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Attention Factors Associated With Head-Up Display and Helmet-Mounted Display Systems

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This report is a review of human attention research literature relevant to head-up display (HUD) and helmet-mounted display (HMD) systems in use or under development for rotary-wing aircraft. The fundamental attentional issue for HUDs and HMDs is division of attention between the outside-the-window scene and the displayed symbology. Selective attention applies more to elements within the HUD or HMD symbology. The review identified a number of areas for further research. These are (a) effects of dichoptic viewing, (b) eye dominance, (c) identification of strategies for effective time-sharing, (d) HUD and HMD training, and (e) pilot selection.

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ATTENTION FACTORS ASSOCIATED WITH HEAD-UP DISPLAY AND HELMET-MOUNTED DISPLAY SYSTEMS

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Introduction

More than thirty years of research and application of head-up display (HUD) and, more recently, helmet-mounted display (HMD) technologies have witnessed disputes within the aviation community concerning these devices' operational effectiveness, safety, and user acceptance. HUDs and HMDs provide the means of presenting virtual images of cockpit instruments superimposed on the external world. These images may be either the direct vision, out-the-window (OTW) scene (as illustrated in Figure 1), or the output of imaging systems such as cameras or infrared sensors. Both the HUD and HMD present instrument displays collimated to optical infinity in the pilot's forward field of view. The collimated image is designed to appear to be at optical infinity--that is, at the same apparent distance as the real-world OTW scene.

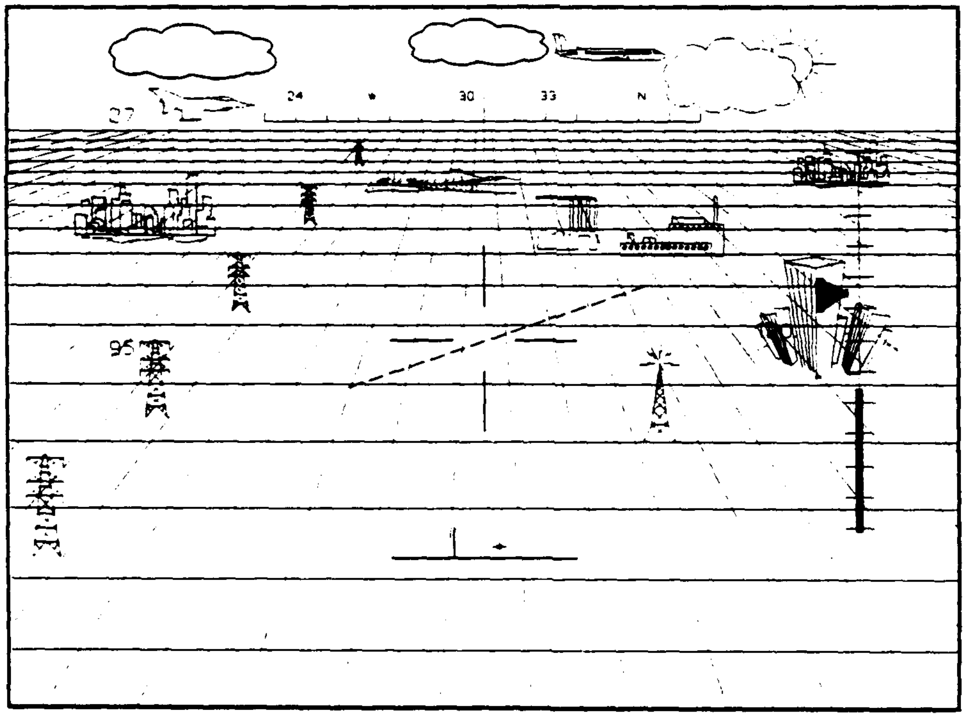


Figure 1. An illustration of HUD symbology superimposed on an out-the-window view. Grid lines do not appear in the HUD display.

The HUD typically generates the virtual image at or near the windscreen; the HMD generates the virtual image in components mounted on the aviator's helmet. The HMD generally presents the instrument symbology to only one eye, as in the AH-64 Integrated Helmet and Display Sight System (IHADSS). The HUD's and HMD's intention is to permit the pilot to monitor essential flight information without having to look down at the cockpit instrument panel.

Although both these virtual imaging systems are being incorporated into a wide variety of military aircraft (Roscoe, 1987a), they have been the object of vigorous support (e.g., Weintraub, 1987; Weintraub, Haines & Randle, 1984) and troubled doubts (e.g., Iavecchia, Iavecchia, & Roscoe, 1988; Roscoe, 1987a,b). Problems identified with HUDs have been disorientation (Barnette, 1976); misjudgments of apparent size, distance, and angular direction of terrain features associated with instrument myopia (Iavecchia, Iavecchia, & Roscoe, 1988: Roscoe, 1987b); and degraded detection of critical events (Weintraub, Haines & Randle, 1985) and targets at optical infinity (Norman & Ehrlich, 1986). These problems are reviewed in detail by Grubb and Ruffner (in preparation).

Research to date has been dominated by investigations into the specific perceptual and performance problems created by virtual imaging systems. Much less of the research has been aimed at finding ways to reduce or compensate for the visual and cognitive sources of these problems. This review examines the cognitive psychology, information processing, and individual differences literature for indications of possible improvements in HUD and HMD implementation and use. Although no ready-made solutions are hidden in existing research, a number of promising directions for evaluation and exploratory research have been uncovered.

Issues

The nature of the optical effects of virtual image displays has now been well documented (Grubb and Ruffner, in preparation). However, the cognitive and perceptual aspects of simultaneously attending to the symbology and OTW scene have become focal points of our research. Issues currently under investigation by researchers interested in HUDs may be categorized broadly as (a) whether the combined HUD and OTW image evokes serial or parallel processing of the total visual array, and (b) how spatial and object perception affects the processing of information from the combined HUD and OTW image. Examples of investigations that define these two issues are discussed in the following section.

Parallel vs. serial processing. The conventional cockpit imposes serial processing of instruments and the external world by virtue of the pilot having to visually scan and focus attention either on the instrument panel or OTW. Parallel (simultaneous) processing of instrument and OTW information is made physically possible by superimposing the symbology on the OTW scene. Researchers have attempted to determine whether parallel processing implicit in the HUD concept is realized in practice. Parallel processing of information is closely associated with sharing attention among the diverse perceptual elements of the overall visual array.

The potential of parallel processing of overlapping information sources has been investigated with HUD-associated aviation tasks and more general information processing tasks. Typical of the first type of investigation is a study by Foyle, Sanford, and McCann (1991), in which subjects flew a simulated slalom course under conditions that included (a) HUD altitude readings present or absent and (b) buildings present or absent. The ground was represented by a grid pattern, and small pyramids denoted the flight paths. The task was to fly a flight path (i.e., follow the pyramids) at an altitude of 100 feet.

The buildings-present condition provided altitude references integral with the external world. On the other hand, the HUD provided altitude information as part of a perceptual object separate from the external world view. Performance differences were predicted to hinge on whether parallel processing of altitude information would be better for the external (building-referenced) or the internal (HUD-referenced) source.

The HUD condition resulted in better maintenance of altitude but at the cost of larger deviations from the prescribed flight path, supporting a similar finding by Brickner (1989). However, the buildings-present condition also resulted in improved altitude maintenance, but without concomitant increases in flight path errors. The results support the conclusion that parallel processing was not occurring with the attentionally segregated HUD and external scene.

This failure to find parallel processing with superimposed attentional objects is consistent with the results of a frequently cited study by Neisser and Becklen (1975). Their study presented subjects with two superimposed (i.e., completely overlapping) videotapes, each depicting different kinds of events. Subjects were required to signal the occurrence of significant events in one, the other, or both videos. Subjects could do so effectively only by attending to one, but not both, of the videos. However, in a recently published study, Stoffregen and Becklen (1989) used the same experimental dual-task paradigm to demonstrate that subjects could attend to two videos (one showing a three-man basketball game and the other an actor's face animated with various expressions).

In the Stoffregen and Becklen (1989) study, detection of target events in both videos significantly improved over two days of practice. Correct detections reached 75% when the targets were all visual or all auditory in both videos. Detections improved to 89% in a cross-modal condition in which visual cues were attended to in one video and auditory cues in the other (attending to redundant auditory and visual target stimuli in both videos did not further improve detections). Maximum detections attained in control subjects who viewed one film only reached 90% and 93% for the unimodal and cross-modal conditions, respectively.

To what do Stoffregen and Becklen (1989) attribute this demonstration of parallel processing of both videos? First, they note that the natural events in their videos have familiar temporal sequences: a ball toss and a particular facial expression each has characteristic anticipatory movements. Subjects presumably could use cues based on familiarity with the dynamics of target events to schedule their attentional shifts and focus on the scene with the highest potential of a target event occurring. Secondly, Stoffregen and Becklen gave their subjects extensive practice in the target detection dual-tasks. On Day 1 of practice, subjects were performing at the same level as the subjects in the hallmark Neisser and Becklen (1975) study. On Day 2, however, subjects improved to the point that they were performing at or close to asymptotic levels.

Other research discussed later in this review will underscore the importance of two determinants of performance in multiple-task, divided attention situations. One such determinant is the marshalling and use of attentional strategies, which coordinate experience-based perceptual and cognitive skills. The other is situation-specific practice in a given multiple-task situation.

Spatial vs. object perception. Current thinking about the limitations in the ability to see several things at once (and then report about them) is divided between spatial-based and object-based theories of visual attention.

Spatial-based theories are based on the notion that attention is focused only on a small area of visual space. Full perceptual analysis can be performed within this "visual spotlight," which frequently is regarded as having a visual angle of about 1° of radius or is adjustable outward from that value to some degree (Johnston & Dark, 1986).

