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**Object-Layering in Visual Attention:
Implications for HUD equipped HMDs**

by

Joseph F. Armstrong

**A Thesis submitted to
The Faculty of Graduate Studies and Research
In partial fulfillment of
The requirements for the degree of**

Master of Arts

Department of Psychology

Carleton University

Ottawa, Ontario

May, 2001

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Acceptance of the thesis:

"Object-Layering in Visual Attention: Implications for HUD equipped HMDs"

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in Partial fulfillment of the requirements for

the degree of Master of Arts

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ABSTRACT

Past research has shown that there are potentially critical performance costs associated with presenting flight symbology on heads-up displays (HUDs) in aircraft. These costs have been associated with object-based mechanisms of visual attention. The present research examined object-based mechanisms of attention in HUD equipped helmet mounted displays (HMDs). Three flight references (aircraft, head, and mixed), using symbology provided by the NATO Technical Cooperation Panel (TTCP2), were tested in a two-day usability study in order to determine the effectiveness of the references in a variety of flight tasks. To determine the degree to which the various symbology reference systems (aircraft, head, and mixed) support the generation of an object layer, a target discrimination task was developed to assess pilot performance in detecting multiple stimulus events within the various symbology-reference systems. The results from the present study suggest that head and mixed reference systems may support the generation of an object layer. Spaced-based attention was also shown to effect pilot performance in the use of the HUD equipped HMD.

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INTRODUCTION

Aircraft have evolved significantly in sophistication, capabilities, and the demands placed on those who fly them. The cockpit is now packed with numerous readouts, gauges and displays that the pilot must continually monitor in order to obtain pertinent flight information. This increase in available information poses high demands upon the pilot, as many discrete and continuous events occur simultaneously throughout flight. During high workload situations there is an increased likelihood that cockpit instrumentation can be misinterpreted. Pilots require easy to interpret instrumentation in order to reduce the chance of a misread gauge or display, which as a worst case, may lead to a potentially fatal air disaster.

Helicopters (as compared to fixed-wing aircraft) place particularly high demands on the pilot and crew. The operational environment of a helicopter extends from the civil air traffic control system to remote and hazardous areas and from day operations under visual flight conditions to night operations in adverse weather. Typical mission profiles include search and rescue, medical transport, construction, agriculture, law enforcement and military operations. Low-level flight requires constant alertness on the part of the pilot in order to avoid terrain features such as mountains, trees, and buildings. During fog, heavy rain, or other obscured environmental conditions, flying becomes increasingly difficult as the pilot can no longer rely on the external visual scene, and must resort to using cockpit instrumentation. Even with good visibility, helicopter pilots must continually perform 'heads-down' scans of the cockpit instrumentation in order to retain awareness of the current status of the aircraft. Looking down at the instruments in the cockpit

significantly reduces the time that pilots spend 'heads-up' looking outside the aircraft for obstacles or targets, increases the overall workload, and reduces their overall awareness of the situation (also known as situational awareness) (Previc & Ercoline, 1999). To assist pilots in maintaining an adequate heads-up position during flight, a display device was designed to reduce the need to scan the cockpit for flight instrumentation.

Heads-up displays (HUDs) were developed to reduce heads-down time by presenting selected flight information on a transparent glass panel that is situated in the pilot's head-up, forward field-of-view. Although HUDs have been favorably received in the aviation community, evidence shows that pilots tend to allocate attention to the HUD display to the detriment of attending to elements in the external scene (Brickner, 1989; Foyle, McCann, Sanford & Schwirzke, 1993; Wickens & Long, 1994). Pilots' failure in attending to the external scene can be hazardous, especially during low-level flight. The purpose of the present research was to investigate the mechanisms underlying pilots' allocation of attention when using HUDs.

Heads-Up Displays (HUDs)

The traditional HUD is a glass plate that remains fixed to the forward windscreen of the aircraft (see Figure 1). Pertinent flight information is presented on the HUD to the pilot's forward field-of-view as they are looking along the longitudinal axis of the aircraft. HUDs that are forward fixed are also known as 'aircraft-referenced' HUDs. Flight information in the form of digitized symbology is presented on the HUD, so that the pilot can potentially see both the flight symbology

and the external scene at the same time. Flight symbology is focused at or near infinity to prevent eye fatigue caused by the constant need to refocus the eyes between the HUD symbology and the outside terrain. HUD symbology is normally displayed in a monochrome color (green, and overlays either the external terrain, or in some systems, a computer generated environment. The use of a single color for the flight symbology was selected for two reasons: a single color differentiates the individual symbols from the external terrain, creating a 'layer' of green symbols on the HUD. Second, only monochrome displays were available to generate the symbology when HUDs were first developed.

Performance Problems With HUDs. The primary goal in equipping aircraft with HUDs is to provide the pilot with fundamental information (symbology) without interfering with the perception of the outside world. The intent is for pilots to process both near (the symbology) and far (the external scene) domains in parallel; however, recent reports have suggested that pilots are unable to attend to both the near-symbology and far-external scenes in parallel (Brickner, 1989; Foyle et al. 1993; Wickens & Long, 1994).

Brickner (1989) observed performance problems with HUD superimposed symbology in a part-task simulation of helicopter flight. Participants flew a simulated helicopter over a course designated by virtual pylons. The flight task consisted of piloting a simulated helicopter around the pylons while maintaining a stable altitude of 100 feet. Altitude information was provided on either a HUD or by virtual pylons in the external scene that were constructed to appear as a known size. There was no other cockpit instrumentation available. When pilots performed the flight task using

the HUD, altitude maintenance was significantly improved relative to the no-HUD condition. However, pilots also made a significantly greater number of impacts with the pylons in the HUD than in the no-HUD condition. The increase in pylon impacts suggests that when attending to information contained in the symbology layer, pilots were unaware of their physical proximity to the pylons. That is, pilots may have difficulty attending to both the near-symbology layer and far-external scene simultaneously.

Foyle, McCann, Sanford and Schwirzke (1993) report a study supporting Brickner's (1989) observation that pilots experience problems attending to near-symbology layers and the far-external scene simultaneously. As in Brickner's study, participants were instructed to maintain an altitude of 100 feet while flying a curved path demarcated by small pyramids on the ground in a simulated flight task. Altitude information was presented via superimposed HUD symbology, or alternatively by observing the relative size of the three-dimensional pylons in the external scene. Foyle et al. found that the superimposed HUD altitude symbology improved altitude maintenance but reduced pilots' ability to accurately follow the curved path. Given that the external scene provides path information, the decrease in path-following performance suggests that pilots have difficulty attending to the symbology layer and the external scene simultaneously.

Wickens and Long (1994) reported a study in which participants were required to make a speeded response to visual stimuli that appeared either in a HUD symbology layer, or on a runway while they performed a simulated runway approach. To accurately guide the aircraft to the appropriate location on the runway, participants

were required to use the HUD ILS (instrument landing system guide indicators) symbology to perform the simulated landing task. Wickens and Long found that pilots took significantly longer (average of 2.5s) to respond to a runway incursion (the appearance of the visual stimuli situated on the runway) when the symbology was presented on the HUD as compared to a condition where the symbology was presented in the far-external scene. Wickens and Long's results suggest that pilots experience difficulty attending to both the near-symbology on a HUD and far-external terrain.

In sum, evidence suggests that attention may limit the effective use of HUD symbology. Pilots using HUDs showed an inability to concurrently perceive events that occur in the near-HUD layer and in the far-external scene. Some researchers have suggested that there is a mechanism of object-based visual attention that limits our ability to perceive a number of visual stimuli at one time, and that this mechanism may be implicated in the use of HUDs (Foyle et al., 1993; Sanford et al., 1992; Wickens & Long, 1994). The following section examines mechanisms of attention in general, and presents the results from research that suggests that an object-based mechanism of visual attention is responsible for performance costs associated with HUDs.

Attention and HUDs

The term 'attention' is commonly used to describe selectivity in processing, and was first referred to by William James (1890). The 'cocktail party' problem illustrates a familiar aspect of attention: our ability to follow one conversation even when several people are talking at once. Comprehension of the attended conversation

is clear, whereas our ability to perceive and remember unattended conversations is poor (Broadbent, 1958; Cherry, 1953). Examples of selective processing such as the 'cocktail party' illustrates what is known as 'focused attention'. Focused attention describes our ability to select certain stimuli from others, and the mechanisms responsible for the selection process. The term 'divided attention' describes our ability to perform more than one task at a time. For pilots, understanding how attention affects their performance is of particular concern due to the number of stimuli to which they must attend during flight.

Source of Attentional Resources. Eysenck and Keane (1990) provide a number of hypotheses describing our ability to perform multiple tasks. One hypothesis assumes that there is a central capacity, or resource pool, that can be allocated to a wide range of processing activities. The degree to which one task interferes with another depends on the demands that each task makes of the resource pool. Performing multiple tasks at the same time will not result in task interference as long the task demands do not exceed the capacity of the central resource pool. Wickens (1984) proposed an alternative account that suggests the degree to which two tasks will interfere depends on their similarity. Tasks are considered to be similar if they share the same stimulus modality, make use of the same stages of processing, or rely on related memory codes. On this view, processing resources are considered to be modular and are associated with different types of processing. Research reported by McLeod (1977) and Treisman and Davies (1973) supports the notion that if tasks are assigned to different modalities (e.g., one task visual, the other auditory) they interfere to a less than if they are performed in the same modality (i.e., both visual).

