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Attentional segregation and superimposed symbology

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ATTENTIONAL SEGREGATION AND SUPERIMPOSED SYMBOLOGY

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ABSTRACT

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Head-up displays (HUDs) present task-specific information to the pilot as a virtual image superimposed over the forward field of view. Research on HUD usage has shown a performance cost when processing switches from the HUD to the world (McCann, Foyle, & Johnston, 1993). McCann et al. termed the switching cost a "domain effect." The source of this domain effect has not been clearly identified. A simulated rotorcraft hover display was used to evaluate the effects of spatial overlap and perspective cues on the domain effect. Spatial overlap between the HUD and outside world information led to increased response times. Response time performance was best when the HUD and world items were spatially segregated. The domain effect was absent in all conditions. Interference and sequential scanning accounts of the findings are explored.

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Abstract

Head-up displays (HUDs) present task-specific information to the pilot as a virtual image superimposed over the forward field of view. Research on HUD usage has shown a performance cost when processing switches from the HUD to the world (McCann, Foyle, & Johnston, 1993). McCann et al. termed the switching cost a "domain effect." The source of this domain effect has not been clearly identified. A simulated rotorcraft hover display was used to evaluate the effects of spatial overlap and perspective cues on the domain effect. Spatial overlap between the HUD and outside world information led to increased response times. Response time performance was best when the HUD and world items were spatially segregated. The domain effect was absent in all conditions. Interference and sequential scanning accounts of the findings are explored.

Attentional Segregation and Superimposed Symbology

Displays that project virtual images onto a combining glass (e.g. Head-Up Display or HUD) or Helmet-Mounted Display (HMD) are becoming commonplace in the aviation and automotive industries. Typically, the HUD is superimposed over the external scene. The main reason for this is to enable the pilot to simultaneously monitor the outside world and critical instrumentation while minimizing "head-down" time (Larish & Wickens, 1991). HUDs have many operational advantages over traditional instrumentation. They have been shown to improve touchdown footprints, improve vertical and horizontal tracking, and aid in other flight tasks (Boucek, Pfaff, & Smith, 1983; Fischer, Haines, & Price, 1980; Johnson, 1988). The use of HUDs has allowed pilots to perform Cat3a (can't see the ground until 700 feet elevation) and dark hole landings (can't see anything) with a precision greater than if the same landing was performed on a clear day with full visibility, but without the HUD (Fischer, Haines, & Price, 1980).

HUD Disadvantages In Practice

These advantages come with a price, however. Using a simulated landing task under difficult environmental conditions, much like those for which the HUD was designed, Fischer et al. (1980) found that response time to a runway incursion took 4.12 seconds with the HUD present as compared to 1.75 seconds without the HUD. It would appear from this result that pilots were not attending to the world domain very effectively while using the HUD. Paradoxically, sharing attention between the out-the-window scene and traditional instrumentation was less of a problem.

The HUD Paradigm

Several recent experiments support the view that the problems with HUD use are attentional in nature (Foyle, McCann, & Sanford, 1991; Lynch, 1993; McCann, Foyle, & Johnston, 1993). The general paradigm used by McCann et al. (1993) involved presenting a simulated night time approach on a computer terminal. The display included a runway outline, centerline, and four geometric items; these comprised the "world" group.

Superimposed on this "out-the-window" scene was a set of "HUD" symbology including four stationary geometric shapes. These HUD symbols remained in a fixed spatial location relative to the screen. The runway and associated items moved in unison to appear as if the viewer was looking out the front window of an aircraft on final approach. All stationary items were considered to be in the "HUD domain," while all moving items were considered to be in the "world domain."

Test participants were instructed to first identify a three letter cue, located either on the HUD or on the runway. If the cue spelled "IFR" (for instrument flight rules), they then searched the HUD symbols for a target, either a diamond or a stop sign, among a set of distracter items. If they found a diamond on the HUD, they were to respond that it was safe to continue with the landing by pressing a labeled key. If they saw a stop sign, they were to indicate abortion of the landing by pressing a different labeled key. If the cue spelled "VFR" (for visual flight rules), the identical target search was carried out in the runway group rather than in the HUD group.

In each group of four items, two items were located to the left of center and two were located to the right of center. Each pair on a side was arranged with one item positioned directly above the other. By arranging the items in this manner, it was possible to manipulate the distance between the cue and the target. If the cue and target were both on the left, they were close to each other. If the cue was on the left and the target was on the right, they were considered to be far from each other.

The cue and target appeared in the same domain on half of the trials, and in opposite domains on the remaining trials. This meant that the cue could be presented on the runway surface and the target on the HUD or vice versa. The cue was presented shortly prior to the target and distracters, which were presented concurrently. The distracters, which were geometric shapes irrelevant to the task, were added to force the participant to perform a search task.

The primary variable under study was the domain affiliation of the cue and target.

Trials where the cue and the target both appeared in the same domain were called "within-group" trials. On these trials, stimulus processing was confined to the HUD or to the world. Trials where the cue and target appeared in opposite domains were called "between-group" trials. In "between-group" trials, the participant was required to process the cue in one domain and then switch domains to acquire the target.

Domain Effect

Using the paradigm just described, McCann et al. (1993) attained an interaction between cue domain and target domain. When the cue and target were in the same domain, response times were faster than when they were presented in opposite domains. This result was termed "the domain effect."

McCann et al. suggested the following account of the domain effect. The very nature of the runway graphics made the runway symbology move differentially from the stationary HUD. Gestalt principles of common location, common fate, and common color forced the HUD display to segregate from the outside view of the world (see also Kahneman & Henik, 1981). Segregation of domains made it easy for participants to attend to either the HUD or the outside world, but not to both concurrently (Foyle et al., 1991).

Since the cue was processed first, the domain containing the cue captured visual attention. Attention was forced to switch from one domain to the other on trials where the cue and target were in opposite domains. Attentional switching can explain the longer response times for the between-group trials.

Distance Effect

The domain effect was qualified by a three way interaction involving cue-to-target distance, cue domain, and target domain. That is, when the target appeared in the same domain as the cue, target processing was fastest when the cue and target occupied adjacent locations. When the target was in the same domain but far from the cue, response times were much slower. When the target appeared in the opposite domain from the cue, however, this distance effect was reduced: response times for all levels of cue-to-target distance in the between-group condition were roughly equivalent. The shift of attention from one group to the other seemed to eliminate the cue-to-target distance effect. Two models of visual-spatial attention can each account for a portion of the McCann et al. (1993) findings.