Object-based theories, on the other hand, attribute limitations in visual attention to the number of separate objects that can be seen. One such theory is that of Neisser (1967), who proposed a two-stage process. The first stage, referred to as preattentive, partitions the visual scene into separate objects based on Gestalt properties such as continuity of contour, and common color or shape. The second stage, focal attention, analyzes a particular object in more detail. Parallel processing is thought to occur in the preattentive stage and serial processing in the focal attention stage.

Until recently, spatial and object attention theories considered attention in only two-dimensional space. Previc (1989), however, proposed a theory of three-dimensional spatial attention and applied it to HUD design considerations. His analysis revealed that the two dimensions of the frontal visual plane are processed as separate quadrants. He proposed that attention is facilitated by placing related information elements into a single quadrant. This arrangement results in the information being processed in one "attentional glance." The third dimension of visual attention is near and far space, corresponding to personal and extrapersonal visual space, respectively. The perceptual analysis of far visual space benefits from brain mechanisms for perceiving highly detailed images.

Previc (1989) claimed that, for most individuals, processing of far visual events is biased towards the upper quadrants, especially the upper right hemifield. "This feature of our visual system strongly implies that the most important alphanumeric information on the HUD display (i.e., altimeter readings) should be placed in its upper right quadrant, since the pilot will ideally be attending to the distant OTW environment when viewing the HUD" (p. 2). Other information, including attitude displays, should be positioned to make use of near vision. Near vision capabilities are global in character; that is, near vision is spatially distributed and tolerant of various forms of image degradation. Therefore, HUD information presented in the lower quadrants should capitalize on images and forms consistent with global perception characteristics.

Previc's (1989) provocative ideas are aimed at resolving two aspects of HUD design: where to position information requiring detailed focal processing and where (and how) to convey spatial orientation (attitude) information. Previc conceded, however, that:

> many HUD tasks cannot be performed preattentively and in parallel [using near vision], including those requiring identification of letters and digits, or fine orientation discriminations. Still, it would be advisable in these cases to present only one digit or fine analog readout per HUD quadrant to maximize the efficiency of the pilot's focal attention resources. (p. 12)

In other words, those HUDs improved using Previc's guidelines still require dividing attention among various elements of the display. Individual display elements need to be monitored and associated with outside events or models of the state of the aircraft. Although Previc's ideas significantly contribute to HUD design from the perspective of spatial and object perception, they do not resolve the issues associated with focused and divided attention. Moreover, it is unclear how Previc's guidelines apply to symbology that is presented to one eye, as is the case with the HMD.

This review examines the attention literature to ascertain under what conditions individuals are able to divide attention between tasks and among complex visual arrays. Laboratory findings in focused and divided attention may suggest new avenues for HUD and HMD research. Individual differences in attentional abilities have not yet been examined, and they may represent a significant variable in performance differences of pilots using HUDs and HMDs. Therefore, this review examines what is known about individual differences in attention and how these findings relate to HUD and HMD use. This review also explores the attentional and cognitive information processing implications of presenting symbology to one eye. What is known about processing binocular information from the HUD may not be able to be generalized to the dichotic situation provided by the HMD.

Attention

HUDs and HMDs present visual processing requirements that call on complementary aspects of attentional processes. Processing inputs from the OTW scene and the flight data symbology can be said to require dividing attention between the two. In this discussion, focused attention (also referred to as selective attention) refers to processes associated with a selected portion of visual space. Focused attention entails processing of spatial relations and objects of perception, and implies a selection of elements or object dimensions for the area under scrutiny. Attention to features within a HUD or HMD display might best be understood from a focused attention perspective.

Divided Attention and Time-Sharing

Divided attention refers to an individual's ability to switch attention between different sources of stimulation, different aspects or characteristics of complex stimuli, or different tasks performed concurrently. The ability to perform multiple tasks in combination is frequently referred to as time-sharing ability (Ackerman, Schneider, & Wickens, 1984).

In recent years, the dual-task performance paradigm has been used to explore various theoretical and applied problems associated with divided attention. Among the theoretical issues is the nature of attentional resources; that is, whether attentional capacity is a unitary or multidimensional resource. Examples of practical issues that have been explored with the dual-task paradigm are the nature of operator workload and the design of complex multi-task work environments, such as those found in aircraft cockpits.

With respect to multitask work environments, Wickens, Mountford, and Schreiner (1981) pointed out four approaches to achieving efficiency in dual-task performance:

1. Training of individuals to obtain a high degree of proficiency in time-sharing.

2. Configuring systems in such a way that operators simultaneously perform tasks that can be efficiently shared, but serially perform task combinations whose dual-task efficiency is low.

3. Configuring the relative location of task controls and displays in such a way that time-sharing efficiency will be maximized.

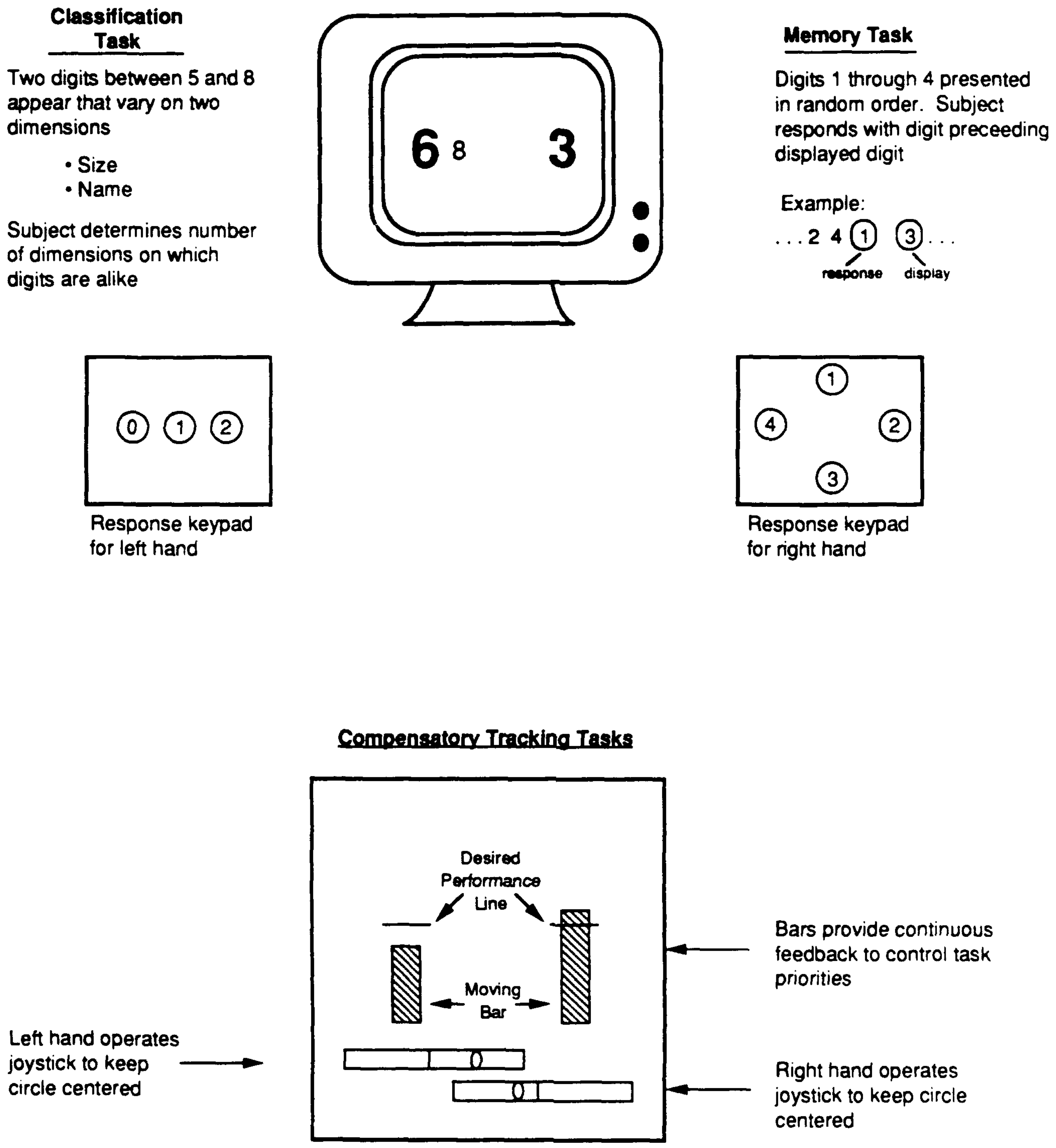
4. Judicious selection of individuals who are relatively more competent to perform in time-sharing environments.

The first two approaches suggest themes that will be used in the following examination of the attention literature relevant to HUD/HMD issues. The third approach is not discussed in this review. The fourth approach (personnel selection) is covered in a subsequent section.

A study conducted by Damos and Wickens (1980) provides a good example of the procedural details of a laboratory-oriented dual-task situation. In addition, the study reports evidence of the existence of time-sharing skills. The purpose of the experiment was to ascertain whether (a) distinct time-sharing skills develop in different task combinations, (b) specific time-sharing skills, such as parallel information processing or intertask switching, can be identified, and (c) general time-sharing skills exist that will transfer among complex tasks that do not share common elements.

The study used discrete information processing tasks and identical compensatory tracking tasks. One of the information processing tasks was a classification task that required the subject to determine whether two displayed digits varied on two dimensions: size and name. The subject determined the number of dimensions on which the two digits varied and then pressed one of three keys. The second information processing task was a short term memory task that involved randomly selected digits (between 1 and 4) presented sequentially to the subject. The subject committed the presently displayed digit to short term memory and identified the value of the most recently presented digit. Responses were made on a four-choice keyboard. Both tasks were self-paced such that a new stimulus did not appear until the subject made a response. These two tasks, simultaneously presented on a computer screen as shown in the upper portion of Figure 2, constituted one dual-task situation.