Previous evidence suggests that pilots experience difficulties in attending to both the near-HUD layer and far-external scene in parallel (Foyle et al., 1993; Sanford et al., 1992; Wickens & Long, 1994). Because HUDs are a visual stimulus, and pilots have many other visual stimuli to process, researchers who have examined HUD performance costs have assumed that these costs are directly related to processes of divided attention. However, research in this area has yet to provide a clear account of the nature in which mechanisms of divided attention interact with HUDs.

Spatial and Object Based Attention: An Overview

Spaced-Based Attention. Pilots' difficulties in attending simultaneously to both the near-HUD symbology and the far-external scene suggests that visual attention is allocated to these domains as separate sources of information. Early accounts of visual attention were based on the notion that attention is spaced-based, in that attention can be focused on a finite region of the visual field at any given moment in time (Eriksen & Hoffman, 1973; Hoffman & Nelson, 1981; Posner, 1980). On this view, attentional resources are allocated to process stimuli within the physical region delimited by the attentional field, much like a spotlight illuminates an actor on a stage. Eriksen and Yeh (1985) proposed that spaced-based attention affects our ability to process more than one spatial location at a time. A number of attempts have been made to specify the parameters associated with spaced-based attention. For example, Eriksen & Hoffman (1973) have proposed that the spotlight has a radius of about 1°. Others (Stelmach, Herdman, & McNeil, 1994; Stelmach & Herdman, 1991) have proposed that focusing attention on a particular region in space modulates the

temporal input response of the visual system for information falling within that region.

Object-Based Attention. In object-based accounts of visual attention, processing limitations are not defined by the spatial proximity of stimuli, but by the number of objects to be perceived in a given scene. Neisser (1967) proposed that perceptual analysis of the visual scene is a two-stage process. In the first stage, the visual field is pre-attentively segmented into separate perceptual groups, or objects. The first stage operates using pre-attentive processing and is assumed to be a fast, efficient and parallel process. Gestalt properties such as spatial proximity, good continuation, shared color, shared movement and so forth are used as identifiers for the parsing mechanisms of visual attention. After a visual scene is broken into separate objects, the second stage, known as focal attention, analyzes a particular object in more detail. Features of an object such as texture, size, orientation, color, and direction of motion are analyzed by focal attention. Neisser assumed that stage two occurs in a parallel fashion when discriminating features of a single object. Discriminations concerning multiple objects are assumed to occur in a serial fashion, as processing resources must be re-allocated across objects. On this view, limitations on the ability to attend to several objects at once are due to the serial processes involved in focal attention. A number of other researchers support this view, and there has been extensive research investigating object-based accounts of attention (Treisman et al, 1983; Duncan, 1984; Lavie & Driver, 1996).

In sum, there is evidence suggesting that both spaced-based and object-based mechanisms of visual attention play a role in our ability to perceive a number of

visual stimuli at a time. Pilots' difficulties in attending simultaneously to both the near-HUD symbology and the far-external scene suggests that visual attention is allocated to these domains as separate sources of information. Some researchers have suggested that a mechanism of object-based visual attention may be implicated in the use of HUDs (Foyle et al., 1993; Sanford et al., 1992; Wickens & Long, 1994). However, the extent to which HUD performance costs are due to space or object-based mechanisms of attention is not clear.

Object-Based Attention and HUDS

As discussed below, theories of visual attention that are based on object-representations may be best suited to account for the attentional costs associated with HUDs. The following section focuses specifically on theories of object-based visual attention and the notion that visual stimuli are grouped on the basis of common perceptual characteristics.

Seminal Studies of Object-Based Attention. Treisman et al. (1983) presented a box that either surrounded a word, or the box and word appeared above and below fixation, respectively (1° of visual angle separated the edge of the frame from the word). Participants were required to identify both the word and the relative location of a gap in the box. Identification performance was significantly better when the box surrounded the word than when the two stimuli appeared at different locations on the display. This effect was noted even though the relative distance between the gap in the box and the target word was held constant. In both single-object and dual-object conditions, there was no change in the relative spatial location across both conditions.

Therefore, the observed performance costs associated with divided attention cannot be due to spatial factors.

Treisman et al. (1983) argued that the frame and word stimuli form a single object in the surrounded format, but two distinct objects in the separated formats. In the single-object condition (the box surrounds the word), attentional resources are oriented towards processing the single object. Concurrent feature judgements for one object can then occur in parallel. In the dual-object condition (the box and word are separated), attention must be oriented across two discrete objects. The time consuming process of allocating attentional resources serially across the objects accounts for the observed performance costs.

Duncan (1984) performed a series of studies that support an object-based view of selective attention. A box (Figure 2) was presented varying in size (small or large) and varying in position of a gap in its contour (right or left), with a line struck through it varying in tilt (clockwise or counterclockwise from the vertical) and varying in texture (dotted or dashed). Participants were required to identify, as quickly as possible, two features of a single object (the line or the box) or a single feature of multiple objects (e.g., the size of the box and the orientation of the line). If the object-based hypothesis of attention is correct, identifying two features of the same object should be easier than identifying individual features of two objects. In contrast, if a spaced-based hypothesis of attention is supported, identification performance should remain constant for both single- and dual-object discriminations.

In accord with an object-based account of attention, Duncan (1984) found that there were performance costs associated with concurrent judgements across two

objects as compared to dual judgements made for a single object. Consistent with Neisser (1967), these results support the notion that attention is allocated to objects.

Duncan and Nimmo-Smith (1996) extended previous findings of object-based attention research by testing concurrent discriminations of surface and boundary systems. A boundary system refers to divisions between one region (e.g., one object) and another, and can be used as the basis for such discriminations as shape, size, orientation, or object location. A surface system fills in the bounded regions with additional properties such as color, brightness, and texture. In the first experiment, participants were asked to judge the color and length of either one or two objects (lines). Concurrent discriminations always concerned different lines. Two-alternative forced choice responses were made separately for each line. The results from this study, and confirming replications, support the notion that dividing attention between two objects produces a cost in performance in relation to a single-object condition. This cost occurs regardless of whether the two discriminations are the same or different (i.e., two surface, one surface one boundary, both boundaries). However, for color, it appears that the similarity of the discrimination may be crucial: a cost appears to be strictly associated with dividing attention and dual color judgements. This suggests that color judgements may be made in conjunction with boundary judgements without impaired performance.

Duncan and Nimo-Smith examined a greater range of surface and boundary judgements in their second experiment. Of specific interest was the previously observed asymmetry for color (a surface attribute) and boundary judgements. The results from these studies demonstrated a dual-discrimination decrement for both the

same and different attribute groups. Additionally, dual judgements of both color and certain boundary features only produce performance deficits for the boundary feature, and not for color. In most cases where a concurrent judgement must be made concerning different objects, a reduction in performance was observed for both same and different attributes. Such reductions are not observed for dual-judgements of the same object. Furthermore, the Duncan and Nimmo-Smith results indicate that visual attention operates in such a manner that subsystems responsible for boundary and surface judgements act in synchrony, allowing different properties of a single object to be simultaneously perceived.

Spaced-based models of attention cannot account for the Duncan (1984) and Duncan and Nimmo-Smith (1996) results, again suggesting that mechanisms of visual attention use object representations to efficiently allocate attentional resources for visual processing. Identifying multiple features of a single object is significantly easier than identifying features of multiple objects. The Duncan and Nimmo-Smith findings add further support to the hypothesis that an object-based mechanism of visual attention allocates processing resources to objects.

The results of Treisman et al. (1983), Duncan (1984), and Duncan and Nimmo-Smith (1996) support the hypothesis that attention is allocated to objects. In accord with an object-based view of attention, it has been suggested that the HUD near-symbolology set and the external scene are attended to as discrete 'object-layers' (Herdman et al., 2000a; Herdman et al., 2000b; Jarmasz et al., 2000). On this view, the near-symbolology set is analyzed by the visual system as a 'symbolology layer'. This symbolology layer is treated like a single object, such that efficient visual processing

occurs for features of the object-layer. Performance costs occur when attention must be redirected to the far-external scene.

Object-Based Attention Across Large Spatial Extents. Previous studies (Duncan, 1984; Duncan & Nimo-Smith, 1996; and Treisman et al., 1983) used stimuli that spanned only small spatial extents. Given the HUD's large spatial extent, it is important to know how object-based attention will function in such devices. Lavie and Driver (1996) describe further tests of object-based mechanisms of visual attention across larger spatial extents. Two long dashed lines spanning 8° were briefly presented on a display. Participants were asked to compare two elements in each such display (each element comprised a dot or a gap that replaced a standard dash) and performed speeded judgements to determine whether the targets were the same or different. The two target elements were either far apart and on the same line (object condition), or far apart but on different lines (far condition), or close together but on different lines (near condition). In accord with the object-based hypothesis, responses were faster and more accurate when the elements belonged to a common object (object condition) rather than two distinct objects (near and far conditions). These findings also suggest that object effects can be elicited for fairly large displays.