Object-Based Models of Attention

Object-based models of attention can account for the domain effect. These models propose that attention is directed to preattentively-defined perceptual objects (Duncan, 1984; Kahneman & Henik, 1981). Many experiments have shown that the visual field is parsed preattentively by Gestalt rules such as common fate and common color. Anything that aids this grouping should aid segregation of domains in the HUD paradigm. Preattentively defined objects are, in terms of attentional allocation, proposed to be the primary perceptual elements in object-based models of attention. If the HUD and world domains are considered to be separate, preattentively defined objects, object-based models can account for the domain effect obtained by McCann et al. (1993).

Space-Based Models of Attention

Within space-based models, attention is deployed to a spatially defined region, sometimes modeled as a "spotlight." Items that fall within this spotlight of attention are processed more quickly than items that fall outside of it. If an item falls outside the spotlight of attention, the spotlight must be moved to where the item is in order to process it. There was evidence supporting a movement of attention in the far-distance same-domain condition of McCann et al. (1993) as shown by increased response time as a function of cue-to-target distance.

Object-based models of attention can account for both the domain-switching times and the lack of cue-to-target distance effects in the between-group condition, while space-based theories can account for the distance effect found in the within-domain condition. Neither theory alone, however, accounts for all the data reported by McCann et al. (1993). The results of McCann et al. (1993) are interesting because they suggest both object-level effects and space-based effects within the same display design.

Concerns With Previous Work

There are several concerns with the methodology used by McCann et al. (1993) which makes it difficult to attribute causality of the domain effect to any specific manipulation.

Size Constancy and Perceived Distance

The experiments by McCann and colleagues used a perspective display with world-linked symbology that appeared to exist at different subjective distances from the observer. By keeping the near stimuli the same size as the far stimuli, the far stimuli may have appeared subjectively larger due to size constancy. If the far items in the opposite domain attracted more attention than the near items due to this phenomenon, size constancy may have changed the nature of the distance effect in the opposite domain conditions.

Perspective Affects Legibility

Presenting the world domain stimuli in perspective may have affected legibility. The targets were designed to minimize the effects of aliasing to maximize legibility. When these shapes were adjusted for a slant transformation in the depth plane, aliasing artifacts may have negatively impacted legibility. The impact of these perceptual phenomena on attentional allocation are unknown.

Too Few Levels of Cue-to-Target Distance

With only two levels of cue-to-target distance, it is impossible to investigate the nature of how the domain effect changes over distance. Is there an abrupt change at a fixed distance? Is there a dividing line between focal attention and diffuse attention (Tsal, 1983), or is it a gradient (Downing, 1988)? It is simply not possible to address such questions with only two levels of cue-to-target distance.

Unequal Set Size

The displays used by McCann et al. (1993) did not have the same number of potential target locations in each group. Once the target was presented, the group containing the cue had three potential target locations, while the group that did not contain the cue had four locations. This was the only way to equate the number of items, excluding the cue, in each group. This compromise was also the result of a decision to place the cue in one of the possible target locations. The unequal potential-set size confounds the number of possible target locations with the domain effect.

Spatial Layout

In the experiment by McCann et al. (1993), all world-domain stimuli were above the center of the display and all HUD stimuli were below. This arrangement was more representative of traditional head-down instrumentation than the superimposed symbology of current HUD implementations. Since only one layout was used, it was not possible to distinguish whether the spatial layout or object-level effects caused the domain effect.

Rationale for Present Experiment

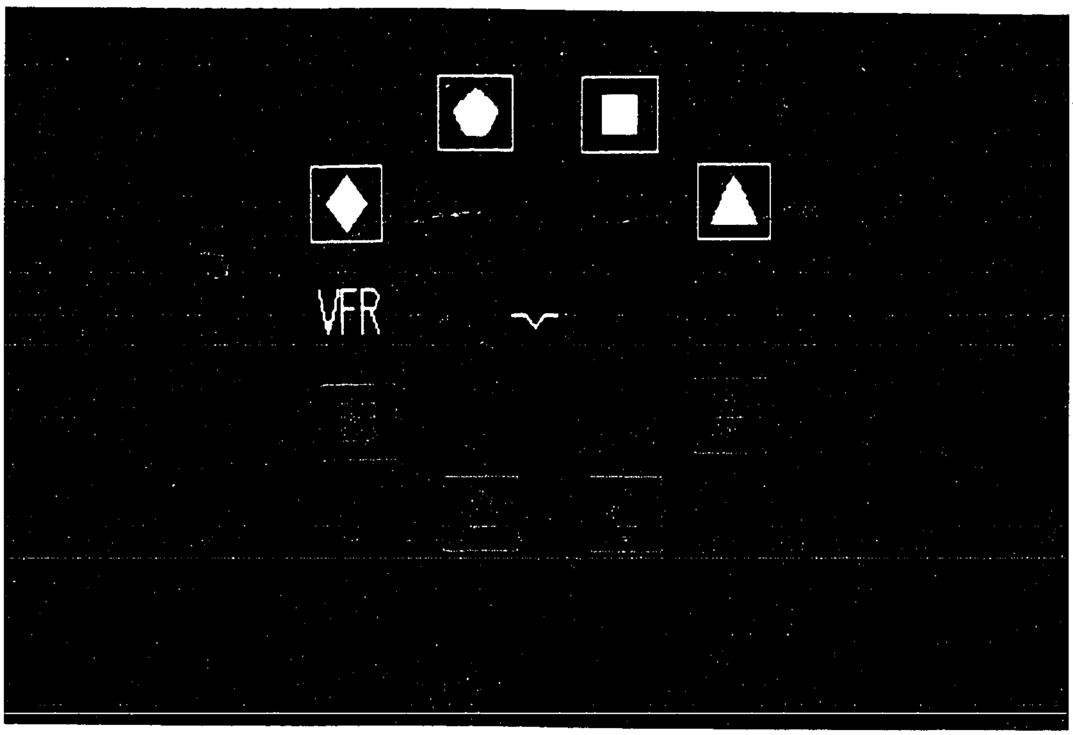
The current study had three goals. The first was to determine whether the domain effect reported by McCann et al. (1993) remained when the HUD and the world stimuli were distributed over the same region of space. The second goal was to use more levels of cue-to-target distance to determine how the domain effect changed across distance. The third goal was to see whether the domain effect remained when differential perspective cues between the HUD and the world stimuli were removed.

Spatial Layout

Two different spatial layouts were used to investigate the effects of spatial overlay on the object-level effects that manifest themselves in the domain effect. One layout followed closely the arrangement used by McCann et al. (1993). Here, all world-domain items were above the cue elevation and all HUD-domain items were below the cue elevation (see Figure 1). This arrangement formed the segregated-layout condition. Since this condition supported domain segregation based on color, motion, and proximity, the domain effect of McCann et al. (1993) was predicted to be observed with this layout.

Figure 1.

Segregated display layout. HUD items are presented in gray. World items are presented in white.