The compensatory tracking task required subjects to keep a moving circle centered in a horizontal track by making appropriate left-right manipulations on a joystick. Two displays (together with a feedback feature) were presented on a computer screen. Subjects' compensatory corrections to the deviation of the circle from the desired target point were input through joysticks controlled by the left and right hands. One joystick corrected one display, and the other joy-stick corrected the second display. Dual-task compensatory tracking is depicted in the lower portion of Figure 2.



Classification Task

Two digits between 5 and 8 appear that vary on two dimensions

- Size
- Name

Subject determines number of dimensions on which digits are alike

Memory Task

Digits 1 through 4 presented in random order. Subject responds with digit preceeding displayed digit

Example:

...2 4 ① ③...

Response keypad for left hand

Response keypad for right hand

Compensatory Tracking Tasks

Bars provide continuous feedback to control task priorities

Left hand operates joystick to keep circle centered

Right hand operates joystick to keep circle centered

Figure 2. Examples of tasks used in a dual-task experiment.

For both the discrete information processing tasks or compensatory tasks, a dual-task condition required the subject to perform two tasks in combination. The identification of a task specific time-sharing skill was made by comparing tasks performed singly with those tasks performed in combination. The existence of a general time-sharing skill focused on a transfer condition that presented dual-task compensatory tracking after practice on dual-task information processing.

Task specific time-sharing ability was demonstrated in both the information processing and compensatory tracking dual-task situations. Dual-task performance improved over trials, whereas performance on the tasks performed singly remained stable. The most effective response strategy in both dual-task situations was rapid (less than 99 msec) responding to stimulus onset, referred to as the simultaneous strategy. Less effective strategies (revealed by higher interresponse intervals) were strategies of (a) alternation between tasks and (b) massing responses to one task before switching to the other.

Transfer of a general time-sharing ability was demonstrated for the group that practiced the information processing dual-task prior to completing trials on dual-task compensatory tracking. Because no common structural elements existed between the information processing and compensatory tracking situations, Damos and Wickens (1980) concluded that a general time-sharing ability developed under the information processing condition. Subjects who completed the information processing tasks singly, rather than in combination, demonstrated negligible transfer.

In discussing their results, Damos and Wickens (1980) emphasized the importance of selecting task combinations such that time-sharing skills make a significant contribution to performance.

> Simply requiring two tasks to be performed "concurrently" does not insure that timesharing skills will contribute significantly to multiple-task performance .... It may be presumed that the inputs to the two tasks must be statistically uncorrelated and that the response selection and execution stages of the two tasks can not be integrated. If either of these two conditions is not met, the subject may be able to combine the tasks and reduce the processing load to a single-task rather than a multiple-task level. Task combinations which require timesharing skills also should show a performance decrement when compared to single-task levels of performance indicating that the tasks have not been integrated and that there is some time pressure on the subject to perform the task. (p. 20)

Other investigators are divided on the issue of whether a general time-sharing ability exists. Fogarty found a time-sharing ability for selected tasks in one study (Fogarty & Stankov, 1987), but could not find such a factor based on a broader range of complex cognitive tasks drawn from the psychometric (i.e., intelligence testing) domain (Fogarty, 1987). In an analytically oriented review of the time-sharing issue, Ackerman, Schneider, and Wickens (1984) reexamined some of the key experimental studies in time-sharing. Their assessment of these studies is summarized in Table 1.

Three of the four studies that Ackerman, Schneider, and Wickens (1984) reviewed could not be used to support the notion of a general time-sharing ability. However, they concluded that the correct methodological approach for future investigations of a general, time-sharing ability will rely on (a) a model of time-sharing ability (either theirs or some other) and (b) adherence to guidelines on the use of multivariate techniques.

Whereas recent discussions have explored the admissibility of time-sharing as a general, trans-situational ability, many other studies have demonstrated the emergence of specific time-sharing skills in dual-task situations. Allport, Antonis and Reynolds (1972) demonstrated that subjects could shadow prose heard through earphones (i.e., repeat what they heard), while at the same time sight read music and play the piano. In the same vein, Shaffer (1975) reported a subject who could shadow text or letters while typing. Evidence for the capacity to read text while writing lists of dictated words was provided by Spelke, Hirst, and Neisser (1976) and Hirst, Spelke, Reaves, Caharack, and Neisser (1980).

In addition to demonstrating the ability of individuals to perform complex information processing tasks concurrently, these studies also point out the role of practice in attaining effective dual-task performance. To reach pre-experimental reading criterion in their reading-writing dual-tasks, Spelke, Hirst et al. provided between 30 to 50 hours of practice to their subjects. In contrast, Allport et al. showed acceptable piano playing scores in their music student subjects after ten minutes of practice in shadowing. These studies, together with those of Damos and Wickens (1980) and Damos, Bittner, Kennedy, and Harbeson (1981), all report that dual-task performance improves over trials.

The sensitivity of dual-task performance to practice effects has led some investigators to interpret time-sharing as an acquired skill, rather than as ability (e.g., Hirst & Kalmar, 1987). Within this framework, Schneider and Detweiler (1988) reviewed the evidence that attaining criterion on single-task performance does not result in immediate dual-task proficiency. Despite single-task proficiency, dual-task effectiveness requires training that generally produces substantial performance improvements. They propose a connectionist/control architecture model that predicts that as a skill is acquired, performance progresses through five stages. Dual- or multi-task performance results from a qualitative change in processing. This is a recent model, however, and has not yet received empirical verification.

Table 1

Summary of Ackerman, Schneider, and Wickens (1984) Critical Review of Significant Time-Sharing Ability Articles

Article	Limitations	Conclusions
Jennings & Childs (1977)	Poor reliability of performance measures	Report of no time-sharing ability based on faulty analysis
	Low subjects/variables ratio	
	Significant practice effects	
	Arbitrary number of factors and incorrect rotation approach for factor analysis	
Sverko (1977)	Failure to examine performance trade-offs between dual-tasks	Report of no time-sharing ability based on faulty analysis
	Inappropriate use of principle components analysis and difference scores	
Hawkins, Rodriguez & Reicher (1979)	Correlations between single and dual-task combinations not reported. Single-task abilities were therefore not assessed against dual-task ability reported	Individual differences in single tasks probably account for time-sharing ability
Wickens, Mountford & Schreiner (1981)	Number of factors and rotation in factor analysis inappropriate	Reanalysis of data revealed significant loading on a dual-task factor. General time-sharing ability supported.
	Use of difference scores between single- and dual-task measures supported	

Support for the trainability of a time-sharing strategy involving visual scanning was provided by Gabriel and Burrows (1968). They addressed the problem of dividing attention between instruments inside the cockpit and the outside scene, a problem that is very similar to a central issue in HUD usage. Their research involved determining pilots' individual scanning patterns and then using adaptive training techniques to decrease instrument scanning time and to increase outside scanning time. The technique was effective in increasing pilots' detection of targets outside the cockpit without concomitant decreases in the quality of flight control or of detecting out-of-tolerance instrument readings.

In contrast to time-sharing viewed as a skill, the predominant current theoretical position is that time-sharing is a manifestation of capacity or resources allocation. Capacity and resource theories have both predictive and explanatory power that earlier attention theories were incapable of addressing. Theories from thirty years ago about attention did not recognize individuals' ability to process multiple inputs or perform multiple tasks concurrently. Broadbent, who is credited with resurrecting attention research (Lachman, Lachman, & Butterfield, 1979, p. 183), equated attention with consciousness, which can handle only one input at a time. The contents of consciousness were controlled by a system that permitted all incoming sensory information to be placed into short-term storage. A filter selectively admitted a portion of the short-term store into the limited capacity perceptual system. Broadbent's filter theory postulated reception of a great deal of information received in parallel, but only the transmission of information into further processing that fulfilled specified requirements (through so-called "tuning" of the filter). Information on that channel entered consciousness, where it was subjected to serial processing, but information left in the store was lost unless processed within seconds of reception.

Treisman (1964) revised Broadbent's filter theory and presented evidence that the meaning of to-be-attended material determined what was admitted to consciousness (i.e., meaning was the basis of filter tuning). Alternative theories of Deutsch and Deutsch (1963), Norman (1968), and Neisser (1967) postulated that parallel processing occurred in later stages of the perceptual system, but that conscious processing still remained limited to one channel, capacity, or analyzer. The admission that preconscious processing occurs paved the way for the view that attention could be thought of as processing capacity coupled with conscious processing (Lachman, Lachman, & Butterfield, 1979).

Development of resource theory was advanced by the publication of Kahneman's theory of effort (Kahneman, 1973). In his view, attention is a limited resource that can be flexibly allocated. Allocation is determined by enduring dispositions (e.g., always attend to one's own name), momentary dispositions (e.g., concentrate on reading this paragraph and ignore the conversation in the hall), and the difficulty of performing a given task. Kahneman's theory provided an explanatory framework for both task interference and time-sharing with its postulate that "... the ability to respond to simultaneous inputs should depend primarily on the demand of activities among which attention is to be divided" (p. 148).

At the same time that Kahneman published his theory, Treisman and Davies (1973) proposed that stimulus features may be processed in structures called analyzers. Implications of this theory of attention are as follows:

a. Responding to the same dimension of various objects is hard, whereas responding to various features of the same stimulus is easy.

b. Dividing attention among stimuli in the same modality is more difficult than dividing attention between stimuli in different modalities.

c. Each analyzer functions as a single channel in which processing is serial. Different analyzers can function in parallel.

Treisman and Davies (1973) showed that monitoring two auditory or two visual messages was more difficult than monitoring one auditory and one visual message. Allport, Antonis and Reynolds (1972) found difficulty in monitoring two auditory messages, but they found effective division of attention between auditory shadowing and sight reading. More recent investigations of this theory are discussed in the section on focused attention.