Lavie and Driver's (1996) results suggest that object-based attention influences processing across fairly large spatial extents. Observing object-based effects in larger displays counters arguments that object-based attention is operationally limited to a visual-spatial region that cannot be further restricted by spatial attention, such as the confines of attentional 'spotlights' (Duncan, 1984). However, the possibility remains that object-based attention may have acted within a

spatially bounded field. Arguably, participants may have set a wide spatially attended field in an effort to 'see' the entire display. Such a strategy is plausible, considering that the target events were equally likely to occur at either extreme of the display, and that the display duration was too short to allow for a serial search of the display. In a subsequent experiment, Lavie and Driver varied the extent of spatial attention relative to the scale of the stimulus, to determine whether or not object-based effects only occur within the spatial focus of attention. Participants were cued to focus 'spatial attention' on one side of the display only, as opposed to distributing attention across the display. The results showed that performance was reliably faster and more accurate for the valid-near condition, in which the target elements both appeared on the cued side. This supports a spaced-based manipulation of covert attention to the cued side of the screen. The object-based effect previously observed was no longer evident. The absence of the object advantage found in the previous experiments is likely caused by the narrow focus of attention engendered by the precue.

In sum, Lavie and Driver's (1996) results suggested that object-based mechanisms of attention can operate across large spatial extents like HUDs. The degree to which object-based attention influences visual processing appears to be partly determined by the initial spatial allocation of attention. Specifically, a distinction between objects that applies across wide spatial extents may be ineffective when a narrow attentional setting is initially adopted. This has implications for the application of object-based theories as an explanation for HUD symbology performance costs. Because pilots are required to use all of the information contained within the symbology layer, the visual system may be cued to operate across the

entire symbology display area. Following from Lavie and Driver, object-based attention should differentiate the HUD symbology layer as an 'object layer' that is separate from the external scene given the wide attentional setting adopted by pilots when using HUDs. The Lavie and Driver results add further support for the hypothesis that HUD symbology performance costs are a direct result of an object-based mechanism of visual attention that segregates the HUD symbology set from the external terrain.

Object-Based Attention in Dynamic Contexts. The impact of perceptual grouping cues on object-based attention must be known in order to determine whether HUD symbology may be grouped as an object layer. If perceptual grouping cues such as common motion play an important part in object-based attention, the motion of the HUD symbology across the external scene may provide object-based mechanisms of attention with sufficient perceptual cues to generate a symbology object layer. Driver and Baylis (1989) report a study in which they compared the relative influence of perceptual grouping between targets and a distractor. Participants responded to variations of a central letter in a horizontal array of five letters of equal size and spacing (Figure 3). The central letters, in conjunction with the outer letters in the array, moved up or down on the display. The intermediate letters remained stationary. The perceptual grouping hypothesis predicts that interference should be expected from the distant, moving letters. The results from their studies appear to support the hypothesis that perceptual grouping can occur as a result of common motion: distant distractors caused more interference than stationary, proximal distractors.

In sum, Driver and Baylis' (1989) experiments show that visual attention operates on objects that are defined through 'common fate'. Of relevance to the HUD symbology performance issue is the similarity between the use of common motion in the Driver and Baylis studies, and the grouping cues provided by the translation of the HUD symbology set across the external scene. Driver & Baylis' results support the hypothesis that the translation of HUD symbology across the external environment generates a perceptual object layer.

Summary. Evidence suggests that attention is allocated to object-centered representations in the visual system. Object-based attention may play a role in the use of HUD symbology. HUD symbology is fixed, such that with aircraft movements, the entire display translates across the external view. Also, HUD symbology is displayed in monochrome. Given that perceptual grouping appears to be aided by common color and motion (Driver & Baylis, 1989), it is hypothesized that the entire HUD symbology set is seen as a unitary 'object-layer' against the external terrain (Herdman et al., 2000a; Herdman et al., 2000b; Jarmasz et al., 2000). These properties of the symbology set may be sufficient to explain many of the performance costs associated with using HUD symbology sets.

HUD Symbology and Object-Layers

If the object-layer hypothesis is correct (Herdman et al., 2000a; Herdman et al., 2000b; Jarmasz et al., 2000), then the characteristics that delineate superimposed HUD symbology from the far domain (external scene) need to be identified. Foyle, Sanford and McCann (1991) have listed at least three perceptual cues that could be factors in segregating attention between the near and far domains. The first and

perhaps the most salient of the perceptual cues that differentiates HUD symbology from the real world is differential motion. Because HUDs are aircraft-referenced, the symbology in relation to the aircraft is stationary, whereas elements in the external scene follow trajectories in relation to the motion of the aircraft (Foyle et al., 1991). The second perceptual cue is color: HUDs are generally rendered in highly saturated green, whereas the world is a continuum of hues and saturations. A third cue is perspective: symbols on the display are vertically oriented with respect to the eye-plane. However, objects in the real world such as runways, buildings etc., are rotated in the depth plane (a consequence of viewing the scene from above and behind).

In order to determine what performance costs are associated with parsing the symbology layer and the external scene into distinct perceptual groups, McCann, Foyle, and Johnston (1993) designed a simulator study to (a) investigate the hypothesis that the symbology layer and the external scene are parsed into distinct perceptual groups and (b) determine whether the transition from the symbology layer to the external scene and vice versa involves a shift of attention. Participants (non-pilots) were seated in front of a CRT display that presented a static scene of a runway close to final approach. Each participant was instructed to monitor either the runway or the symbology layer at the beginning of each trial for a three-letter cue. The three-letter cue indicated where a following target would appear, either on the runway or on the HUD. The targets (two sets of three geometric symbols) were displayed on the runway and the HUD, with one of the targets in each either a diamond or a stop sign, or both. McCann et al. suggest that if attention is fully captured by the HUD or the runway grouping, the congruency effects with their design should be smaller when

the non-target appears in a perceptual group that is not attended, versus the non-target appearing in a group that is initially processed. McCann et al. cite Erikson and Erikson's (1974) research demonstrating that a non-target stimulus facilitates responses to the target if the response associated with the target and non-target are the same (when the target and non-target are stop signs). Additionally, non-target stimuli interfere with processing of the target if the target and non-target are associated with different responses (the target is a stop sign whereas the non-target is a diamond). When the non-target is fully unattended, congruency effects are eliminated (Yantis & Johnston, 1990).

McCann et al.'s (1993) design provides a test of the attention-switching hypothesis by cueing the participants to attend exclusively to either the HUD or the runway. The presence of a potential target in either the HUD group or the runway group tests the hypothesis that when attention is focused on one perceptual group, objects in the other group are excluded from processing. Participants responded 63 ms slower when the relevant target was on the HUD and the cue appeared on the runway than when the cue and target appeared in congruent locations. In addition, when the target appeared on the runway and the cue appeared on the HUD, participants responded 143 ms slower than when the cue and target both appeared on the runway. This result suggests that transitioning from the HUD to the world and vice versa involves a shift of attention that operates as a serial process. The results from the congruency portion of the experiment provide support for the hypothesis that object-based mechanisms of attention do not process both the HUD and runway groupings in parallel. In addition, the observed asymmetry in participant responses to

runway-HUD vs. HUD-runway target combinations suggests that the HUD acts as a strong perceptual object, and may impair the ability for visual attention to re-direct processing to the external scene. These results are consistent with the object-layer hypothesis which states that the near-symbolology set and far-external scene are treated like unitary objects, and that both object layers cannot be processed in parallel by the visual system.

Sanford et al. (1992) reported an experiment that further supports the object-based attentional hypothesis that accounts for the heading/altitude performance trade-off reported by Brickner (1989). They suggest that if proponents of the spatial-location based models of attention are correct, moving heading and altitude information within the attentional spotlight may allow for more efficient, parallel processing of both sources of information, thus decreasing heading/altitude performance tradeoffs. The object-based attentional hypothesis denies the ability of attention to efficiently process two sources of information unless they belong to the same perceptual group. In the simulated flight tasks, pyramids on the ground provide heading information in a dynamic scene, and altitude information is provided by static symbology. Therefore the heading and the altitude information do not belong to the same perceptual group.

Sanford et al. (1992) designed a simulated flight task that varied the proximity of digital altitude symbology to the pictorial heading information (the virtual pyramids). A control condition was also used in the study to determine the usefulness of presenting symbolic altitude information. Fourteen participants took part in this experiment. Participants were instructed to maintain an altitude of 100 ft while

following the path-defining pyramids. Altitude and heading errors were collected and analyzed as the dependent variables. The results showed that the presence of symbolic altitude information significantly aided altitude maintenance. This improvement in altitude performance was unaffected by the distance between the altitude symbology and the heading information in the terrain. In addition, heading performance was significantly better when the attitude symbology was not present than in the proximal condition. Heading performance when the HUD was absent, and when the HUD was in the intermediate and distal conditions was better than when the HUD was in the proximal condition. These results do not support a location-based attentional model of the heading/altitude performance tradeoff. Indeed, the lack of an altitude/heading tradeoff in the distal and intermediate conditions is contrary to the predictions of the location-based model. The object-layer hypothesis accounts for the performance tradeoff in the proximal condition by proposing that the heading and altitude information are parsed into separate perceptual objects.