The other layout interleaved the stimuli from the two domains about the perimeter of an imaginary circle. Consequently, each item was flanked by items in the opposite domain (see Figure 2). With this arrangement, the stimulus arrays from both the world and HUD domains occupied the same location and spatial extent. This arrangement formed the overlapped-layout condition. This condition allowed a determination of whether grouping by object, and the domain effect, would occur based solely on motion and color (that is, without the grouping cue of proximity).

The overlapped-layout made it impossible to segregate groups simply by moving the attentional focus to a particular spatial region. Object-based models predicted that this should not affect the domain effect since attention would have been allocated to one perceptual group or the other regardless of spatial overlap. Space-based models predicted that the overlapping of the two objects would increase response time by a constant amount by doubling the number of items to be processed within the spotlight of attention. By including both layouts in the current experiment, we were able to directly evaluate the effects of spatial layout on the domain effect.

Circular Arrangement of Stimuli

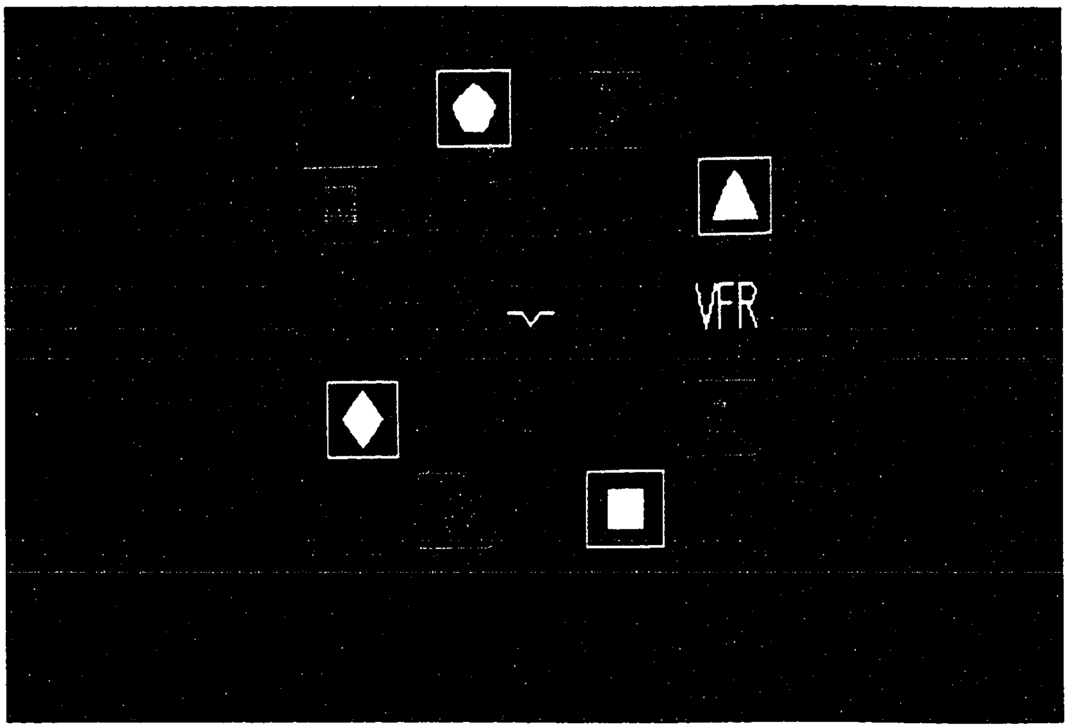
To better assess how the domain effect changes across distance, four levels of cue-to-target distance were used. A circular arrangement of stimuli was used to equate cue-to-target distance between domains regardless of spatial-layout condition.

Hover Display

Each trial consisted of a simulated rotorcraft hover display. By simulating hovering over a helipad, all world items had the same perspective as HUD items. In addition, target size in both domains remained constant over time, eliminating size constancy issues. The display consisted of illuminated boxes on a black background. This had the effect of simulating a night hover with good visibility. "HUD" boxes were presented in green, while the boxes on the helipad were presented in white (see Figure 1). The boxes on the helipad moved in unison while the HUD boxes were stationary. The movement of the

Figure 2.

Overlapped display layout. HUD items are presented in gray. World items are presented in white.



boxes in the helipad group simulated the pitch and yaw of a rotorcraft during hover. The HUD and world domain segregated from each other by the Gestalt principles of common fate (motion) and common color.

Separate Cue Location

The current experiment solved the embedded-cue and unequal set size problem in McCann et al. (1993) by placing the cue in one of two locations that did not coincide with any of the potential-target locations (see Figure 1). By taking the cue out of the set of potential-target locations, this left exactly four potential target locations in the cued group and four in the uncued group. All non-target boxes contained geometric distracters.

Following McCann et al. (1993), participants monitored the display for the appearance of a three-letter cue, which appeared in one of two boxes in either the HUD or world group. If the cue spelled "IFR," participants searched the four boxes on the HUD for either a diamond or a stop sign. If the cue spelled "VFR," however, participants carried out the same search through the symbols occupying the four boxes on the helipad.

A foil target was presented in the uncued domain to encourage cue processing. If the target was a stop sign, the foil target was a diamond, and visa versa. Therefore, if the participant ignored the cue and responded to the foil target, they would make an error. If the participant adopted an alternate strategy of only looking at one domain, i.e., the HUD, and if the cue spelled IFR, then they could have responded conventionally; otherwise they could have responded with the opposite answer. Several participants reported adopting this strategy for a few trials, but returned to the correct strategy due to the additional cognitive overhead.

Method

Participants

Forty-eight volunteers (17 males and 31 females), between 17 and 40 years of age, participated in the study. All participants stated that they had normal or corrected to normal vision and no known color-perception anomalies. All participants were recruited through the San Jose State University Psychology Department Subject Pool and were given course credit for their participation. All participants were treated in accordance with the ethical guidelines of the American Psychological Association and the San Jose State University Human Subjects-Institutional Review Board (APA, 1981).

Apparatus and stimuli

The experiment was administered on an IBM compatible personal computer with an Intel 80486 processor. The display used was a 14 inch diagonal SVGA color monitor. The monitor had a pixel height of 0.45 mm and a pixel width of 0.59 mm. All aspects of stimulus presentation and data collection were controlled by the computer. Participants viewed the display from a distance of 75 cm.

The display was made up of nine boxes which were arranged about an imaginary circle with a diameter of 6.33 degrees visual angle (see Figure 1). Each box occupied 1.15 degrees visual angle both horizontally and vertically. Four of the boxes were stationary and green. These comprised the HUD set. Four additional boxes comprising the world set were white and moved in unison following a pseudo-random pattern centered about the screen center. The horizontal movement followed a sinusoidal function with a period of 1.34 Hz and an amplitude of 20 pixels. The vertical movement also followed a sinusoidal function but had a period of 1.74 Hz and an amplitude of 6 pixels. Together, these movements simulated the effects of minor wind buffeting and attitudinal corrections of the craft during hover. Depending on cue-domain condition, the final box held the cue stimulus and was part of either the HUD or world domain, (i.e., was either green and stationary or white and moving). All stimuli were presented on a black background to increase color saturation and contrast.