In taking stock of divided attention research and theorizing, Navon and Gopher (1979) observed that in the same way that researchers had abandoned the single channel theory in favor of a single pool theory of attentional resources, a more refined view is that multiple resources are available for information processing:

> Not only can the processing system as a whole be involved in several activities in variable proportions but a specific mechanism or modality is not necessarily dominated by one process exclusively but instead can accommodate more than one process at the expense of quality or speed of performance. In other words, resources may not be homogeneous because the human system is probably not a single-channel mechanism but rather a complicated system with many units, channels, and facilities. Each may have its own capacity (which is, roughly, the limit on the amount of information that can be stored, transmitted, or processed by the channel at a unit of time). Each specific capacity can be shared by several concurrent processes; thus it constitutes a distributable resource. Different tasks

> may require those different types of resources in various combinations. (p. 233)

What these resources might be and how dual-task situations can be constructed to demonstrate multi-task facilitation and interference has been undertaken by Wickens and his associates (Wickens, 1980, 1984a, 1984b, 1991; Wickens, Tsang, & Pierce, 1985). Their multiple resource theory in its original formulation postulates that the capacity to perform tasks may be defined by three dichotomous dimensions. "There are two stage-defined resources (early versus late processes), two modality defined resources (auditory versus visual encoding), and two resources defined by processing codes (spatial versus verbal)" (Wickens, 1984a, p. 302). These are illustrated in Figure 3.

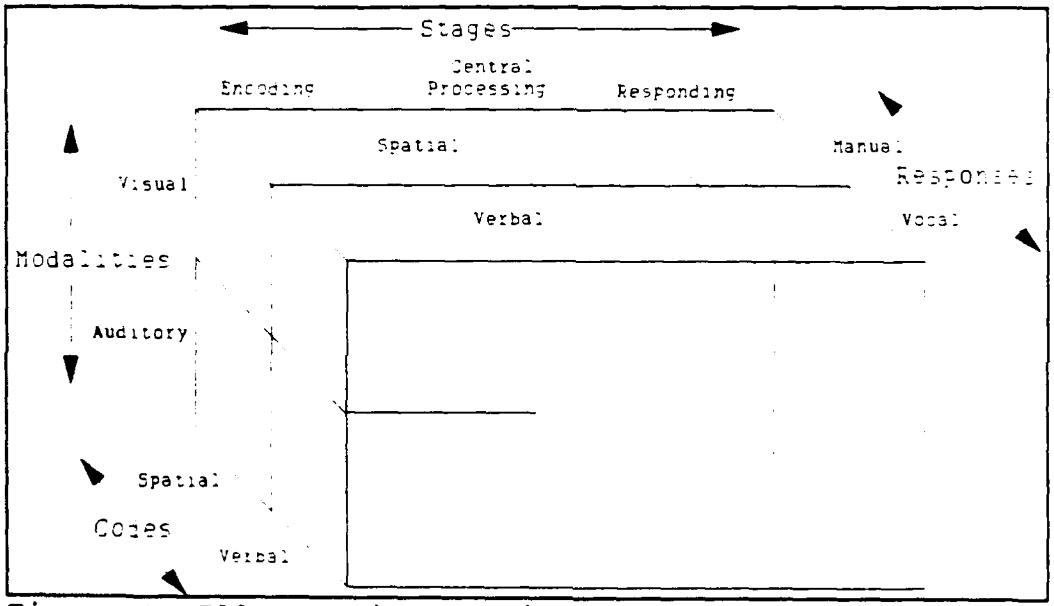


Figure 3. Illustration of Wickens' Multiple Resource Theory (from Wickens, 1984a).

The first dimension, stage, posits that perceptual and other cognitive processing draws on one resource pool that is functionally separate from resources associated with response generation. Evidence to support this claim has been shown with experiments that manipulate response difficulty without impact on a concurrent task that is more cognitive or perceptual in nature. The reverse has also been demonstrated (Wickens, 1984b).

The second dimension, modality, refers to the effects of intermodal reception of information or the generation of responses. Information received through different modes (auditory and visual) is more effectively processed than information received intramodally. Likewise, greater time-sharing efficiency has been shown in tracking tasks that used vocal as opposed to manual responses for a concurrent discrete task (Wickens, 1984b). Recently, Wickens (1991) has questioned whether the stimulus input aspect of the modality dimension should rightly be considered in resource terms. Task structure or other interference effects might be a more correct interpretation.

The final dimension, codes of perceptual and central processing, refers to the dichotomy between the processing of verbal and visuo-spatial material. This dichotomy is related to the specialization of functions between the left and right hemispheres. Discussion of this phenomenon and the implications for dual-task performance is provided in a separate section.

To the extent that tasks demand separate, rather than common resources, the following implications may be made (Wickens, 1984a,b):

1. Time-sharing will be more efficient.

2. Changes in the difficulty in one task will be less likely to influence performance on the other (referred to as difficulty insensitivity), and

3. Resources withdrawn from the performance of one task cannot be used to support the performance of another.

Damos (1991) recently reviewed the characteristics of dual-tasks and alternative configurations of the dual-task paradigm. Six characteristics are presented in Table 2, along with generalizations about dual-task performance in comparison with single-task performance drawn from the research literature. These generalizations are applicable to HUD and HMD experiments that use the dual-task paradigm.

Researchers interested in time-sharing generally design their experiments to specifically disallow information exchange between the tasks. However, the dual-task paradigm has provided the opportunity to determine the effects of stimulus or response cross-over between the two tasks. Damos (1991) unintentionally found task integration in a situation involving two choice reaction time tasks. Subjects responded to the digits 1 through 4 with the left hand and the digits 5 through 9 with the right. With practice, time-sharing appeared to be perfect. However, on closer examination, the subjects were found to be responding to a combined stimulus (e.g., "15") with a two-handed response.

An example of intentional cross-over between two tasks in a dual-task paradigm is provided by Goettl and Wickens (1989). The purpose of the experiment was to demonstrate that multiple resource model prescriptions for use of separate resources might not optimize performance that requires information integration. To examine this issue, perceptual and central processing aspects of a classification task were varied by presenting four types of discrete stimuli: visual-spatial (arrows), auditory-spatial

Table 2

Six Characteristics of Dual Tasks and Their Relationship to Dual-Task Performance (Adapted from Damos, 1991)

Characteristics	Alternative configurations	Experimental results	Comments
Number of Stimuli	Two - Physically Separated	Dual tasks performed less effectively than single tasks	
	Two - Superimposed	Dual tasks performed less effectively than single tasks	
	One - Shared	No dual-task decrements	
Stimulus Modality	Same Different	Stimuli using different modalities result in better dual-task performance	Tasks performed in combination still reveal a decrement as compared to tasks performed singly
Correlation between Stimuli	0.0 (Independent) to 1.0 (Dependent)	Values of stimuli in one task that inform about stimulus values in the second task appear to result in better dual-task performance	Few experiments have explored this characteristic, and contradictory results have appeared
Central Processing	Independent	Dual-task decrements generally obtained	
	Correlated	See Correlation between Stimuli above	
	Integrated	Inconclusive results of using information from one task to perform another task	See Goettl & Wickens (1989) experiment description on p. 15 of this report
Number of Response Channels	Two - Separate	Using separate responses (e.g., left and right hand) for each task impairs dual-task performance	Infrequent responding in one response system improves dual-task performance
	One - Shared	Using one response system eliminates dual-task impairments	Research limited to dual-axis tracking studies. Other tasks not examined.
Response Modality	Different or Same	Different response modalities (e.g., hand and speech) results in better dual-task performance.	Tasks performed in combination still reveal a decrement as compared to tasks performed singly

(tones), visual-verbal (text), and auditory-verbal (speech). All four types of stimuli referenced the directions of up, down, left, and right. The concurrent tracking task required the subject to keep a cursor on a cross on the center of the display screen. Four crosses equally spaced on an imaginary circle surrounded the center cross. For the integration condition, the discrete task provided essential information for the tracking task. Once a subject had performed a classification of the discrete stimuli, he or she momentarily moved the cursor to one of the four peripheral crosses in the tracking display. The correct peripheral cross corresponded to one of the four directions provided in the classification task. For the dual-task condition, the two tasks were independent (i.e., no information sharing). With respect to the act of responding, the integration condition placed the response controls (joystick and classification response trigger) in the right hand in contrast to the dual-task condition that divided response controls between both hands.

The multiple resource model predicts that auditory cues and verbal central processing would yield superior total task performance, whereas an integration model predicts that visual cues and spatial central processing would result in superior total task performance. With respect to stimulus code, better classification performance was shown for verbal codes (text and speech) than was shown for spatial codes (arrows and tones) as the tracking task (a predominantly spatial task) was performed. This was true for both the dual-task and integration conditions. These results support the multiple resource model. If the stimulus type is not considered, an advantage was found for the integration condition. When compared to the dual-task condition, the integration condition showed less decrement as two tasks were performed concurrently as compared to separately.

With respect to response integration (single- as compared to two-handed responding), the integration condition resulted in better performance on the classification task if responses were made with one hand. The dual-task condition (independent tasks) revealed the reverse. That is, classification performance was superior when responses were divided between two hands.

Recently, researchers have begun to look at individual differences with respect to task integration. These developments are discussed in the section on individual differences.

Selective Attention

Discussions of theoretical and empirical issues of attention differentiate between divided and selective (focused) attention, a distinction that emphasizes different aspects of how attention is allocated to information processing and response demands. However, these discussions of attention generally emphasize either divided or selective attention, and not the interplay of both in skilled performance.