PRESENT RESEARCH

Past research has shown that there are potentially critical performance costs associated with presenting flight symbology on HUDs in aircraft. The results of this research are consistent with an object-based attention framework in which the HUD symbology forms an object layer that is differentiated from the layer of information presented in the external scene (Herdman et al., 2000a; Herdman et al., 2000b; Jarmasz et al., 2000). To date, research on attention and HUDs has examined traditional aircraft-referenced HUDs, where information is presented to the pilot's heads-up forward field of view. The present research was designed to examine object-

based attention (layering) effects in HUD-equipped Helmet Mounted Displays (HMDs).

The HUD-equipped HMD provides the pilot with a head-referenced HUD fixed directly in front of one or both eyes. The presumed advantage of HUD-equipped HMDs is that pertinent flight information can be continually presented to the pilot's field of view. It is possible, however, to configure the HMD system such that the HUD symbology is not always in the pilot's field of view (a mixed reference). Mixed reference sets are of interest to the design of HUD-equipped HMDs as a method of displaying critical flight symbology in a head-referenced design, while maintaining non-critical flight information in a traditional HUD, aircraft-referenced format. In addition, there are concerns that appropriate head-referenced attitude indicators (a device used to display the aircraft's physical orientation in space) are difficult to design for HUD-equipped HMDs (Armstrong, Jennings, & Craig, 2000). However, traditional HUD-equipped HMD designs have not used mixed reference systems. To this end, an International Technical Cooperation Panel 2 (TTCP2) developed a configurable symbology set for use in HUD-equipped HMDs (Figure 4).

The TTCP2 proposed three options for referencing the HUD symbology on the HMD. The first option references all of the symbology to the forward field-of-view of the aircraft, in a similar manner to traditional glass-panel HUDs. With this aircraft-referenced HUD symbology, when the pilot turns their head off-boresight (away from the forward axis of the aircraft), the symbology remains fixed to the front of the aircraft, and the pilot loses sight of the symbology. The second option references all of the symbology to the pilot's forward field of view, so that regardless

of the pilot's head position, the symbology remains fixed to their central field-of-view. During head movements, the symbology layer moves across the far-external scene with two axes of motion (up and down, left and right) (Figure 5). The final option was developed to evaluate the effectiveness of a minimally cluttered frame of reference for use in off-axis head positions. This option uses a reference system whereby non-critical flight symbology is aircraft-referenced, while critical flight indicators (torque, radalt, and airspeed) are head-referenced. With this mixed-reference system, the three head-referenced indicators move across the external scene, and also move across the aircraft-referenced symbology (again with two axes of motion) (see Figure 5). The head-referenced indicators for the mixed-referenced system (torque, radalt, and airspeed) are the three flight instruments most often used by pilots with conventional instrumentation, or traditional HUD displays.

There are a number of potential costs/benefits that may arise from the use of HUD-equipped HMDs if the object-layer hypothesis is correct. Previous research suggests that when pilots attend to the HUD symbology, their responses to events that occur in the external scene are significantly reduced when compared to events that occur within the symbology (Foyle et al., 1993; Wickens & Long, 1994). These results suggest that while using HUDs, pilots may experience difficulties responding to events that occur in the external environment of their aircraft. In addition, HUD symbology is relatively permanent (remains fixed to the aircraft cockpit) when compared to the external scene, which undergoes motion relative to the HUD. The permanence of the HUD may act to cue pilots to attend to the HUD symbology at the

expense of the external scene. In the worst case, pilots may inadvertently attend to only the HUD if their view of the external scene is degraded.

The benefits associated with HUDs lies in the presentation of pertinent flight information to the pilots' forward field of view, reducing the need to scan the cockpit instrumentation heads-down. In the case of HUD-equipped HMDs, this benefit extends to the pilots' field of view regardless of their head position. If the object-layer hypothesis is correct, then the generation of a perceptual object layer from the HUD symbology should provide pilots with the ability to quickly retrieve flight status information from the HUD. The components of the HUD symbology are perceptually grouped into a unitary object layer, and are then analyzed in parallel by the visual system. In addition, the strong perceptual grouping cues used in HUD symbology may assist pilots in directing their attention to the HUD when a critical change in the symbology has occurred.

The degree to which HUD-equipped HMDs effect pilot performance is unknown. The object-layer hypothesis suggests that the presence of HUD symbology may impact pilot performance by affecting the pilots' ability to attend to the HUD symbology and far external scene in parallel. Research into the effects of HUD-equipped HMDs on pilot performance has not yet examined this issue. The evaluation reported in the present study incorporates an understanding of object-based mechanisms of visual attention and provides an appropriate avenue for testing the presence of object-layers in the TTCP2 reference systems. This research on object layering in HUDs was conducted as part of a usability study examining various aspects of the different TTCP2 HMD reference systems.

According to the object-layer hypothesis, a symbology set may be perceived as a unitary layer of symbology that allows object-based mechanisms of visual attention to analyze events within the layer in parallel. Based on Gestalt principles of perceptual grouping, properties of the symbology-reference systems such as common motion and common color should allow for the generation of a symbology object-layer. The degree, or strength to which the proposed symbology layer is formed should depend on the degree to which the reference system in use (aircraft, head, or mixed) provides Gestalt principles of perceptual grouping during pilot head movements. The aircraft-referenced system, fixed to the forward axis of the aircraft, is proposed to provide a minimal number of perceptual grouping cues. When the pilot moves their head, the aircraft-referenced symbology layer does not move across the external scene, and in some cases, is completely outside of a pilot's field-of-view. The only perceptual grouping cues provided by the aircraft-referenced system are common color (green) the movement of the fixed symbology set across the external scene due to aircraft motion.

The mixed-reference system provides additional perceptual grouping cues through the motion of the three head-referenced flight-status indicators (torque, airspeed, and radalt) across the external scene during pilot head-movements. However, if a symbology object layer is generated with the mixed-reference system, it should be isolated to the three head-referenced indicators. The aircraft-referenced symbology that is fixed to the forward field-of-view in the mixed-reference system may in fact disrupt the generation of a symbology object layer in the mixed-reference due to the common color that these symbols share with the head-referenced

indicators. Additionally, the differential motion of the aircraft-referenced portion of the mixed-reference system due to aircraft motion, and not pilot head movements, may also impair the creation of a symbology object layer.

The fully head-referenced symbology set should provide the strongest perceptual grouping cues to allow for the generation of an object layer by the visual system. With the head-referenced symbology, all of the HUD symbols provide common color, as well as strong common motion cues through the translation of the near-symbology set across the far-external scene due to pilot head movements. The lack of any interference from other symbology that is not head referenced, such as in the mixed-reference system, should also support the generation of a symbology object layer. In this condition, events that occur within the head-referenced layer should be processed significantly faster than in either the fully aircraft-referenced, or mixed-referenced conditions.

The opportunity arose to test the effects of the object-layer hypothesis in a simulated flight-task using HUD-equipped HMDs. In order to determine the degree to which the various symbology reference systems (aircraft, head, and mixed) support the generation of an object layer, a target discrimination task was developed to assess pilot performance in detecting multiple stimulus events within the various symbology-reference systems. Similar to past research on mechanisms of object-based attention (Duncan, 1984; Lavie and Driver, 1996), participants were required to discriminate the color of two circles that simultaneously appeared around two of three components of the TTCP2 symbology (the torque, RADALT, and Airspeed indicators) (See Figure 13). The spatial proximity of the targets to each other was

manipulated by varying the symbology around which the targets encircled (near - Torque and RADALT; middle - RADALT and Airspeed; far - Torque and Airspeed). According to the object-layer hypothesis, if object-based mechanisms of visual attention perceptually group the TTCP2 symbology into an object layer, the physical separation of the targets should have no impact on participant responses to the discrimination task as the visual system analyzes the features of the object layer in parallel. In addition, the degree to which the three TTCP2 reference systems (air, mixed, and head) provide perceptual grouping cues to the visual system should determine the degree to which those reference systems will facilitate the generation of a perceptual object-layer.

METHOD

General Overview

This research was conducted as part of a two-day simulator-based usability study of the three TTCP2 referencing systems for use in HUD-equipped HMDs across a variety of flight tasks. The first day of the usability study consisted of a two-hour orientation phase followed by a three-hour flight evaluation. The orientation phase familiarized participants with the simulator equipment, virtual environment, and flight model used in the study. During the following flight evaluation, participants performed a variety of flight tasks in order to generate a subjective opinion on the efficacy of the three TTCP2 reference systems throughout various phases of flight. Participant opinions about the three reference systems were assessed through a series of questionnaires completed after experiencing each TTCP2 reference system in the assigned flight-tasks.

The present research on object-layering was conducted on the second day of the usability study. This ensured that participants were familiar with the apparatus, simulated environment, and the flight-model.

Participants

Six male Canadian Forces helicopter pilots aged 36 to 43 years volunteered for the usability study (see Table 1). The pilots had an average of over 3,000 hours experience flying rotary aircraft. Most pilots had some simulator experience. Two of the pilots had little to no night-vision goggle (NVG) experience.