Layouts. Two display layouts were used. In the segregated-layout condition, the four boxes in the world domain occupied the top half of the circle while the remaining four boxes on the HUD made up the bottom half of the circle (see Figure 1). In the overlapped-layout condition, the four boxes from each group were positioned alternately about the circle (see Figure 2).

Cue. Each trial contained a three-letter "cue" indicating which domain contained the target. On half of the trials, the cue spelled "IFR" for "instrument flight rules." On the other half of the trials, the cue spelled "VFR" for "visual flight rules." The cue was presented in one of two locations on the horizontal centerline of the display, either on the left or right side of the circle of boxes (see Figure 1). The cue assumed the color and motion properties of either the HUD or the world domain.

Target. The target, either a diamond or a stop sign, was presented in either the HUD or world domain. Aside from the target, there were three distracter shapes in each group. The distracters consisted of a triangle, a square, and a pentagon. The target and distracter stimuli averaged 0.76 degrees visual angle in height and 0.69 degrees visual angle in width. The target assumed the color and motion properties of the domain that it appeared in.

Foil target. To prevent the participant from simply performing a serial search of all eight locations for the target, a foil target was used as the fourth distracter in the irrelevant (non-target) domain. If the target was a stop sign, the foil target was a diamond. Conversely, if the target was a diamond, the foil target was a stop sign.

Cue-to-target distance. Cue-to-target distance was varied by placing the target in different boxes around the array on different trials. The four levels of distance of the target from the cue were 1.53, 3.44, 5.19, and 6.33 degrees of visual angle. The first two levels were similar to those used by McCann et al. (1993).

Procedure

Participants were tested individually in a small experimental room at San Jose State University. The lights in the room remained on for the duration of the experiment. The participants were asked to decide, as quickly and accurately as possible, whether to continue with a simulated rotorcraft landing based on the information presented. Although speed was stressed, accuracy was stressed over speed. Participants were instructed to rest their index finger on the center key of the numeric keypad between the two response keys and to use the index finger on that hand for all responses.

Each trial began with only the empty HUD, cue, and world boxes present. This allowed time for the participant to orient to the domain which would contain the cue. After 2 s, the cue appeared. The target and distracter shapes were presented simultaneously 350 ms after the cue was presented. If the cue spelled "IFR," the relevant target was to be found among the HUD elements. If the cue spelled "VFR," the relevant target to be found among the world elements.

Participants then performed a visual search task for the target in the group indicated by the cue. When the target was a stop sign, the participant pressed the "2" key on the numeric keypad to indicate further delay of the landing. When the target was a diamond, the participant responded by pressing the "8" key on the numeric keypad to indicate initiation of the landing. Feedback for incorrect responses was provided by displaying an error message on the screen simultaneously with a short series of low-frequency tones.

Design

Each participant completed one session of eight blocks of 64 trials for a total of 512 trials. Participants were encouraged to take breaks between blocks, but not during a block. Most participants were able to complete the entire session in less than 60 minutes. Participants were randomly assigned to one of four groups. These four groups were determined by the combination of two between subjects variables, cue domain and spatial layout presentation order, each with two levels. Cue domain was the primary between-subjects variable. Half of the participants performed the tasks with the cue on the HUD, the other half with the cue in the world. In addition, the two possible orders for spatial layout were counterbalanced between subjects. Half of the participants performed the first four blocks with the segregated-layout and the last four blocks with the overlapped-layout. The remaining participants performed the first four blocks with the overlapped-layout and the last four with the segregated-layout.

Cue-to-target distance (4 levels), cue-to-foil distance (4 levels), target domain (2 levels), and target shape (2 levels) were orthogonally balanced within each block. This design required 64 trials for a single replication of these variables. Each participant received eight replications of the within-block variables. The main dependent variable was latency from target onset to target response. Error rates were also collected.

Results

In an attempt to reduce the possibility of Type I errors, the .01 level was selected as the criterion for a significant effect (Keppel, 1991). Trials with incorrect responses (3% of total) or response times longer than 3 s (an additional 2% of total) were discarded prior to the analysis. On these criteria, a total of 1,283 trials, representing 5.2% of the 24,576 original trials, were discarded. The remaining trial times were entered into a 2 (cue domain) x 2 (target domain) x 2 (spatial layout) x 4 (cue-to-target distance) mixed analysis of variance. Cue domain was the between-subjects factor.

Our first goal was to determine whether the domain effect reported by McCann et al. (1993) remained when the HUD and the world stimuli were distributed across the same region of space. However, the domain effect characterized by an interaction between cue domain and target domain, was absent in both the overlapped and segregated display conditions, $F(1,46) = 2.70$, $p = .108$ (see Table 1). When the cue was on the HUD, the response times were nearly equivalent regardless of whether the target was on the HUD or in the world group. When the cue was presented in the world group, however, response times were faster overall but still did not depend on whether the target was on the HUD or in the world.

Our second goal was to determine how more levels of cue-to-target distance affected the domain effect. Since the domain effect itself was not significant, it was not possible to adequately test this question. However, there were some interesting effects. First of all, there was a main effect of cue-to-target distance, $F(3,138) = 29.23$, $p < .0005$ (see Figure 3). The intermediate levels of cue-to-target distance were faster than the nearest and