Divided attention, as we have seen in the previous section, relates to the deliberate allocation of attention to separable stimulus, central processing, and response components of multiple tasks. The degree of component separation determines such performance phenomena as time-sharing and multicomponent coordination. On the other hand, selective attention encompasses the processes and phenomena associated with attending to a delimited area of space or a related set of perceptual elements of the total attentional space. Selective attention is concerned with perceptual issues relating to objects and space (e.g., stimulus features, expectancies, cuing) and stages of information processing that determine single-task performance.

The examination of selective attention that follows is drawn largely from a review by Johnston and Dark (1986). Their approach to reviewing the selective attention literature was to formulate a number of generalizations that appear to be supported by converging empirical results. They also evaluated the two major theoretical positions in selective attention for their capacity to accommodate these generalizations.

Taking their lead from a distinction made by the nineteenth century psychologist William James, Johnston and Dark (1986) describe two categories of selective attention theory--cause theories and effect theories--which have not changed substantially in a hundred years.

Cause theories stipulate two domains of processing of stimulus inputs, variously called nonconscious and conscious, preattentive and attentive, passive and active, to name only a few. The first-named domain of these pairs (generically called Domain A by Johnston and Dark) is "a relatively large-capacity, nonconscious, and passive system that is responsible for encoding environmental stimuli. Domain B is a relatively small capacity, conscious, and active system that is responsible for controlling various forms of information processing including selective attention" (Johnston & Dark, 1986, p. 66). Specific cause theories differ on whether Domain B influences processing of elements in Domain A, and on the degree of perceptual encoding that occurs for stimuli that are not selected for further processing.

Effect theories, on the other hand, view attention as a by-product of perceptual events prompted by expectancies, plans, or schema. A major proponent of this view is Ulric Neisser. For him, perception is orchestrated in a top-down fashion by schema, which are constructs that combine cognitive structures and context-specific contents to guide selective attention. Neisser (1976) defines schema as follows:

> that portion of the entire perceptual cycle which is internal to the perceiver, modifiable by experience, and somehow specific to what is being perceived. The schema accepts information as it becomes available at sensory

> surfaces and is changed by that information; it directs movements and exploratory activities that make more information available, by which it is further modified.... In one sense, when it is viewed as an information accepting system, a schema is like a *format* in a computer programming language. Formats specify that information must be of a certain sort if it is to be interpreted coherently. Other information will be ignored or will lead to meaningless results....
>
> A schema is not merely like a format; it also functions as a *plan*.... Perceptual schemata are plans for finding out about objects and events, for obtaining more information to fill in the format. One of their important functions in seeing is to direct exploratory movements of the head and eyes. But the schema determines what is perceived even where no overt movements occur (listening is a good example), because information can be picked up only if there is a developing format ready to accept it. Information that does not fit such a format goes unused. Perception is inherently selective. (pp. 54-55)

Once activated, a schema results in the ability to attend to one set of sensory inputs to the exclusion of another. The Neisser and Becklen (1975) study that demonstrated subjects could attend to one of two overlapping videotapes suggests the application of the schema notion for interpreting the results. Subjects could not integrate the two disparate videos (hand-clapping and basketball game) into a coherent whole. Once instructed to search for target events in one or the other video image, they chose the schema that accommodated the images (and target events) belonging to a single video source.

In Johnston and Dark's discussion, they indicate that research on selective attention phenomena does not discriminate clearly between the cause and effect theories. However, the empirical results stand on their own merits. Based on their review of many studies, Johnston and Dark (1986) summarized evidence in the form of generalizations, synopsized below, some of which may be relevant to HUD and HMD attentional issues.

1. *Selection based on sensory cues is usually superior to selection based on semantic cues.* Selective attention to stimuli differentiated on the basis of physical differences (e.g., color, shape, sound) is generally more accurate and requires less effort than selective attention based on semantic features (e.g., names, categories).

2. *Spatial cues comprise a special kind of sensory cue.* Cues that inform the observer of the location in which a target stimulus will appear enhance the speed and probability of detection, as compared to cues that inform the observer about other features (e.g., color, shape, identity) of the to-be-presented target. Likewise, recall of target items is

facilitated by cues to the target's presentation location. With respect to split brain studies, "a cue presented to one hemisphere can tell the other hemisphere where, but not what, a stimulus will be in a brief display that is presented to the other hemisphere" (Johnston & Dark, 1986, p. 50).

3. *Selection on the basis of spatial cues has the properties of an adjustable-beam spotlight that can be focused most sharply at the center of the fovea; processing outside the spotlight is confined mainly to simple sensory features.* Attention assumes the characteristics of an adjustable beam spotlight and is independent of eye fixations. Experiments have shown reaction time to target stimuli is fastest at the center of fixation (about 1° of visual angle) and increases as targets are displaced outward from the center. However, precuing the location of impending targets facilitates target detection as far away as 24° from fixation, indicating movement of the attentional spotlight away from the fixation point. These capabilities, however, are not without some costs in resolution, which decreases as the attentional spotlight is widened from the narrow point of fixation.

Semantic processing does not generally occur for stimuli outside the attentional spotlight unless influenced by top-down effects such as priming. "Priming is said to occur when one stimulus, the prime stimulus, affects the processing of another stimulus, the test stimulus. Priming can be conceived of as either the activation or the establishment of internal codes by the prime stimulus that correspond in some way to the test stimulus" (Johnston & Dark, 1986, p. 46). However, simple physical features (e.g., red and green as features of the color dimension) can be processed outside the attentional spotlight. Such features, however, may be subject to incorrect conjunctions (called illusory conjunctions).

4. *Selection inside the spotlight is based on configural properties of objects.* In addition to the spatial factors that influence attention, selection is facilitated by the perceptual organization of presented stimuli. A single target is easier to detect among distractors if it is not part of a perceptual group to which the distractors belong. For instance, a T is easier to detect among a series of Fs if it lies outside the line of Fs rather than within it. Likewise, multiple targets that form a perceptual group are easier to identify than targets that do not form a perceptual group. "If the target information is integrated into one perceptual group, one object, then it will be easily selected. However, if the target information is distributed between two perceptually distinct groups, two objects, then the selection task will be more difficult." (Johnston & Dark, 1986, p. 57).

5. *Nonselected objects within the spatial foci of attention undergo little or no semantic processing. However, irrelevant*

stimuli sometimes receive semantic processing, especially if they correspond to an active schema. The Neisser and Becklen (1975) study provides the kind of evidence that supports the first part of this generalization. Support for the second part comes from studies of personality variables, which demonstrate that words related to a self-schema can affect selection of relevant items if they appear in the list of irrelevant (distractor) items. Hearing one's name spoken at a cocktail party while engaged in another conversation is another example of attention influenced by a continually active self-schema.

6. *Spatial and object-based attention are both influenced by priming at various levels of stimulus analysis.* Priming is possibly one mechanism involved in the top-down control of selective processing. Identity priming is the facilitation of stimulus recognition by prior exposure to the same stimulus. Semantic priming is the facilitation of stimulus processing by prior exposure to semantically related items (e.g., processing of the test word, such as butter, is improved by preceding its appearance by a semantically related priming word, such as bread). Schematic priming relates to natural categories of images, actions, and expectations. Schema "activated by prime events (e.g., the name of a category) may bias various levels of analysis toward particular test events (e.g., instances of a category)" (Johnston & Dark, 1986, p. 47).

These six generalizations are drawn from a wide variety of research studies. These studies used experimental procedures that generally impose unusual viewing conditions on the experimental subject. One condition is the limited number of stimuli used. Another is the small or restricted set of stimulus features such as color or shape. The rate of exposure of the stimuli is frequently very brief (sometimes on the order of a few hundred milliseconds to preclude eye movements). And, stimulus locations are carefully determined with respect to the point of foveal fixation.

These constraints could pose some limitations on the applicability of the forgoing generalizations to understanding selective attention processes associated with the HUD or HMD. As illustrated in Figure 4, selective attention processes apply to objects within the OTW and HUD/HMD domains. As discussed earlier, divided attention applies to switching between these two domains. Symbology objects of the HUD or HMD appear to share many characteristics with the selective attention objects of laboratory research. Objects in the OTW domain share fewer of these characteristics because they are dynamic (e.g., a moving target changes shape and location along its trajectory). However, guidance from the research literature on how selective attention may function with dynamic stimuli is not forthcoming. For example, even with respect to static stimuli the role of eye movements in selective attention has not been explored in much detail (Kinchla, 1992).

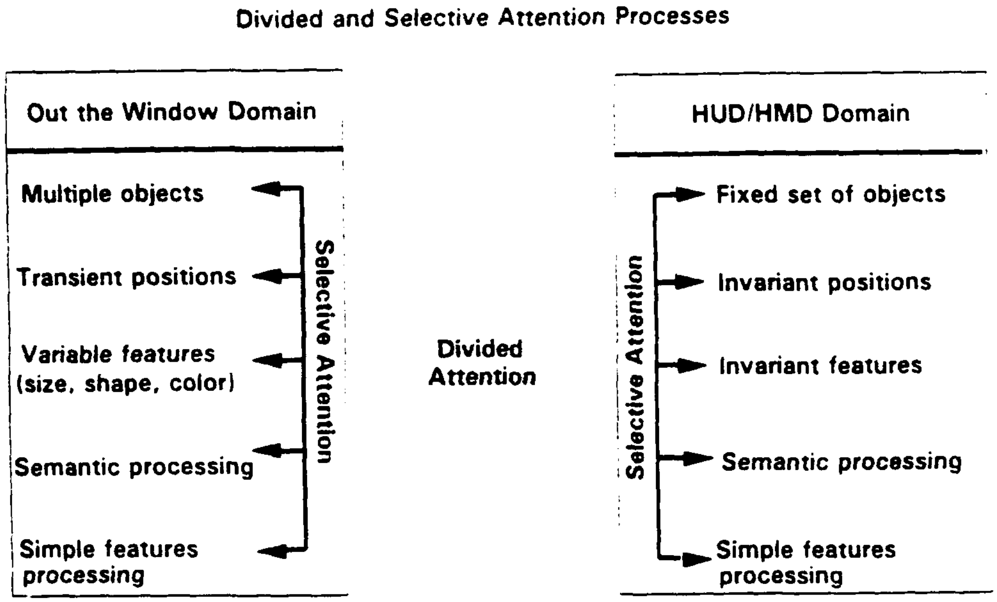


Figure 4. Characteristics of divided and selective attention processes with HUD or HMD use.