Testing Environment

Test Site. The usability study, and the proposed research on object-layering in HUD-equipped HMDs was conducted at the BAE (British Aerospace Electronics, formerly Canadian Marconi Company) facility in Kanata, Ontario, Canada. The BAE facility has a number of low-fidelity flight simulators that are used for various Air Force research projects. These simulators are on-loan from the Department of National Defense (DND Canada). The flight simulator used for the proposed research was implemented with a Silicon Graphics (SGI) Octane workstation to generate the virtual environment and the generic rotary-wing flight-model. A second SGI Octane workstation was dedicated to collecting performance data from the flight controls, the HMD, and the virtual environment. A Polymous Inc. magnetic head-tracking unit mounted on a stand above the participants' head was used to judge the physical position of the HMD within 3-dimensional space. The data from the head-tracker was used to refresh the virtual environment and HUD symbology displayed in the HMD in accordance with pilot head-movements.

Displays. The virtual environment and HUD symbology were displayed on an N-Vision Inc. HMD system that consisted of two LCD panels with 50% of visual overlap (Figure 6), providing an approximate stereoscopic image. The imagery provided by the N-Vision HMD was rendered in VGA with 1024 X 768 lines of resolution with a refresh rate of 30 Hz. This refresh rate corresponds to the upper limit that the virtual environment and HUD symbology could be updated in the HMD during participant head movements. Participants were able to calibrate the HMD to ensure that the imagery from both LCDs were properly fused, and were of the same luminosity. A set of levers adjusted the luminosity of the LCDs for both eyes, and a set of dials on either side of the HMD was used to adjust the separation of the LCD panels to calibrate image fusion.

Controls. Participants sat wearing the HUD-equipped HMD in an adjustable Sea-King Helicopter flight-chair that was mounted on a wooden platform, with embedded cyclic, throttle, and rudder controls (Figure 7). The position of the flight chair was adjusted to provide a comfortable position for each participant. The throttle control was positioned on the immediate left of the flight chair in order to conform to standard helicopter control positions. The cyclic, which controls the rate was positioned directly in front of the flight chair within easy reach of the participants, conforming to standard control positions. The cyclic control was a five-button unit, and the button positions conformed to those of a generic helicopter cyclic. One button was positioned at the front of the cyclic, and four thumb-activated buttons were positioned on the top faceplate of the cyclic. Responses were made with the button on the front of the cyclic, and the bottom button on the faceplate of the cyclic. The rotor

controls were positioned immediately behind the cyclic, conforming to a standard control position.

Software. The software that was used to generate the virtual environment and flight symbology consisted of a VAPS software package, a common virtual environment-modeling tool. The flight model for the study was generated using HELI-SIM, a software package often used for simulated-flight studies of rotary-wing aircraft. The software code for the data-collection aspect of the study was written using C++, and was integrated with both the VAPS and HELI-SIM applications.

The virtual environment consisted of a square map, with an airport located at its centre, and four major 'sites of interest' in each corner of the map, equidistant from the airport (Figure 8). The terrain consisted of a green-colored flat plain populated with virtual trees designed to appear approximately 25 - 75 feet in height, with continual clear visibility (Figure 9). Each 'site of interest' consisted of virtual buildings designed with the intent to provide areas for participants to conduct tactical maneuvers with the TTCP2 symbology references in a realistic environment. The various sites ranged from a 400' castle, an enclosed monastery with a courtyard large enough to permit hover-landings, a small village consisting of three small houses, and a farmhouse. An ADS-33 (American Design Standard-33) type side-step course created for the first day of trials was also used with this environment, consisting of two hover pads joined by three parallel rows of pylons. The ADS-33 maneuver is a standardized flight task used during flight-tests as a method of validating both pilots and new aircraft equipment.

A simulated cockpit instrument panel, the main rotor blades, and the interior of the aircraft were visible to the participants while wearing the HMD. The simulated cockpit was included as pilots often use such visual cues during flight as reference points against the external terrain. However, the simulated cockpit instruments were not detailed enough to be read by the participants, thus ensuring that they relied on the TTCP2 symbology for flight information.

The TTCP2 flight reference systems for the HUD-equipped HMD were generated with the VAPS software tool. Each of the TTCP2 reference systems were colored green, and had a field of view of approximately 50°.

Procedure

The object-layering experiment was conducted over the course of the second day of the usability study. Participants arrived at the facility at approximately 8:00 am and left at approximately 4:00 pm. Participants flew through two sessions, conducted in the morning (practice) and afternoon (experimental). For the morning practice session, participants practiced flying the various missions and performing the target discrimination task. This practice ensured that participants were very familiar with the flight model, the three TTCP2 reference systems, and the object-layering task. Practice also provided the opportunity to calibrate the HMD and position of the flight chair for the experimental period. Participants practiced the target discrimination task by performing one 10-minute trial with each reference system for a total duration of 30 minutes. During the experimental session, participants flew three 10-minute missions for each symbology reference set (a total of nine missions). A brief 15-minute break was provided between each experimental session. The order that

participants flew each TTCP2 referencing configuration was counterbalanced across participants.

The experimenter remained in the simulator room during the trials to monitor the apparatus and assist participants entering and exiting the simulator. A data readout displaying (a) the status of the flight-model, (b) the position of both the simulated aircraft and a target ellipse in the virtual environment, and (c) the view from the left display of the HMD was available on a monitor in the simulator room (Figure 10).

Flight Task. Each trial phase began with the simulated helicopter on the ground at the central airport. Participants were then instructed to attain an altitude of 75', an airspeed of 100 knots, and a heading in the direction of one of the selected maneuvering sites (transition phase).

In order to provide the perceptual grouping cue of common motion through the translation of the TTCP2 symbology across the virtual environment, it was critical that pilots moved their heads during the transition phase. To ensure head-movements, participants were instructed to scan the virtual environment for a small solid sky-blue ellipse that could appear unpredictably in the surrounding terrain. The presentation of the ellipse was controlled by the experimenter, and placed approximately every 30 seconds into the environment throughout the duration of each transition phase. Participants were instructed to respond verbally whenever they detected the target by stating the location of the ellipse by its cardinal co-ordinates with respect to the simulated aircraft's current heading. Helicopter pilots use the cardinal co-ordinate system to indicate potential obstacles and targets to their crewmembers, and therefore this was assumed to be familiar to the participants, and easily integrated as part of

their standard flight procedures. Participants were also instructed to defer responding to the appearance of the ellipse in favor of the target discrimination task.

Upon arriving at one of the maneuvering sites, participants conducted several low-intensity tactical maneuvers including landing, hovering, and pirouette. The tactical maneuvers ensured that participants continued to move their heads. After a period of two minutes, participants were instructed to proceed away from the maneuvering site with a new heading, re-attaining an altitude of 75', airspeed of 100 knots, thus initiating another transition phase. At the end of the trial, participants were instructed to land the simulated helicopter in the virtual environment. Upon landing, participants were instructed to close their eyes before they were repositioned from their current location to the airport. Participants were then repositioned when they verbally indicated that they had closed their eyes. The abrupt change in the visual scene could be potentially disorienting if participants' eyes remained open. The next trial began as soon as participants indicated they were ready to continue. The duration of each transition phase was approximately four minutes. Each mission lasted approximately 10 minutes.

Discrimination Task. The object-layering hypothesis was tested by having participants perform a target discrimination task while flying the flight missions. Participants were instructed to monitor their three primary flight indicators (airspeed, torque, and RADALT indicators) for the simultaneous appearance of two circular targets (Figure 11). Each target encircled one of two indicators, and appeared on the display for 100 ms. The targets would randomly appear as the same color (either mauve, or blue) or as different colors (one mauve, the other blue; Figure 13).

Participants were instructed to quickly press either the front trigger of the cyclic if the targets were the same color and the thumb-activated trigger if they were different. Collected data included response times and error rates.

Each pilot performed the target detection task with each reference set. For each ten-minute mission, 30 targets were randomly presented throughout each mission at approximately 22 sec intervals. For each mission, participants were required to raise and land the simulated helicopter, which took approximately 2 minutes at the beginning and end of each trial. During these periods, the target detection task was not initiated. Out of 30 targets, 15 targets appeared as the same color and 15 as different colors. For each color block, five of each possible symbology combinations were presented (i.e. targets appearing around radalt/torque, radalt/airspeed, and airspeed/torque). Therefore, for each symbology reference, participants experienced a total of 90 trials (30 per flight), consisting of 45 same-trials, 45 different-trials, with a total of 15 trials for each target/indicator combination per same/different trial.

At the end of the study, participants were debriefed as to the purposes of the object-layer study. They were thanked for their participation in the two-day study, and were provided a Carleton University coffee mug in appreciation of their efforts.

