or the horizon. Future global proximity system-derived location information will allow presentation of a fully conformal runway as part of the HUD symbology. With a conformal runway and a guidance cue indicating where on the runway the airplane should land, the

HUD and world domains would then be integrated. The HUD symbology and the runway would then share the same motion cues.

References

Andersen, G. J., & Kramer, A. F. (1993). Limits of focused attention in three-dimensional space. *Perception & Psychophysics, 53,* 658-667.

Baylis, G. C., & Driver, J. (1992). Visual parsing and response competition: The effect of grouping factors. *Perception & Psychophysics, 51,* 145-162.

Boucek, G. P., Pfaff, T. A., & Smith, W. D. (1983). The use of holographic head-up display of flight symbology in varying weather conditions. *SAE Technical Paper Series,* (No. 831445). Long Beach, California: Aerospace Congress & Exposition.

Brickner, M. S. (1989). Apparent limitations of head-up-displays and thermal imaging systems. In R. S. Jensen (Ed.). *Proceedings of the Fifth International Symposium on Aviation Psychology, 2,* (pp. 703-707). Columbus, OH: Ohio State University, Department of Aviation.

Broadbent, D. (1982). Task combination and selective intake of information. *Acta Psychologica, 50,* 253-290.

Driver, J., & McLeod, P. (1992). Reversing visual search asymmetries with conjunctions of movement and orientation. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 22-33.

Eriksen, C. W. & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics, 40,* 225-240.

Fischer, E., Haines R. F., & Price, T. A. (1980). *Cognitive Issues in head-up displays.* (NASA TP-1711) Moffett Field, CA: NASA-Ames Research Center.

Gibson, E. J., Gibson, J. J., Smith, O. W., & Flock, H. R. (1959). Motion parallax as a determinant of perceived depth. *Journal of Experimental Psychology, 58,* 40-51.

Iavecchia, J. H., Iavecchia, H. P., & Roscoe, S. (1988). Eye accommodation to head-up virtual images. *Human Factors, 30,* 689-702.

Johnson, T. (1988, June). The why and how of the HUD. *Professional Pilot,* pp. 58-62.

Kahneman, D., & Henik, A. (1977). Effects of visual grouping on immediate recall and selective attention. In S. Dornic (Ed.), *Attention and performance VII* (pp. 307-332). Hillsdale, NJ: Erlbaum.

Kramer, A. F., Tham, M. P., & Yeh, Y. Y. (1991). Movement and focused attention: A failure to replicate. *Perception & Psychophysics, 50,* 537-546.

Larish, I. & Wickens, C. D. (1991). Divided attention with superimposed and separated imagery: Implications for head-up displays. (ARL-9-4 / NASA HUD-91-1). Urbana, Il: Aviation Research Laboratory Institute of Aviation.

Lauber, J. K., Bray, R. S., Harrison, R. L., Hemingway, J. C., & Scott, B. C. (1982). *An operational evaluation of head-up displays for civil transport operations.* (NASA

Report No. 1815) Moffett Field, CA: NASA-Ames Research Center.

McCann, R. S., Foyle, D. C., & Johnston, J. C. (1993). Switching attention between HUDs and worlds: A chronometric analysis. *Proceedings of the Seventh International Symposium on Aviation Psychology.* Columbus, Ohio.

McLeod, P., Driver, J., Dienes, Z., & Crisp, J. (1991). Filtering by movement in visual search. *Journal of Experimental Psychology: Human Perception and Performance, 17*, 55-64.

Neisser, U. (1967). *Cognitive Psychology,* Englewood Cliffs, NJ: Prentice Hall.

Neisser, U., & Becklen, R. (1975). Selective looking: Attending to visually specified events. *Cognitive Psychology, 7*, 480-494.

Nordwall, B. D. (1992, July 20). Northwest Airlines developing HUD/EVS for more on-time flights. *Aviation Week & Space Technology,* 50-51.

Prinzmetal, W. (1981). Principles of feature integration in visual perception. *Perception & Psychophysics, 30,* 330-340.

Roscoe, S. N. (1987). The trouble with HUDs and HMDs. *Human Factors Bulletin, 29*, 1-2.

Sanford, B. D. (1992). *Head-up displays: Effect of information location on the processing of superimposed* *symbology*. Unpublished master's thesis, San Jose State University, San Jose, CA.

Treisman, A. (1982). Perceptual grouping and attention in visual search for features and for objects. *Journal of Experimental Psychology: Human Perception and Performance, 8,* 194-214.

Velocci, A. L. (1992, March 2). Hughes to buy flight dynamics in bid to capture commercial HUD market. *Aviation Week & Space Technology,* p. 59.

Weintraub, D. J., Haines, R. F., and Randle, R. J. (1984). The utility of head-up displays: Eye-focus vs. decision times. *Proceedings of the Human Factors Society 28th Annual Meeting*, 529-533. Santa Monica, California: Human Factors Society.

Weintraub, D. J., Haines, R. F., and Randle, R. J. (1985). Head-up display (HUD) utility, II: Runway to HUD transitions monitoring eye focus and decision times. *Proceedings of the Human Factors Society 29th Annual Meeting*, 615-619. Santa Monica, California: Human Factors Society.

Wickens, C. D., Martin-Emerson, R., & Larish, I. (1993). *Attentional tunneling and the head-up display*. Presented at the International Conference on Aviation Psychology, Columbus, Ohio.

Appendix A

Signed Approval Forms

SJSU SAN JOSE STATE UNIVERSITY

A campus of The California State University

College of Social Sciences • *Department of Psychology*
One Washington Square • San José, California 95192-0120 • 408/924-5600 • FAX 408/924-5605

December 3, 1992

TO: Jean Lynch, MA candidate

FROM: Kevin Jordan, MA Coordinator

RE: Design and analysis review

Drs. Feist and Wise 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, however, Dr. Feist needs you to be more specific about your fourth independent variable (congruency). This concern can be addressed in the final version of your thesis.

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
Feist
Jordan
McCann (NASA-ARC; forward to Jordan)
Wise
file

SJSU SAN JOSE STATE UNIVERSITY

A campus of The California State University

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: Jean Lynch
630 N. San Pedro St., #5A
San Jose, CA 95110

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

Date: July 29, 1993

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

"Head-Up Displays: The Effects of Color and Motion on Switching Attention"

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.

c.c.: Kevin Jordan
John Jacobs