The HUD and HMD present a fixed set of symbology objects in invariant locations. Determining pilots' fixations on these symbology objects, and the conditions under which these fixations occur, may be a useful first step in addressing selective attention aspects of HUD and HMD use. What objects pilots are *looking at*, *how frequently* they select individual objects, and how long they dwell on each object can be determined with the use of an eye tracking device, provided the device does not interfere with the instruments presenting the display symbology.

Brain Laterality

Hemispheric specialization, or lateralization of brain function, is an important factor underlying the performance of attentional and information processing tasks. Sperry and Gazzaniga's landmark research (Gazzaniga, 1971; Sperry, 1964) established that cognitive functions tend to be specialized in the two hemispheres of the cerebral cortex: speech is processed in the left hemisphere, and nonverbal, spatial and more perceptual information is processed in the right hemisphere. The specialization of language in the left hemisphere is generally the case if one is a right-handed male, with no family history of family lefthandedness, and handwriting is done with the hand in the normal, as contrasted to an inverted, position. If one is female, left-handed, or writes in the inverted position, then the hemispheric rule is less likely to apply (Ashcraft, 1989). The two halves of the brain do not act in isolation, however, because they are connected by a neural pathway, the corpus callosum, that permits exchange of messages across the two hemispheres.

Another anatomical feature of the nervous system that impacts cerebral functioning is contralaterality: sensory input from one side of the body is projected in whole or part to the cerebral hemisphere on the other side of the body. Figure 5 illustrates this feature for the visual system. Note that the left portion of the retina of each eye is connected by ascending fibers with the left visual cortex; ascending fibers connect the right portion of the retina to the right visual cortex. However, images on the retina are reversed by the lens. The result is that stimuli appearing to the right of fixation are projected by each eye to the left cortex. Likewise, images to the left of fixation are projected to the right cortex. This "crossing over" of images from the right and left hemifields to the opposite cortex holds true when either one eye or both eyes are viewing an image. In the case of two-eyed (binocular) viewing, visual fields partially overlap resulting in some redundancy of visual information received in each visual cortex.

Note that either one eye or two eyes can be enlisted in transmitting visual information to either visual cortex. The essential requirement for transmitting to one or the other cortex is to place the image in either the left or right hemifield[1]. This feature has been used in experimental investigations that direct verbal and visuo-spatial material to "compatible" and "incompatible" sides of the brain.

The phenomenon of brain lateralization has provided a point of convergence for developments of multiple resource theory, discovery of rules governing effective time-sharing, and differentiation of cognitive processing modes. Research in these areas has generally adopted one of two approaches. The first examines hemispheric specialization by varying the structure of tasks (i.e., whether tasks are verbal, spatial, or motoric) that are presented to both eyes or ears. The second approach retains the structural differentiation of tasks, in addition to examining interactions of task content and hemispheric specialization by presenting task input to one or the other cerebral hemisphere via one eye or ear. Both approaches use the ubiquitous dual-task paradigm to assess laterality effects.

A program of research using the first approach was undertaken by Friedman and her associates. Friedman and Polson (1981) developed the idea that each hemisphere controls its own set of processing resources. In their version of a multiple resource model, they assumed that two tasks dependent on one hemisphere may not be performed optimally if their joint demand exceeds the limited resources of that hemisphere. However, if the

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[1] Another requirement is that the image must stay in a fixed position relative to the retina during observation. This can be accomplished by moving the image as the eye moves, requiring special experimental arrangements. The more commonly used method is to present the image for durations of between 100 and 200 msec, too brief an exposure for any eye movement to occur.

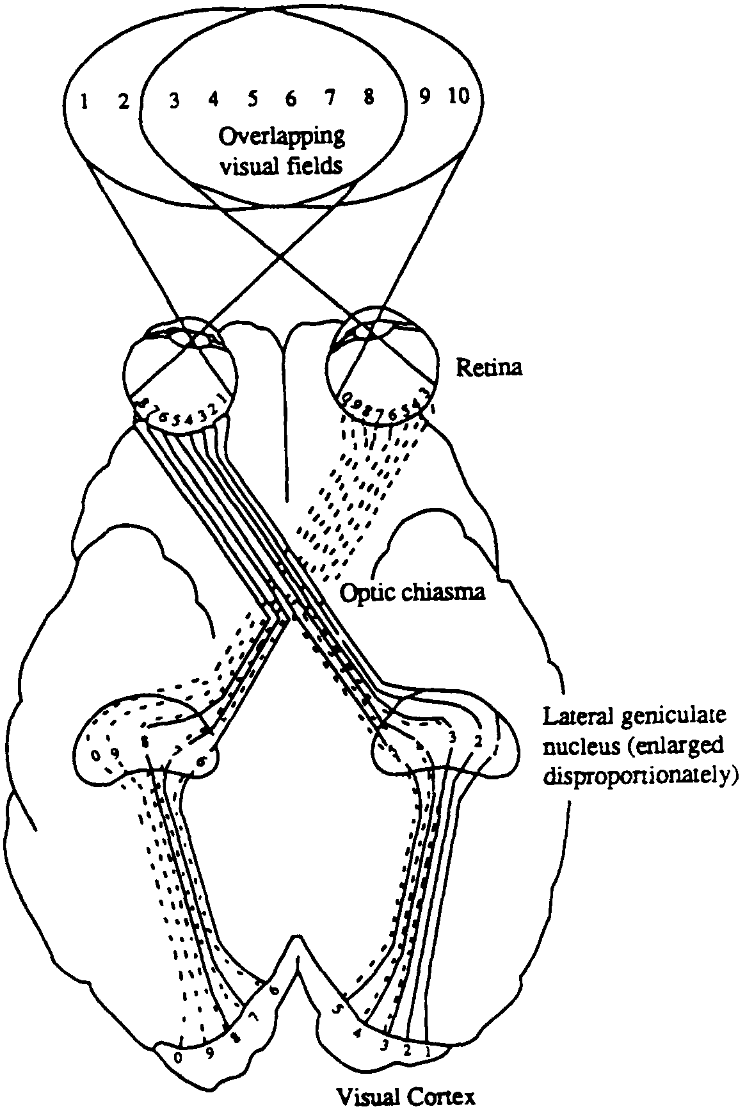

Figure 5. Schematic representation of the visual pathways from each eye to the visual cortex, via the optic chiasma and the lateral geniculate nucleus. The parts of the visual field represented at each level are indicated by tracing the numbers through the system (from Haber & Hershenson, 1980).

task demands are within the limited capacity of the hemisphere, or if one of the tasks can be performed using the resources of the other hemisphere, then dual-task performance should be accomplished.

> It follows from the general multiple resources logic that if two tasks demand resources from the same hemisphere, they should normally be able to trade performance with each other when attention is shifted between them. When they demand resources from different hemispheres, however, they should not be able to trade. One implication of this is the undifferentiated resources assumption: The resources of a given hemisphere should be able to be shared among tasks that do not have any readily apparent overlapping component processes. (Friedman, Polson, & Dafoe, 1988, p. 61)

In one test of their hypotheses, Friedman et al. (1988) had right-handed men perform a verbal memory task while concurrently tapping the index finger of either hand as rapidly as possible. As discussed earlier, verbal processing occurs in the left hemisphere of right-handed persons. In addition, the left hemisphere controls simple motor behavior (i.e., behavior not controlled by complex motor programs). The prediction was that, because both verbal memory task and right-hand tapping are mediated by the left hemisphere, performance would be poorer when the right hand was tapping than when the left hand was tapping. The prediction was borne out. Not only did right-hand tapping rate decrease while remembering verbal material (as contrasted to reading to-be-remembered material), but memory scores also decreased with right-hand tapping.

Lateralization effects are evident when information processing tasks are demanded of subjects. Prichard and Hendrickson (1985) presented a geometric form and instructed subjects to hold it in memory. They then presented a pair of verbal or spatial items: either words ("oak" and "maple") or typewriter symbols ("$ % &" and "$ $ %"). Same or different judgements were required for this interpolated pair. The final stage of a trial presented a second geometric form and required subjects to judge whether this form was the same or different than the original form presented a few seconds earlier. Thus, the primary task of spatial memory of the geometric form (right hemisphere locus) was combined with a word-content task (left hemisphere resource) or spatial-content task (right hemisphere resource). Processing of the interpolated spatial pair was expected to result in poorer recognition of the original spatial target stimulus.

As predicted, reaction time for the same-different judgement to the second geometric form was slower when it was preceded by the spatial pair than when it was preceded by the verbal pair. This result was not a consequence of differences in difficulty between the verbal and spatial pairs, or the time required to make same-different judgements to spatial and verbal materials. The results support the notion of separate spatial and verbal resource pools.

Before turning to examples of research that presented task inputs to one hemisphere specifically, the results of requiring performance of a verbal or spatial task while executing a simulated flying task are presented. The theoretical context of this dual-task situation was an expansion of stimulus-response (S-R) compatibility phenomena to include compatibility of mode of processing (i.e., spatial versus verbal). Wickens, Sandry, and Vidulich (1983) reviewed earlier research, which has shown that a compatible relationship appears to exist between modalities of input (auditory and visual), output (manual and speech), and central processing (verbal and spatial). Auditory input and speech output (A/S) is most effective when associated with verbal central processing, whereas visual input and manual output (V/M) is most effective when associated with spatial central processing. This S-C-R (stimulus-central processing-response) model integrates central processing differences with input-output compatibilities known for some time in the human factors literature. It articulates the performance relationships among the resource dichotomies of Wickens' multiple resource theory.