RESULTS

Data analyses were carried out on mean participant response latencies and error data. For latencies, any data point that fell beyond 3.0 standard deviations from a participants mean latencies was considered to be a potential outlier, and was removed from the data set (.01% of the data points were considered outliers). A 3

(Reference Set: aircraft, mixed, head) x 3 (Target Location: near, middle, far) x 2 (Target Type: same, different) repeated measures ANOVA design was used for the overall analyses of the latency and error data. The ANOVA showed that participants responded significantly faster to the targets when they appeared in the same color (mean = 1248 ms) than when they appeared in different colors (mean = 1293 ms) ($F(1,5) = 8.137, p > .034$). Target type (same vs. different) significantly interacted with the Target Location variable ($F(2, 10) = 4.490, p > .041$). On the basis that the Target Type variable was significant, separate 3 (Reference Set: aircraft, mixed, head) x 3 (Target Location: near, middle, far) ANOVAs for same and different targets were conducted. The main effects and interactions were examined using 95% confidence intervals which were generated using the MSE terms from the ANOVAs.

Response Latency Analyses

Same Trials. Table 10 shows the mean participant response latencies and standard deviations for the Same trials. The corresponding ANOVA summary is shown in Table 4. The 95% confidence intervals showed that participants responded significantly faster to targets appearing in the near and far locations when compared to the middle location, while using the head and aircraft reference systems (see Figure 14). In contrast, while using the mixed reference system, participant response latencies were unaffected by the Target Location variable. The Reference Set by Target Location interaction is unusual in that the results contradict the predictions of space-based hypothesis.

Different Trials. Table 11 shows the mean participant response latencies and standard deviations for the Different trials. The corresponding ANOVA summary is

shown in Table 5. The Mean Square Error term from the 3 (Reference Set) by 3 (Target Location) interaction used to calculate the 95% confidence intervals is located in Table 5. The 95% confidence interval showed that participants using the head reference responded slower (mean = 1389 ms) to targets appearing closest together than those appearing in the middle (mean = 1224 ms) and far locations (mean = 1280 ms) (see Figure 15). The Reference Set by Target Location interaction is unusual in that these results contradict the predictions made by spaced-based hypothesis of attention. Table 11 shows the mean participant response latencies and standard deviations for the Reference Set by Target Location interaction for different trials.

Participant Accuracy

Same Trials. Table 12 shows the mean participant accuracy's (percent of incorrect trials) and standard deviations for the Same trials. The corresponding ANOVA summary is shown in Table 6. The 95% confidence intervals in Figure 16 show that participants using the head-reference system made significantly fewer errors when targets appeared in the near and far locations than when they appeared in the middle location. With the mixed reference system, the 95% confidence intervals showed that participants made significantly fewer incorrect responses when targets appeared in the near location when compared to targets appearing in the middle and far locations. When using the aircraft reference, the 95% confidence intervals showed that participants made fewer incorrect responses when targets appeared in the far location than in the middle location. Overall, participants made fewer incorrect responses with the aircraft reference (26%) than with either the mixed (37%) or head (34%) reference, which contradicts the predictions of the object-layer hypothesis.

Participants also made fewer errors when targets appeared in the near and far locations compared to the middle location. The present results partially support the predictions of space-based hypothesis of visual attention. For both the head and mixed reference sets, participants made fewer errors when the targets appeared close together. However, when participants used the head and aircraft reference systems, they made significantly fewer incorrect responses to targets that were in the far location when compared to targets in the middle location. These results appear to contradict the predictions of space-based hypothesis of visual attention.

Different Trials. Table 13 shows the mean participant accuracy's (percent of incorrect trials) and standard deviations for the Different trials. The corresponding ANOVA summary is shown in Table 7. The 95% confidence intervals showed that for different trials, participants made significantly fewer errors (11%) with the head reference than with the mixed (18%) and aircraft reference (23%) (see Figure 17). Also, the 95% confidence intervals showed that participants were more accurate when discriminating targets that appeared in the far location (17%) than in the middle (25%) or near (27%) target locations, but only when using the aircraft reference. Similar to the results found in the Same trial analysis, this reverse spatial effect contradicts the predictions of space-based hypothesis of attention. However, additional evidence was found supporting the object-layer hypothesis, suggesting that the head-reference system provides sufficient perceptual grouping cues to significantly reduce the number of incorrect responses made by participants.

Missed Responses

Same Trials. Table 14 shows the mean participant missed responses (mean percentage missed) and standard deviations for the Same trials. The corresponding ANOVA summary is shown in Table 8. The 95% confidence intervals showed that participants missed significantly more targets with the aircraft-reference in the middle and far locations than with either the head or mixed references in those locations (See Figure 18). These results support the predictions of the object-layer hypothesis. In addition, when participants used the aircraft reference, they missed fewer trials when targets appeared in the near location than in the middle and far locations, showing an effect supporting space-based hypothesis of attention.

Different Trials. Table 15 shows the mean participant missed responses (mean percentage missed) and standard deviations for targets that were different. The corresponding ANOVA summary is shown in Table 9. The 95% confidence intervals showed that participants missed fewer targets with the head- and mixed-references in the middle and far target locations (See Figure 19). These results suggest that when the targets are different, the head and mixed reference sets provide perceptual groupings cues that are used to create a perceptual object-layer. Features of the perceptual object layer are analyzed efficiently by the visual system, resulting in fewer missed trials than with the aircraft reference. Finally, the results showed a significant interaction between the type of reference set and the location that targets appeared. The 95% confidence intervals show that participants missed significantly more trials when using the aircraft reference, and targets appeared in the farthest location (22%), than with any other reference set and target location combination

(See Figure 19). The reference set by location interaction suggests that the head and mixed reference sets provide sufficient perceptual grouping cues to allow object-based mechanisms of visual attention to perceptually group the head-fixed symbology, leading to fewer missed responses.

Summary

In sum, the results from the present research suggests that both object based and space based mechanisms of attention may affect the use of HUD-equipped HMD symbology sets. However, the analysis of participant response latencies also showed some unusual findings, which are discussed in the following sections. Table 3 summarizes the present results supporting the object-layer hypothesis.

Evidence for Object-Layering. In support of the object-layer hypothesis, the results from the error analysis showed that participants made fewer incorrect responses with the head reference than with the mixed and aircraft references. Participants also missed fewer trials while using the head and mixed reference sets than with the aircraft reference. In addition, participants were more accurate with the head reference set, but only when the targets were different. The present study suggests that the head and mixed symbology were analyzed by object-based mechanisms of visual attention, therefore leading to fewer missed responses.

Evidence for Spaced-Based Attention. The results from the present research suggest that space-based attention also affects the use of HUD-equipped HMDs. In support of traditional space-based hypothesis, participants missed fewer targets when the targets appeared in the near and middle locations than in the far location. This effect was most pronounced for the aircraft reference and head reference systems,

suggesting that the aircraft referenced symbology was analyzed by space-based mechanisms of visual attention. Participants also responded faster and were more accurate when targets appeared in the near location when compared to the middle location while using the head and aircraft references.

The present results also demonstrated an effect of target location that is counter to traditional space-based accounts of visual attention. While using the head and aircraft reference sets, participants were significantly faster, and were more accurate in responding to same-targets that appeared in the far locations than in those appearing in the middle location. In addition, participant response latencies were faster for different-targets appearing in the middle and far locations than to those appearing in the near location while using the head reference set (See Figure 19). The results from the response latency and accuracy data suggest a reverse-effect of target location that contradicts the evidence obtained supporting traditional spaced-based hypothesis. Spaced-based accounts of visual attention predict that participant response latencies should be smaller for targets that appear closer together.

GENERAL DISCUSSION

HUD-equipped HMDs and Visual Attention

The results from the present research support the notion that HUD symbology is grouped as a unitary object-layer by object-based mechanisms of visual attention. Participants made significantly more errors and missed a greater number of targets with the aircraft reference, suggesting that aircraft-fixed symbology does not provide sufficient perceptual grouping cues to allow the visual system to analyze the symbology as a unitary object-layer.

However, the use of the aircraft reference set in the present research introduced a confound. As the aircraft reference remained fixed to the nose of the aircraft, participants may have turned their head away from the HUD symbology during off-axis head movements. Therefore, the greater number of missed and incorrect trials while using the aircraft reference may have been a result of the aircraft referenced symbology being outside of participants' field of view when the targets appeared. However, if participants were consistently missing targets due to off-axis head movements, the results from the present research should have shown a greater number of missed responses for the aircraft reference in all possible target locations (near, middle and far). The present results cast doubt on this explanation, and show that for the near and middle target locations, participants experienced only a slight increase in missed targets while using the aircraft reference when compared to the head and mixed reference systems. However, without the ability to measure participants' head positions in relation to aircraft-fixed symbology, it is difficult to determine why participants experienced a greater number of missed trials using the aircraft reference set.

The present results also showed that participants missed fewer targets when the targets appeared in the near and middle locations than when they appeared in the farthest location. This effect was most pronounced for the aircraft reference system (See Figure 31). These results support a spaced-based account of visual attention. However, the present results also support the predictions made by the object-layer hypothesis, suggesting that the head and mixed reference symbology are grouped as a unitary object-layer. Participant error rates and missed responses reflect this notion,

suggesting that the head and mixed references were analyzed as an object-layer, thereby reducing the spatial effect of target location (See Figure 31). In contrast, the aircraft reference does not provide the visual system with sufficient perceptual grouping cues to generate a symbology object-layer. As a result, the visual system analyzes the aircraft referenced symbology using spaced-based mechanisms of visual attention. This is reflected in the effect of spatial location for the aircraft reference set. However, as noted above, participants using the aircraft reference may have missed targets due to their head-position, and not from insufficient perceptual grouping cues.