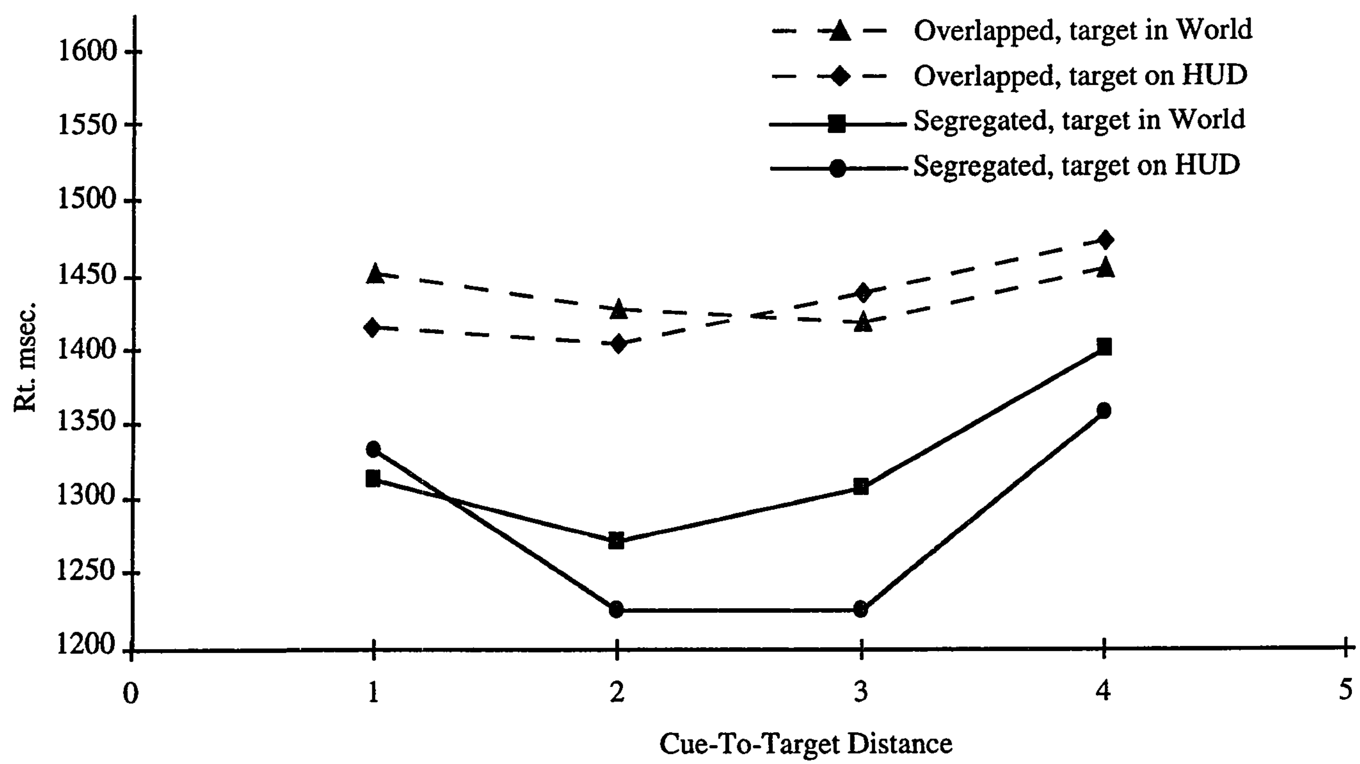
Table 1.

Mean response times in ms for cue and target domain affiliations.

	Target Domain	
Cue Domain	HUD	World
HUD		
M	1406	1403
Std Error	18.2	19.2
World		
M	1349	1320
Std Error	18.4	17.7

Figure 3.

Response time as a function of cue-to-target distance, target domain, and spatial layout.



farthest levels. Moreover, the main effect of spatial layout was qualified by the presence of a cue-to-target distance by spatial layout interaction, $F(3,138) = 11.30$, $p < .0005$. This curvilinear effect of cue-to-target distance on response time manifested itself more strongly in the segregated layout condition, $F(3,138) = 37.13$, $p < .0005$, than in the overlapped condition, $F(3,138) = 5.04$, $p = .002$. This significant three way interaction was the source of the cue-to-target distance by spatial layout interaction.

The analysis revealed a significant main effect for spatial layout, $F(1,46) = 46.22$, $p < .0005$. As shown in Figure 3, response times were slower by an average of 132 ms in the overlapped condition (1435 ms) relative to the segregated condition (1303 ms).

There was also a significant two-way interaction between target domain and spatial layout, $F(1,46) = 10.27$, $p = .002$. Figure 3 shows that in the segregated condition only, targets in the world group took significantly longer to respond to than those on the HUD, $F(1,46) = 14.117$, $p < .0005$.

Target domain interacted with cue-to-target distance, $F(3,138) = 7.01$, $p < .0005$. In the segregated condition, a significant interaction between cue-to-target distance and target domain shows that the effect of cue-to-target distance on response time was diminished when the target was in the world group, $F(3,138) = 7.08$, $p < .0005$. This is shown most clearly by the flatter line in the segregated target-in-world condition (see Figure 3). The addition of more levels of cue-to-target distance provided a new counter-intuitive pattern of results.

The error rates were entered into a 2 (cue domain) x 2 (target domain) x 2 (spatial layout) x 4 (cue-to-target distance) mixed analysis of variance. Again, cue domain was the between-subjects factor. Participants made .61% more errors in the overlapped layout condition than in the segregated layout condition, $F(1,46) = 13.01$, $p =.001$. No other main effects or interactions were discovered in the error rates. There was no evidence of a speed-accuracy tradeoff.

Discussion

There were three major findings in the present study. First, no significant domain effect was found although there was a non-significant trend toward a domain effect. Second, response time was significantly slowed in all conditions when the groups were spatially overlaid. Finally, the function relating cue-to-target distance to response time was much flatter in the overlapped condition than in the segregated condition. These findings will be discussed in turn.

Domain Effect

The domain effect reported by McCann et al. (1993) was characterized by a significant two-way interaction between cue domain and target domain. When the cue and target were in different domains, response times were on average 50 ms longer relative to when the cue and target were in the same domain. In the current experiment, this pattern of results did not appear.

Explanations for Lack of Domain Effect

Perspective cue hypothesis. One goal of the current experiment was to see if the domain effect remained when perspective cues were absent. In experiments by Sanford (1992) and McCann et al. (1993), simulated 3-D out-the-window scenes were portrayed by presenting all out-the-window stimuli in perspective. The viewpoint was always from above and behind the external stimuli. Presenting the stimuli in this way made the world stimuli appear tilted back in space. This may have been the perceptual cue that allowed the two groups to segregate perceptually. Perspective cues were eliminated in the current experiment in exchange for better control over stimulus legibility and size constancy. This tradeoff may have inadvertently eliminated the very perceptual grouping cue necessary for the two sets of items (world and HUD) to segregate into two perceptual objects. Although perspective is a less dominant grouping cue than color, motion, or proximity, it is possible that the elimination of perspective cues may have eliminated the domain effect.

Causality may be determined in a future experiment by going back to a aircraft landing task with a forward looking HUD while keeping the current spatial layouts. If the domain effect returns, then it can be concluded that perspective cues drive the object-level effects that manifest themselves in the domain effect.

Search difficulty hypothesis.

In the current experiment, targets and distracters were composed of solid geometric shapes. Subjectively, this seemed to have the effect of making target search more difficult, possibly even requiring serial processing of the distracters. This was supported by the subjective experience of eye movements being required to process possible target locations. Most participants reported adopting some sort of scanning strategy to perform the task. In so doing, each potential target location would have been processed separately. If each location was processed in turn, attention may have jumped or moved from one location to another. This switch to a serial search strategy would inhibit the use of object-level parallel-processing abilities, their inherent advantages, (same object savings) and disadvantages (object switching costs). Thus, the switch to serial processing could explain why all same-object advantages were eliminated in the current experiment (Treisman, 1982).