The S-C-R model was tested in an F/A-18 simulator mockup with experienced pilots. Pilots were required to fly a serpentine course while concurrently performing a secondary task of either spatial or verbal processing demands. The spatial task was target designation of forms that appeared intermittently on the display. The verbal task involved a series of navigation, communication, and identification tasks, each requiring encoding, storage, and retrieval of verbal information at various times during the flight mission. These side tasks were presented in auditory or visual form, and required either spoken or manual responses.

The predictions were substantially supported. Time-sharing efficiency of the side task was helped by auditory input if the task was verbal, in contrast to spatial (S-C compatibility). On the output side, the spatial task was helped by manual responding (C-R compatibility), whereas the verbal task was not. From the perspective of the flying task, mission performance was adversely affected more by the spatial side task than by the verbal. The best performance was obtained when the verbal task was presented auditorially with speech output and when the spatial task was presented visually and responded to manually. In sum, this experiment stands as a good example of the effects of task structure on resources, and demonstrates the utility of Wickens' three-dimension resource theory in predicting effective time-sharing multi-task situations.

Turning to those studies that present inputs to one side of the brain or the other, the general approach is to compare single- and dual-task performance of each hemisphere on tasks assumed to be lateralized in some way. A series of experiments performed by Hellige and Cox (1976) and interpreted by Friedman and Polson (1981) within their cerebral specialization theory succinctly summarizes this line of inquiry.

Hellige and Cox (1976) presented right-handed individuals with target tasks (i.e., tasks "targeted" to one hemisphere only) by means of visual half-field techniques. These tasks were preceded by none or a varying number of "load" tasks to be held in memory and recalled after the interpolated target task. Load tasks were not presented laterally.

The load tasks were remembering either 2, 4, or 6 nouns or remembering 4, 7, or 11 dots in 3 x 3, 4 x 4, or 5 x 5 matrices. In single-task trials, the dot pattern task was considerably harder than the noun task (a maximum difference of 40% in accuracy between the 11 dot and 6 noun tasks). The target task consisted of noun naming. As expected, the load tasks had different effects on noun-naming accuracy depending on the hemisphere to which the nouns were presented.

The different dot pattern memory loads did not have differential effects on naming accuracy for either hemisphere. However, presenting the noun-naming task to the right visual field-left hemisphere resulted in a higher absolute level of noun-naming accuracy. These findings are consistent with other research findings that effective time-sharing occurs with combinations of verbal and spatial tasks.

With respect to remembering nouns, the target tasks of naming two or four nouns did not decrease left hemisphere noun-memory accuracy, whereas naming six did. This is attributed to the fact that the limited capacity of the left hemisphere was exceeded with the six noun memory-naming combination.

Remembering six nouns decreased naming accuracy for the left visual field-right hemisphere presentation also, but memory for two or four showed an increase. This apparently paradoxical result is not unexpected because the right hemisphere has some capacity for rudimentary processing of familiar nouns. Friedman and Polson (1981) attribute the improvement to the fact that the right hemisphere had to call on the left hemisphere to accomplish the response production portion of the noun-naming task. Specifically, the left hemisphere is known to be instrumental in speech production. Thus, with both hemispheres involved in the noun-naming task under the left visual field presentation of the target task, the right hemisphere could show an increase in accuracy until the capacity limit of the left hemisphere was reached in the six-noun condition.

Friedman and Polson's (1981) explanation of this last result has the appearance of being ad hoc, but investigators such as Moscovitch (1979) view the cerebral cortex as having structurally differentiated parts with general, specialized, and shared capabilities. Moscovitch (1979) developed a model to explain why lateralization effects are shown under some conditions but not others. In his view "... two different sets of structures exist within a unified system--a primary set that is fundamentally different on the left than on the right, and a secondary set that is basically similar on the two sides but that, by virtue of its location, is compelled to interact mainly with the primary structures on its side" (pp. 410-411).

According to Moscovitch, lateralization effects are precluded if processing can be accomplished at earlier stages in the sensory channel as illustrated in Figure 6. If sensory input is passed through these stages, it becomes lateralized, and effects due to hemispheric specialization will become apparent. Therefore, a task that requires processing at one of these earlier stages will not show the effects of which side of the body received the stimulation. "The initial stages extract sensory features such as brightness, texture, color, and contour if the stimulus is visual, or loudness, pitch and clarity if the stimulus is auditory" (Moscovitch, 1979, p. 383).

On the other hand, a task that requires processing that cannot be accomplished at an earlier stage will be transmitted to one hemisphere or the other. If the sensory input has been received on the side of the body projected to the hemisphere "compatible" with the verbal or visuo-spatial content of the message, the task will show an advantage in processing. If the sensory input is received on the "incompatible" side, processing may occur to some level on that side and the remainder of the task will be transferred or shared with the other side.

Before concluding this discussion on brain laterality differences, the issue of transformation of stimulus materials is considered. Klatzky and Atkinson (1971) investigated cerebral lateralization using the memory scanning paradigm. This paradigm consists of presenting a set of letters to subjects who hold them in memory. The subject is then presented a test stimulus of a single letter and is asked to indicate with a keypress whether the letter matches one of the members of the memory set. Reaction times are generally shown to be slower as the size of the memory set becomes larger.

Klatzky and Atkinson (1971) cite earlier research that presented pictures and letters as test stimuli bilaterally. With picture stimuli, the subject makes a response only if the first letter of the name of the pictured object is a member of the memory set. Reaction times to the picture test stimuli are greater than they are to the single letter stimuli. "Since the transformation of a picture test stimulus to the initial letter of its name is a verbal process, it is possible that the resulting test stimulus representation is a verbal label of that letter.... In contrast, the representation of a letter test stimulus may be a spatial pattern." (p. 335). This finding raised

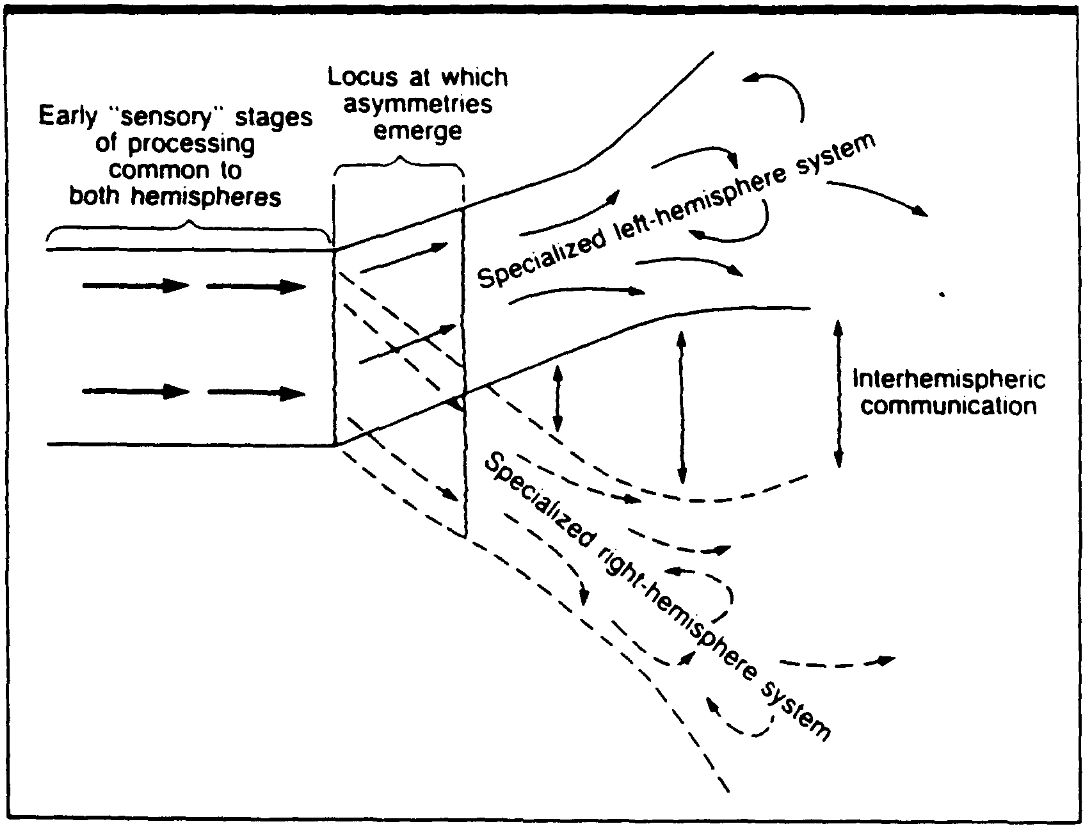

Figure 6. Illustration of Moscovitch's principle of transmitted lateralization. Laterality effects will only begin to appear at the point of which neutral messages make contact with the specialized processing resources of the two hemispheres. (from Moscovitch, 1979)

the interesting question of what the effects would be for picture and letter stimuli presented to the left and right visual fields.

To answer this question, Klatzky and Atkinson (1971) found that faster reaction times were obtained when the letter stimuli were presented to the right hemisphere and when picture stimuli were presented to the left hemisphere. This appears to be the opposite of what would be expected based on the research reviewed so far. However, the results are consistent with the interpretation that letter and picture stimuli are represented as spatial and verbal forms, respectively. The reaction times for letters presented to the left hemisphere and pictures to the right hemisphere are higher by a constant (i.e., the reaction time functions are parallel) than these stimuli presented to the other hemisphere. This implies that the stimuli were transformed, and then transferred to the other hemisphere for further processing, which more time.