The significant Reference Set (head, mixed, aircraft) by Target Location (near, middle, far) interaction for response latencies in the present research raises questions regarding spaced-based mechanisms of visual attention. Participant response latencies for different-trials in the near location were significantly slower than either the middle or far target locations. The present results appear to contradict traditional spaced-based accounts of visual attention. However, examining the means for the different-trials shows an apparent reversal of the same-trial interaction. Though the different-trial reversal is not significant, it does suggest that HUD-equipped HMDs may impact the operation of spaced-based mechanisms of visual attention. Future research is required in order to determine if the reverse spatial effect is reliable.

The design of HUD equipped HMDs

The evidence from the present research suggests that traditional HUD performance costs may occur in HUD equipped HMDs. Head and mixed reference systems appear to provide the perceptual cues necessary to allow object-based

mechanisms of visual attention to group the symbology. If symbology can be grouped by the visual system, then there may be an increased risk that pilots will experience difficulty attending to both the near-symbology layer and far-external scene in parallel. Due to the fact that the symbology is grouped as an object layer, pilots may also experience an increased ability to detect events that occur within that layer. It is unclear whether the potential benefit of enhanced event detection within the TTCP2 symbology outweighs the potential costs associated with traditional HUD devices. However, evidence gained from the first day of the usability study shows that the majority of pilots rated the head and mixed designs as providing highly useful information not otherwise available in heads-up positions. Though the head and mixed reference systems appear promising, designers of HUD based systems must be aware of both the potential costs and benefits to pilot performance through the use of these devices in order to maximize their potential utility.

Future Research

The results from the present research indicate that both object and spaced-based mechanisms of visual attention impact the performance of pilots using HUD-equipped HMDs. However, similar in nature to previous research on visual attention in HUDs, the present work focused solely on aspects of divided visual attention. Of interest to pilots is the impact of HUD symbology in an environment that contains both visual and auditory stimuli.

Wickens (1984) proposed that if tasks are assigned to different modalities (one task visual, the other auditory) they interfere to a less degree than if they are performed in the same modality (both visual). Simulated environments offer the

ability to extend research on visual attention and HUDs by providing the means to generate stimuli in multiple sensory modalities. A direct test of the modular-resource hypothesis can be provided by incorporating a visual discrimination task similar to that used in the present research with a concurrent auditory discrimination task. According to Wickens, the degree of task interference between simultaneous auditory and visual discriminations should be minimal. Simultaneously discriminations of the color of two targets and the pitch of a tone should not result in impaired performance for either task. However, if visual attention is effected by the concurrent auditory task, this would provide support for the notion that attention uses a centralized pool of resources.

Object-Layering and NVDs. The Night Vision Device (NVD) is a helmet-mounted instrument that enables pilots to see in low-level light conditions. Without NVDs, pilots of rotary wing aircraft would be unable to fly at night. However, NVDs are known to have a number of disadvantages that include a restricted field of view (typically 40 - 50°), and a monochrome green image. These drawbacks are known to significantly increase pilots' workload during flight. Therefore, HUD symbology sets are being integrated in NVDs as supplementary display aids to reduce pilot workload. However, future research needs to determine the extent to which traditional HUD based performance costs may arise in HUD-equipped NVDs. Due to the reduced visual environment provided by night vision displays, pilots may rely heavily on the HUD symbology for critical flight information. In addition, most HUD-equipped NVDs are head referenced, which in conjunction with the perceptual cues common to HUDs may allow object-based mechanisms of visual attention to group the NVD

symbology as a unitary object-layer. As a result, pilots who use HUD-equipped NVDs may experience difficulty attending to the HUD symbology and the external scene in parallel to a greater degree than with traditional HUDs.

Summary

The present research provides evidence for an object-based attention framework in which the HUD symbology forms an object-layer that is differentiated from the layer of information presented in the external scene (Herdman et al., 2000a; Herdman et al., 2000b; Jarmasz et al., 2000). Object-based mechanisms of visual attention allocate processing resources to events that occur within an object-layer in parallel and serially allocate resources across object-layers. As a result, pilots using HUDs are unable to attend to both the object layer and far-external scene in parallel.

The advent of HUD-equipped HMDs has provided the opportunity for the pilot to wear a traditional HUD symbology set in their field-of-view at all times. This raises the question of how best to display flight-symbology for HMDs, as there is concern that HUD performance costs may occur with these devices. The present research has taken a step toward assessing object-based mechanisms associated with HUD-equipped HMDs, and the potential impact that use of these devices may have on pilot performance.

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APPENDIX A

Glossary of Acronyms and Terms

ADS-33	American Design Standard-33. A set of standardized flight tasks designed to test pilot ability, mental workload, and aircraft handling.
Collective	A helicopter control used during flight to collectively alter the pitch (angle) of all of the rotor blades simultaneously.
Cyclic	A helicopter control used during flight to selectively control the 'tilt' of the rotor disc, and thus affects the direction and speed of the helicopter.
Flight-Model	A mathematical model used in flight-simulators that defines the physical and aerodynamic characteristics of simulated aircraft
HUD	Heads-Up Display
HMD	Helmet-Mounted Display
Indicated Air Speed	Flight symbology used to indicate the forward speed of an aircraft.
Knot	Unit of horizontal motion equal to 1.1 miles per hour (approximately equal to 6, 076 feet/hour or 1 nautical mile/hour)
NVD	Night Vision Device. These devices are used to enhance our ability to perceive in low-level light conditions.
RADALT Indicator	(Radar Altitude Indicator) TTCP2 Flight symbology that is used to indicate the current altitude of an aircraft in either feet or meters.
Torque Indicator	Flight symbology that gives an indication of the amount of Torque that is being output by the engines
NATO TTCP2	International Technical Cooperation Panel 2. An international panel consisting of members from the US, Canada, Australia, and the United Kingdom.
VSI	Vertical Speed Indicator. A rotating line surrounding the TTCP2 RADALT symbol that displays the rate at which the aircraft is ascending or descending.

Table 1.
Summary of Pilot Experience

S	Training	Rotary Hrs.	Simulator Experience	Hrs NVG	Glasses
1	<ul style="list-style-type: none"> • HT406 Standards Flight Commander until. Dec 99 • Instructor Pilot Aug. 96 – Dec 99 • OFTT Instructor Sep 96 – Dec 99 	<ul style="list-style-type: none"> • 1700 hrs overall • CH 139 Jet Ranger • Sea King 	<ul style="list-style-type: none"> • Sea King OFTT 	0	Yes
2	<ul style="list-style-type: none"> • Military Pilot Wings Graduate 1981 • Instructor Bell 206 (1300 hrs) • Instructor Griffon (800 hrs) 	<ul style="list-style-type: none"> • 3600 hrs overall • CH136 Kiowa • CH139 Jet Ranger • CH135 Twin Huey • CT134 Musketeer • CT114 Tutor • Ch146 Griffon 	<ul style="list-style-type: none"> • Bell 212/412 Simulator • Griffon Simulator 	60	Yes
3	<ul style="list-style-type: none"> • Tactical Helicopter (NOE) Fly • SAR; AB Initio Flight Instructor • Test Pilot 	<ul style="list-style-type: none"> • 3600 hrs overall • Bell 206; 212 • MBB 105 • HV – 11 (Labrador) 	<ul style="list-style-type: none"> • UH 1 • H 46 • H 53 	40	Yes Instrument Flight
4	<ul style="list-style-type: none"> • Instructor 83-86 3CFFTS CT-134 Musketeer 	<ul style="list-style-type: none"> • 2300 hrs overall • CH136 Kiowa • CH135 Twin Huey • CH139 Jet Ranger • CH146 Griffon • Bell 206; Bell 212 • Bell 412 	<ul style="list-style-type: none"> • none 	30	yes
5	<ul style="list-style-type: none"> • CH –135 OUT TAC Instructor Pilot 3yrs. • CH-135 NVG IP 5yrs. • CH-146 NVG SPEC 2yrs 	<ul style="list-style-type: none"> • 3500 hrs overall • CH 136 Kiowa • CH 139 Jet Ranger • CH 135 Twin Huey • CH 146 Griffon 	<ul style="list-style-type: none"> • ~10 hrs Griffon & FSI • CT 114 Tutor 	600	No
6	<ul style="list-style-type: none"> • CT 134 Musketeer • CT 114 Tutor • CH 139 Jet Ranger • CH 135 Twin Huey • Kingair 	<ul style="list-style-type: none"> • 3300 Overall • CH 139 Jet Ranger • CH 135 Twin Huey • Enstrom Single Engine Piston 	<ul style="list-style-type: none"> • C 90 King Air • UTIAS/DCIEM Sea King Trials • C 17 Globemaster 	2	No

Table 2
Participant Schedule

Participant	Trial Order	Participant	Trial Order
Pilot 1	Head/Aircraft/ Mixed	Pilot 4	Head/Mixed/ Aircraft
Pilot 2	Aircraft/Head/ Mixed	Pilot 5	Aircraft/Mixed/ Head
Pilot 3	Mixed/Head/ Aircraft	Pilot 6	Mixed/Aircraft/ Head

Table 3.