In the McCann et al. (1993) experiments, targets consisted of outlined geometric shapes that may have been easily processed with diffuse attention. The use of outlined targets by McCann et al. (1993) may have had the effect of simplifying the task by not requiring the use of a serial search strategy to locate the position of the target. This may have contributed to the improved object-level effect and the manifestation of the domain effect.

By changing our solid targets back to outlined targets in a future experiment, serial processing may be replaced by more efficient parallel processing of groups. Here, the distribution of attention over the cue and relevant target locations would speed processing by allowing parallel search (Treisman, 1982). Doing so might reinstate the domain effect. If this parallel processing of objects occurs, and the domain effect is observed, then the role of filled-in vs outlined targets will become more clear. With this knowledge, HUD designers will be able to use symbology that capitalizes on these properties.

Perceptual-belongingness hypothesis. In the experiment by McCann et al. (1993), the cue was embedded directly in one of the potential-target locations. This may have helped the cue to be perceived as part of that perceptual group. By group, we mean a group of objects that segregate by Gestalt principles such as common location, common fate, or common color (Kahneman & Henik, 1981).

In the segregated-layout condition of the current experiment, the cue was located between the two groups of four potential target locations defined by common color and motion. By not presenting the cue in one of the potential-target locations, we may have increased the cue's segregation from either perceptual group. This segregation may have forced the cue and all potential target locations to be processed as three separate perceptual objects; one cue and two groups. If this indeed happened, it could explain why all same-domain advantages were lost.

If embedding the cue in one of the potential target locations facilitated the processing of items in the cued group at the expense of items in the uncued group, we should be able to replicate the domain effect in a future experiment by simply embedding the cue in one of the potential target locations.

Insufficient group speed hypothesis. One reason for failure to replicate the domain effect may have been insufficient speed of movement of the items defining the world group. The movement of the world domain in this experiment may not have been sufficient to make the two groups of four potential target locations segregate into two separate perceptual objects. If this were the case, then this could explain why any object level effects were lost.

A simple way to test this theory would be to rerun the experiment with increased speed of movement for the world group.

Cue-To-Target Distance Effect

Though a significant effect of cue-to-target distance was present in the omnibus analysis, space-based models of attention would not predict the pattern of response times shown in Figure 3. The space-based models would have predicted an increase in response time with increased cue-to-target distance, regardless of whether the cue and target were in the same domain. In the segregated-layout condition, the nearest and farthest target locations from the cue were responded to slowest, while the two intermediate items were responded to an average of 60 ms faster. In the overlapped-layout condition, not only was this effect absent, but all response times were roughly equal and significantly longer than those for the segregated-layout condition.

There are three possible explanations for: (a) the main effects of spatial layout; (b) the effect of cue-to-target distance; and (c) the spatial layout by cue-to-target distance interaction. The first two consist of an attentional-scanning account and the effect of interference from adjacent irrelevant stimuli. The third is a movement filter account.

Sequential-scanning strategy. An experiment by Sanford (1992) suggested that eye movements can improve performance in a flight task when information from the HUD and out-the-window scene need to be monitored simultaneously. This conclusion followed from the fact that flight performance was impaired when the HUD overlaid relevant information in the world, relative to when the HUD and world information were spatially separated. The conclusion was that eye movements, or sequential scanning, interrupted "attentional tunneling" and thereby helped facilitate an attentional switch from one perceptual object (the HUD) to another (the world).

A sequential-scanning account can explain the main effect of spatial layout on response time in the current experiment by considering the number of eye movements required to find the target. In the segregated-layout condition, once the target domain was determined (i.e., by cue identification), participants could simply have made an eye movement to the middle of the target group and began searching from there. Sanford's (1992) study showed that making an eye movement could improve performance by breaking attentional tunneling on the attended domain. In addition, since the center of the group in the segregated-layout condition coincided with the location of the middle two possible target locations, and if the spotlight of attention could cover the two center targets, it would have been advantageous to make an eye movement to the center two items and move outward from there. Since the cue location was randomly chosen, having a predetermined starting point for target search may have reduced cognitive overhead by removing the decision about where to start searching. This may explain why these two locations were processed faster than either the nearest or farthest locations which had roughly equal probability of being searched next.

If there were eye movements from one location (the cue) to another (the center of the target group in the segregated condition), this movement may have eliminated the object-level effects that are critical to the domain effect. Sanford's (1992) experiment showed that a larger eye movement could reduce the costs associated with switching from one object to another when compared with a smaller eye movement. In this way, it is possible that an eye movement may have broken the attentional lock on the domain it started on. Once attention moved from the cue, which group it landed on did not have an impact on response time. The sequential scanning account explains the failure to replicate the domain effect by showing how the cue domain failed to hold attention once the cue was processed.

The location nearest the cue showed a slight advantage over the location furthest from the cue in the segregated-layout condition, regardless of cue or target domain affiliation. Consistent with space-based accounts, the nearest two locations may have received some preattentive processing during cue processing (Eriksen & Eriksen, 1974; Kramer & Jacobsen, 1991).

In the overlapped-layout condition, the center of each group of four possible target locations coincided with the center of the circle of all possible target locations. If people retained the strategy of making an eye movement to the "center" of the group, even in the overlapped-layout condition, this could serve to flatten the response time by cue-to-target distance curve by eliminating the advantage of simply making a saccade to the center of the group. In addition, the sum of the distances between potential target locations was larger than in the segregated-layout condition. Each group was defined over a larger area in this condition (see Figure 2). This may have made for longer eye movements on average to locate the target. This could explain why response times for the overlapped-layout condition were longer overall than those for the segregated-layout condition. Since the pattern of response times in the overlapped-layout condition was relatively flat, and since most participants reported having to "search around" for the target, this explanation fits well with the findings.

Interference account. An alternative explanation involves the concept of interference from irrelevant items. In an experiment by Kramer and Jacobsen (1991), participants responded to a centrally located target while attempting to ignore adjacent distracters. The distance between targets and distracters was either 0.25 or 1.00 degrees visual angle. When irrelevant distracters were close to the target (0.25 degrees), target processing may have been significantly slowed in all conditions of all three experiments. This suggests that there was significant interference from irrelevant proximal stimuli. B.A. Eriksen and C.W. Eriksen (1974) also showed performance costs when irrelevant distracters fell within one degree of visual angle of task-relevant information.

Performance in the current experiment may also have been adversely affected by the presence of task-irrelevant stimuli which may have required the use of limited attentional resources. If items from a neighboring group had to be filtered out in order to process potential targets, and this filtering required the use of limited attentional resources, decreases in distance between potential-target locations and objects in the opposing group may have lengthened response time by increasing the effect of this interference. This could account for the main effect of the spatial layout manipulation.