Results from the present study supporting the object-layers in HUD equipped HMDs.

	Response Latencies (ms)	Incorrect Responses (%)	Missed Targets (%)
Object Layer Hypothesis (Same Trials)	No	No Aircraft < Mixed	Yes Head and Mixed < Aircraft
Object Layer Hypothesis (Different Trials)	No Head X Near > Mixed and Aircraft	Yes Head < Mixed and Aircraft	Yes Head and Mixed < Aircraft

Table 4.

ANOVA Summary Table for Reference Set X Target Location Response Latency Analysis. (Same Trials)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Reference Set	69118.537	2	34559.269	3.644	.065
Error(Reference Set)	94826.133	10	9482.613		
Target Location	62497.128	2	31248.564	3.574	.067
Error (Target Location)	87426.339	10	8742.634		
Reference Set x Target Location	16744.844	4	4186.211	.369	.828
Error (Reference Set x Target Location)	226890.598	20	11344.530		

Table 5.

ANOVA Summary Table for Reference Set X Target Location Response Latency Analysis. (Different Trials)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Reference Set	27065.943	2	13532.971	.659	.538
Error(Reference Set)	205335.639	10	20533.564		
Target Location	11807.994	2	5903.997	.891	.441
Error (Target Location)	66297.076	10	6629.708		
Reference Set x Target Location	99770.435	4	24942.609	2.180	.108
Error (Reference Set x Target Location)	228820.902	20	11441.045		

Table 6.
ANOVA Summary Table for Reference Set X Target Location Incorrect Response Analysis. (Same Trials)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Reference Set	1183.172	2	591.586	2.291	.152
Error(Reference Set)	2582.586	10	258.259		
Target Location	1101.997	2	550.998	1.638	.243
Error (Target Location)	3364.598	10	336.460		
Reference Set x Target Location	575.173	4	143.793	1.111	.379
Error (Reference Set x Target Location)	2588.200	20	129.410		

Table 7.
ANOVA Summary Table for Reference Set X Target Location Incorrect Response Analysis. (Different Trials)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Reference Set	1270.963	2	635.481	5.795	.021
Error(Reference Set)	1096.564	10	109.656		
Target Location	259.436	2	129.718	.966	.414
Error (Target Location)	1343.093	10	134.309		
Reference Set x Target Location	315.386	4	78.847	1.077	.394
Error (Reference Set x Target Location)	1464.799	20	73.240		

Table 8.
ANOVA Summary Table for Reference Set X Target Location Missed Response
Analysis. (Same Trials)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Reference Set	732.117	2	366.058	7.834	.009
Error(Reference Set)	467.289	10	46.729		
Target Location	41.193	2	20.596	.693	.522
Error (Target Location)	297.129	10	29.713		
Reference Set x Target Location	157.748	4	39.437	1.723	.184
Error (Reference Set x Target Location)	457.710	20	22.886		

Table 9.
ANOVA Summary Table for Reference Set X Target Location Missed Response
Analysis. (Different Trials)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Reference Set	1118.095	2	559.047	22.167	.000
Error(Reference Set)	252.197	10	25.220		
Target Location	460.718	2	230.359	4.476	.041
Error (Target Location)	514.709	10	51.471		
Reference Set x Target Location	547.136	4	136.784	3.146	.037
Error (Reference Set x Target Location)	869.476	20	43.474		

Table 10.

Mean Response Latencies and Standard Deviations for The Reference Set by Target Location Interaction. (Same Trials)

	Head Reference			Mix Reference		
	Near	Middle	Far	Near	Middle	Far
Mean (ms)	1210	1308	1210	1291	1308	1287
St. Dev	66	82	148	104	151	114

	Aircraft Reference		
	Near	Middle	Far
Mean (ms)	1178	1274	1174
St. Dev	78	49	129

Table 11.

Mean Response Latencies and Standard Deviations for the Reference Set by Target Location Interaction. (Different Trials)

	Head Reference			Mix Reference		
	Near	Middle	Far	Near	Middle	Far
Mean (ms)	1389	1224	1280	1263	1295	1233
St. Dev	164	82	130	50	137	135

	Aircraft Reference		
	Near	Middle	Far
Mean (ms)	1286	1312	1356
St. Dev	69	148	158

Table 12.

Percent Incorrect Error Rates and Standard Deviations for Reference Set by Target Location Interaction. (Same Trials)

	Head Reference			Mix Reference		
	Near	Middle	Far	Near	Middle	Far
Mean (%)	29	42	31	28	44	39
St. Dev	14	8	19	19	14	25

	Aircraft Reference		
	Near	Middle	Far
Mean (%)	28	30.	20
St. Dev	14	14	23

Table 13.

Percent Incorrect Error Rates and Standard Deviations for Reference Set by Target Interaction (Different Trials)

	Head Reference			Mix Reference		
	Near	Middle	Far	Near	Middle	Far
Mean (%)	9	16	9	19	17	17
St. Dev	7	20	9	5	9	13

	Aircraft Reference		
	Near	Middle	Far
Mean (%)	27	25	17
St. Dev	10	13	6

Table 14.

Percent Missed Responses and Standard Errors for Reference Set by Target Location.
Interaction (Same Trials)

	Head Reference			Mix Reference		
	Near	Middle	Far	Near	Middle	Far
Mean (%)	3	2	1	2	3	1
St. Dev	4	3	3	5	6	3

	Aircraft Reference		
	Near	Middle	Far
Mean (%)	6	12	12
St. Dev	5	5	11

Table 15
Percent Missed Responses and Standard Errors for Reference Set by Target Location
Interaction. (Different Trials)

	Head Reference			Mix Reference		
	Near	Middle	Far	Near	Middle	Far
Mean (%)	2	2	7	2	2	1
St. Dev	5	3	5	3	3	3

	Aircraft Reference		
	Near	Middle	Far
Mean (%)	9	6	22
St. Dev	8	5	12

Figure 1.
A typical aircraft referenced Heads-Up Display

Honeywell/GEC Marconi's HUD 2020

Figure 2

Displays used in experiment 1 of Duncan (1984). (Top left, Main task: small box with gap on right, dotted line with tilt. Top right, large box with gap on left, dashed line tilted counterclockwise. Bottom left: stimuli used to determine exposure duration for participants. Bottom right, mask.)

Figure 3

Example of the moving targets and distracter letters in the Driver & Baylis (1989) experiments. This image shows both the proximal and distal moving stimuli.

Figure 4

NATO TTCP2 symbology reference (the words and the large white circle do not appear in the real symbology). This image depicts the fixed TTCP2 symbology reference as it would appear to the pilot with the symbology fully centered in the helmet (aircraft reference). The head-referenced symbology would appear the same, regardless of head position.

Figure 5

The Mixed-Referenced TTCP2 reference. Note how the circled symbologies remain fixated to the pilots' forward field-of-view during off-axis head positions.

Figure 6
The N-Vision HUD equipped HMD

Figure 7

Picture of participant wearing the HUD equipped HMD, gripping the cyclic with his right hand and the collective with his left.

Figure 8

Map of Flight-Environment showing the participants helicopter placed on the airport at the center of the map. Note the blue target ellipse to the left of center and the four major sights of interest at each corner of the map.

Figure 9

The flight environment as viewed in the left display. Note the symbology reference overlaying the external scene.

Figure 10

Picture of the simulator monitors. The pilots view is displayed on the terminal to the right while the virtual environment was controlled by the left terminal.

Figure 11.

This image shows an example one of the sights of interest around which participants could maneuver the helicopter (The Town).

Figure 12

The airport starting location showing the blue ellipse to the centre left of the screen.

Figure 13

Various target combinations in the target discrimination task. Note that all combinations of target circles (near, middle and far) appear in the upper left, upper right, and bottom images respectively.

Figure 14. Mean Response Latencies for the Target Location (near, middle far) by Type of Reference Set (Head, Mixed, Aircraft). (Same Trials)

Note: 95 % Confidence Interval: 90.7

Figure 15. Mean Response Latencies for the Target Location (Near, Middle, Far) by Type of Reference Set (Head, Mixed, Aircraft) Interaction. (Different Trials)

Note: 95% Confidence Interval ± 91.09

Figure 16. Percent of Incorrect Responses for Target Location by Type of Reference Set Interaction. (Same Trials)

Note: 95% Confidence Interval ± 9.69

Figure 17. Percent of Incorrect Responses for the Target Location by Type of Reference Set Interaction. (Different Trials)

Note: 95% Confidence Interval ± 7.29

Figure 18. Percent of Missed Responses for the Target Location (Near, Middle, Far) by Type of Reference Set (Head, Mixed, Aircraft) Interaction. (Same Trials)

Note: 95% Confidence Interval: ± 4.07

Figure 19 Percent of Missed Responses for the Target Location (Near, Middle, Far) by Type of Reference Set (Head, Mixed Aircraft) Interaction. (Different Trials)

Note: 95% Confidence Interval: ± 5.62