In the segregated-layout condition of the current experiment, the nearest and farthest potential target locations from the cue (cue-to-target distance levels 1,4 in Figure 3) were closest to distracters in the opposite domain. Each may have been subject to interference from a single adjacent flanker in the other domain. This could explain why targets that were presented in these two locations were responded to slower than those presented farther from items in the opposite domain (cue-to-target distance levels 2,3 in Figure 3).

In the overlapped-layout condition, however, each potential target location was flanked by two objects in the opposite domain. If these flankers caused interference, then filtering costs would be high for every relevant element in the group containing the target (Eriksen & Eriksen, 1974). A possible additive effect of flankers may have required more resources to filter two flankers than it did to filter one. This could explain why the overall response times obtained in overlapped-layout condition were longer than those in the segregated-layout condition. In addition, each potential-target location may have required more resources than any one target location in the segregated-layout condition. This could explain the relatively flat response times across the levels of cue-to-target distance in the overlapped-layout condition.

The differential movement and color of the cue and target domains in the current experiment were simply how the relevant-irrelevant item discrimination was implemented. Because this theory only applies to what happens after the cue is processed, it does not address the domain effect.

Since the interference account is a spatially-based explanation of the results, it could be easily tested by manipulating the distance between relevant and irrelevant items in the display. An increase in separation between relevant and irrelevant stimuli should produce a decrease in response time by reducing the interference from adjacent flankers. The sequential-scanning account, however, predicts an increase in response time due to increased size of the search area. Performing an experiment with increased distance between relevant and irrelevant items would disprove one of these accounts.

<u>Movement filter account.</u> Driver and McLeod (1992) performed an experiment where participants had to search for a tilted (9 or 45 degrees vs. vertical) target in displays of intermingled moving and stationary stimuli. They found that processing of target items

was fast and parallel when the target discrimination task was easy (45 degree tilted targets) and the targets were moving. Driver and McLeod proposed a movement filter theory where moving items are processed by a movement filter and both moving and stationary items are processed by a form subsystem. In their experiment, difficult discriminations among stationary targets were faster than difficult discriminations among moving targets. When the target discrimination task was more difficult (9 degree tilted targets), processing was slow and serial regardless of whether the targets were moving or stationary. Thus, Driver and McLeod's (1992) findings suggest that the stationary HUD items in the current study should have been responded to faster than the moving world items. That was the reverse of what was obtained in the segregated-layout condition of the current experiment. In the overlapped-layout condition, response times were flat across levels of cue-to-target distance.

Target Domain and Cue-to-Target Distance Interaction.

Alone, neither the sequential-processing account nor the interference account can explain the interaction of target domain and cue-to-target distance in the segregated-layout condition. The shape of the cue-to-target distance by response time curve was flatter when the target was in the world than when it was on the HUD (see Figure 3). In addition, mean response times for targets in the world were 37 ms longer than for targets on the HUD. If moving targets were simply more difficult to process, then response times for all levels of cue-to-target distance should have been longer by a constant amount.

In the overlapped condition, however, the effect of target domain on response time was not significant. Response times were unaffected by whether the target appeared in the HUD group or the world group. More research is required to find the source of the domain effect.

Summary

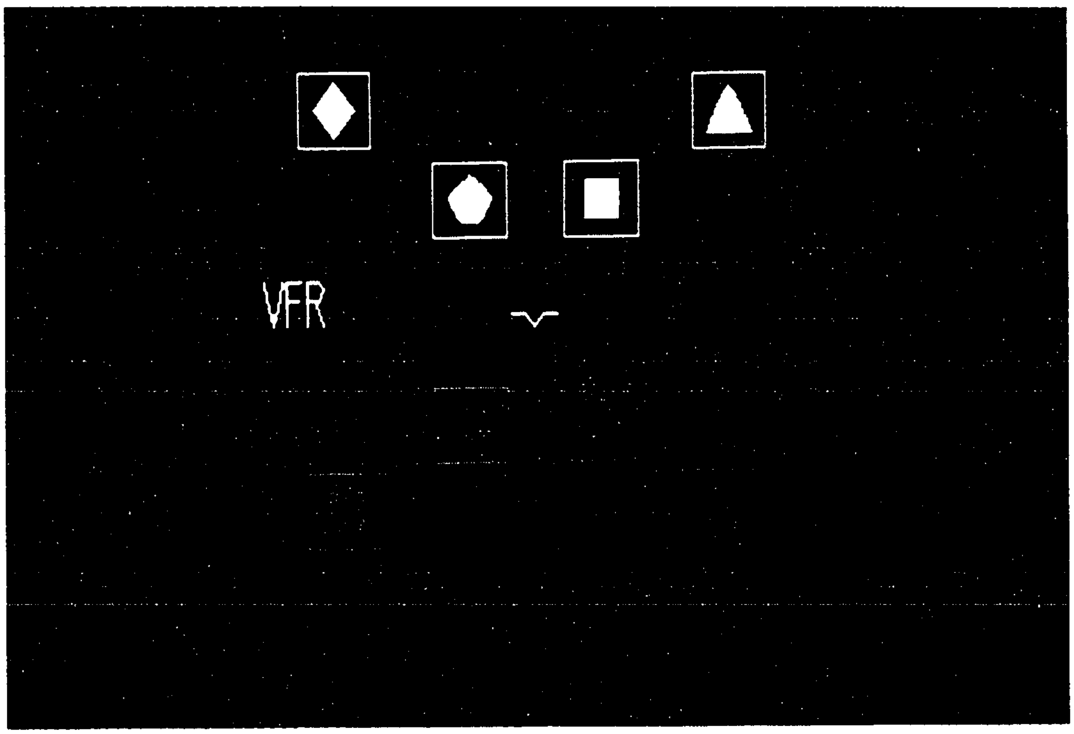
In this experiment, we changed several factors relative to the experiment by McCann et al. (1993). One or more of these factors eliminated the domain effect. Since the domain effect has been implicated in many problems associated with HUD usage, discovering which factor or factors in the current experiment were responsible for eliminating the opposite-domain disadvantage is important (Emerson & Wickens, 1995; Roscoe, 1987; Sanford, 1992; Sojourner & Antin, 1990). These are factors that should be of primary concern to HUD designers. Since there is now one experiment where the domain effect does not exist, and one where it does (McCann et al., 1993), we are in a good position to begin isolating the conditions that cause it. There are three main differences between the displays used in the current experiment and those used by McCann et al. (1993): (a) the spatial layouts overlapped in one condition, (b) perspective cues were eliminated, (c) the cue was presented spatially separate from the potential-target locations, and (d) the visual search stimuli were different.

Since both the sequential processing and interference accounts of the results can explain the obtained pattern of results, the next logical experiment would be an experiment that could reject one of these accounts. Both of these accounts have roots in existing theories. The attentional-movement account has a strong space-based component, whereas the interference account has links to object-based models of attention. Many of the tests used to discriminate between space and object-based models of attention could be modified to discriminate between the attentional movement and interference explanations.

One such modification to the segregated layout condition of the current experiment could include placing the nearest and farthest cue-to-target distance locations more distal and the middle two locations more central (see Figure 4). Since the sequential movement account does not posit any effect of items in the irrelevant domain, it would predict the same pattern of results as obtained in the current experiment. The interference account would predict a reversal of the shape of the cue-to-target distance curve in the segregated-layout condition. That is, the central locations would now show longer response times than the more peripheral locations. This would be due to increased interference between central items in the two domains combined with the decrease in interference from the more

Figure 4.

Proposed future display layout. HUD items are presented in gray. World items are presented in white.



peripheral items. Since the more peripheral target locations would now have less interference than the more central locations, they should be processed fastest. One of these explanations will surely be rejected by this proposed experiment.

Regardless of the theoretical models, there are some recommendations that designers of current systems can utilize from these findings. Designers should try to group HUD symbology and place them spatially separate from groups of objects of importance in the view beyond. Keeping HUD symbology grouped to one side, above, or below the field of view appears to be the best way to maximize the ability to share information between domains, however counter intuitive it may seem. The use of outlined objects on the HUD may help reduce the domain effect. These recommendations will, however, need to be tested further in the laboratory under controlled conditions.

It is clear that the current line of research is quickly narrowing in on the conditions that cause the object level effects that are a vital component of the domain effect. The knowledge gleaned from this line of research has many applications. For example, HUD designers could use the findings to design safer and more usable HUDs. Attention researchers could apply these findings to refine their models of attention or discriminate between models. Through this strong-inference line of research, we should progress rapidly in advancing our understanding of the human perceptual system while discovering new ways of exploiting it.

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San Jose State University
Human Subjects-Institutional Review Board

Request to Use Human Subjects in Research Cover Sheet

Date Submitted: 6-20-1994 Project Period: From 7-20-1994 To 7-20-1995

Funded By:

Name: Robert W. Edmiston Department: Psychology

Phone Number: Work 415-604-0052 During 9-5 Home 415-967-2475 During pm.

Address: 1665 Alexander Ct. Los Altos, CA 94024

Faculty ___ Student X Staff ___ Non-SJSU (contact) ___

Title of Proposed Project: Attentional segregation and superimposed symblogy: the effects of spatial grouping on the domain effect.

Abstract: Displays utilizing superimposed virtual imaging are becoming commonplace in the aviation and automotive industries. These images are usually either presented on a combiner glass(e.g. Head-Up Display or HUD) or as part of a head mounted display(HMD). There are problems with integrating information between superimposed symbology and the imagery beyond. Past research on HUD usage has shown qualitatively differential processing between the attended domain (HUD or world) and the unattended domain. The source of the processing differences has not been identified. By manipulating the grouping of items between the HUD and the world, we will be able to test the predictions made by both the object-based and feature-based models of attention.

Number of Subjects: 24 Age of Subjects: 18-40 years of age

Type of Subjects: normal or corrected to normal vision with no color deficiency

Proposed Research Method:

What Kinds of Data Will Be Collected: reaction time and accuracy

Is a copy or description of each data collection instrument attached:	YES ___	NO X
Are procedures to protect confidentiality delineated:	YES X	NO ___
Are agreements from participating institutions (on their letterhead) included:	YES ___	NO X
Is a consent form attached:	YES X	NO ___
Is it on SJSU letterhead?	YES X	NO ___

Possible Risks: Minimal risk; no more than would be expected with 30-60 minutes at a computer terminal.

Category of Risk:

(A) Research involving only minimal risk to human subjects:
Probability and magnitude of harm or discomfort are no greater than encountered in daily life.

B. Research involving reasonable risk to human subjects:
Risks to the subject are reasonable in relation to anticipated benefits to the subjects and the importance of the knowledge that may reasonably be expected to result.

Please submit two copies of the completed protocol and supporting materials to: San Jose State University, Human Subjects-Institutional Review Board, Admin. Bldg., Room 150, San Jose, CA 95192-0025. For questions call the HS-IRB at (408) 924-2479.

Responsible Faculty Member Form

Must be submitted with all student research protocols

Title of Proposed Project: Attentional segregation and superimposed symbology: the effects of spatial grouping on the domain effect.

Student Investigator(s): Robert W. Edmiston

Responsible Faculty Member(s): Dr. Kevin Jordan

I (we), the undersigned, have reviewed the above named study and believe the research conforms to federal, state, and SJSU policy for the protection of human subjects in research. Further, I (we) will monitor the course and conduct of the proposed research.

[signature] 6/20/94 Psychology

Signature | Date | Department

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

AGREEMENT TO PARTICIPATE IN RESEARCH AT SAN JOSE STATE UNNIVERSITY

Responsible Investigators: Robert Edmiston, Kevin Jordan, Professor of Psychology

I have been asked to participate in research on attentional mechanisms in human perception. The possible benefits I might gain from my participation include learning more about how the visual system groups and searches stimuli that are presented simultaneously. The possible risk is minimal eye strain equivalent to what might occur normally from 60 minutes work on a computer.

If I decide to participate, I will be asked to decide whether to continue with a simulated helicopter landing based on signals presented on a computer screen. Once I locate and read a signal on the screen, I will be required to press one of two keys in response. This process will be repeated 256 times. However, the experiment is fast paced and will take less than 60 minutes.

Data gathered from this study will be stored on a computer disk which no one but the experimenter will be able to access. In case the results of this study are published, any information that is obtained from me in connection with this study and that can be identified with me will remain confidential.

My decision to participate or not participate will not in any way prejudice my future relations with San Jose State University. If I decide to participate, I am free to withdraw my consent and to discontinue my participation at any time without penalty.

If I have any questions, I may ask them prior to the start of the experiment. If I have any questions after the experiment, I may contact Robert Edmiston at (415)604-0051 or Dr. Kevin Jordan at (408)924-5626 or drop by DMH 342. If I have any complaints about the procedure, I may contact Dr. J. Ken Nishita, Psychology Department Chair at (408)924-5600(DMH 157). For questions about research participants' rights, or in the event of research-related injury, I may contact Dr. Serena Stanford (Associate Academic Vice President for Graduate Studies) at (408)924-2480.

I am making a decision whether or not to participate. My signature indicates that I have decided to participate having read the information provided above. My signature also indicates that I have received a copy of this consent form for my records.

PRINTED NAME:______________________________ SSN:_____ ___ _______

SIGNATURE:______________________________________ DATE:___________

SIGNATURE OF INVESTIGATOR:_______________________________________