The nature of the task (comparing input to a memory set of verbal material) was the key factor in this seemingly unusual lateralization result. However, the results point to the importance of specifying the mental model to which incoming stimuli will be compared or incorporated. This model, and stimulus transformations that may occur, are necessary components of the predictions of which hemisphere may be the most compatible for receiving the input.

Crowley (1989) reviewed the cerebral laterality literature, and other research literature of sensory and motor laterality, to determine if these factors influence aviator performance. His review noted that handedness is closely linked to cerebral dominance. That is, right-handed individuals demonstrate verbal functions primarily localized in the left hemisphere and spatial and musical functions localized in the right hemisphere. Left-handed individuals show much less left-right cerebral specialization. Crowley then considered the implications of these laterality differences for pilot performance. Some of the research literature, supplemented by anecdotal data, shows that pilots demonstrating strong cerebral laterality perform better than pilots with less well defined laterality. In this context, strong laterality is associated with definitive right-hand preference (i.e., little or no reliance on the left hand for common tasks).

Although the laterality research and aviation literature are "full of contradictions and weak associations" (Crowley, 1989, p. 67), he suggests that research should continue into the pilot performance implications of cognitive laterality. Cerebral asymmetry can be indexed by handedness measures that measure the degree of hand preference. Given the availability of these instruments, and the ease of their administration, obtaining handedness measures appears warranted in future HUD and HMD research.

Dichoptic Viewing

The foregoing conclusions on laterality effects are based on experiments using stimuli presented to the left and right hemifields. Such presentation ensures that stimuli are initially processed by one cerebral hemisphere. This line of research aims at understanding functional differences between the cerebral hemispheres by using unusual conditions of left-right presentation of generally very short duration. Less unusual is the situation of two unrelated images being presented to both eyes. Common examples include looking through a telescope, a microscope, or the viewfinder of a camera with one eye. Although experienced users keep the other eye open, they ignore the unrelated image by focusing their attention on the eye using the instrument. A similar situation of visually unrelated OTW and symbology images being presented to each eye exists for pilots using an HMD[2].

The effects of presenting stimulus materials to only one eye (dichoptic viewing) has not received research emphasis. Two issues are of interest in dichoptic as compared to binocular presentation. The first is the nature of attentional phenomena associated with one- as contrasted to two-eyed viewing. The second is whether various forms of eye dominance are associated with dichoptic viewing performance differences. These issues are discussed in the following sections.

Attentional Aspects of Dichoptic Viewing

In their study of attention to two unrelated video images, Neisser and Becklen (1975) compared performance under both binocular and dichoptic viewing conditions. In the binocular condition, the videos were superimposed on one viewing screen. In the dichoptic condition, subjects viewed one video with the left eye and a second video with the right eye. Superimposed video images, regardless of binocular or dichoptic viewing, resulted in poorer detection of target events as compared to single video presentation. However, the binocular viewing condition resulted in better detection of target events than did the dichoptic condition, but there was no clear advantage with respect to false alarm rate. The authors noted their experience of less "effort" associated with switching between the two videos under binocular as compared to dichoptic viewing. Neisser and

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[2] It is important to distinguish two types of situations with the HMD. One case is the situation in which each eye receives completely different images. An example is the HMD arrangement that presents a FLIR image (and perhaps superimposed symbology) to the one eye while the other "bare" eye can be used to scan cockpit instruments. The second is the situation in which the symbology image is presented to one eye superimposed on the same image that is simultaneously being presented to the other eye.

Becklen speculated that this may have been associated with the better detection performance.

More recently, researchers have begun to look specifically at attentional issues associated with dichoptic viewing characteristic of HMDs. Gopher, Grunwald, Straucher, and Kimchi (1990) had subjects fly a low fidelity simulated helicopter as it traversed a curved spatial trajectory. At the same time, the pilots performed a secondary task--detecting the appearance of a target letter in briefly presented letter pairs. These pairs appeared every 3 sec. at one of five different retinal locations. The subjects controlled the helicopter by moving a mouse; positive and negative responses to the letters were made on the right and left mouse buttons.

A variety of binocular and dichoptic conditions were examined in the experiment. Of relevance to the present discussion is one binocular condition and some of the dichoptic conditions. To control the helicopter, a cross had to be kept within a square. The cross and square were presented (a) binocularly, (b) together to one eye, or (c) separately to each eye. With respect to the secondary task, letter pairs were presented to the same eye as the tracking symbols or to the eye not receiving the tracking symbols. Superimposing the letter pair on the tracking symbols, or displacing it 4° or 8° to the side, provided yet another condition.

Overall, response time to the letter classification task increased under the dichoptic viewing conditions. However, response time under dichoptic conditions did not differ when (a) the letters were presented to the same or different eye from the tracking symbols or (b) when the tracking symbols were presented together to one eye or separately to each eye. Moreover, the best reaction time to letter pairs occurred when the pair appeared superimposed on the tracking symbols. Detection fell off as the letter pair appeared at more peripheral positions.

Error rates tended to be higher in dichoptic viewing as compared to binocular viewing. However, errors in the letter classification task were lower when this task was presented to the same eye receiving the tracking task symbols. In addition, when OTW kinds of cues were not present to support the tracking task, more errors occurred in the letter classification task. It appears that the absence of OTW cues forced greater fixation on the tracking task symbols. This was the case for both binocular and dichoptic viewing conditions.

These results demonstrate that a secondary task presented to only one eye results in some degradation of performance. However, information processing capacity for the two tasks (tracking and classification) is not further degraded when both tasks are presented to one eye. Additional degradation occurs as a function of how far from foveal fixation one task is displaced from the other. However, costs with respect to the secondary task increase if fixation on the primary task is increased.

It should be noted that these last two conclusions are not necessarily a function of dichoptic viewing. Similar results have been shown to occur with tasks presented under binocular conditions. Specifically, presenting a stimulus at increasing distances from fixation results in correspondingly degraded performance in an area of visual space referred to as the visual lobe (Drury & Clement, 1978). In addition, increasing the demands of a task within the foveal area impairs performance of a peripheral or secondary task. Performance on the peripheral task tends to fall off gradually in an area roughly circular in shape. Williams (1982) has described this area as the functional field of view, which is sensitive to the workload present in the foveal task.

Kimchi, Rubin, Gopher, and Raij (1989) investigated subjects' ability to focus and divide attention under conditions of binocular and dichoptic viewing. The stimuli used were the letters H and T composed of Hs or Ts, as shown in Figure 7. Subjects were presented a display of two stimuli. Their task was to search for a letter at the global level (e.g., a composite H such as item number 2 in the figure), the local level (e.g., an individual H such as in item number 3 in the figure), or at both levels (e.g., a composite or an individual H such as in item number 1 in the figure).

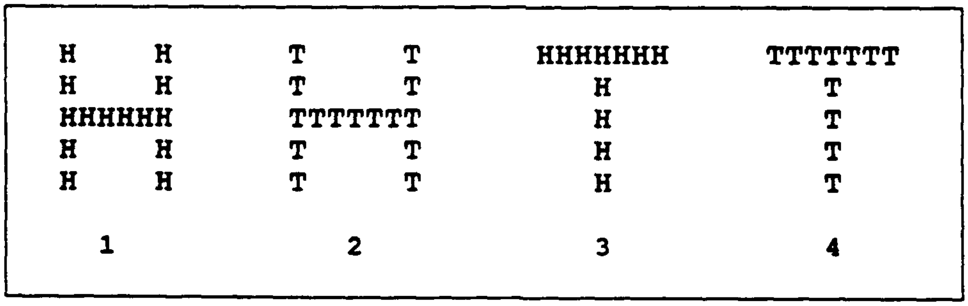

Figure 7. Stimulus set used in Kimchi, Rubin, Gopher, and Raij (1989) experiment.

In the dichoptic viewing condition, one stimulus was presented to the left eye and the other to the right. In the binocular viewing condition, both eyes viewed the stimulus pair. The search task involving the stimuli was performed under two attention conditions. In the focused attention condition, the subject was instructed to attend to only one stimulus: the stimulus appearing in either the left or right eye under the dichoptic viewing condition; the stimulus appearing in either the left or right visual field under the binocular viewing condition. In the divided attention condition, the subject was required to attend with both eyes or to both visual fields.

Performance was mainly affected by the attention conditions rather than by the viewing conditions. A significant interaction appeared between the attention condition and task demands. Performance in the focused attention condition was faster and more accurate than in the divided attention condition for the local-directed search task. However, performance in the divided attention condition was significantly faster and more accurate for the globally-directed task. The only effect of viewing condition was that local search was significantly slower in the divided attention condition under binocular viewing.

The overall result of the experiment was that subjects' ability to focus and divide attention under dichoptic viewing was not significantly different than their ability to do so under binocular viewing. In addition, if the subject had to focus on one stimulus, that focusing "set" facilitated selecting one aspect of the selected stimulus for further processing. Furthermore, a similar "set" operated at the global level. Thus it was concluded that an observer attended better to global details of a object if he or she was dividing attention between objects.

In conclusion, the Neisser and Becklen (1975) and Gopher, Grunwald, Strauscher, and Kimchi (1990) studies show that responding to dynamically changing images appears to introduce a small but demonstrable performance degradation when the images are viewed dichoptically. However, selective and divided attention effects appear to operate similarly when either one or two eyes are engaged in performing a task as demonstrated in the Kimchi, Rubin, Gopher, and Raij (1989) study.

Effects of Eye Dominance

Porac and Coren (1976) define the dominant eye as "the eye whose input is favored in behavioral coordinations in which only one eye can be used, the eye preferred when monocular views are discrepant, or the eye manifesting physiological or refractive superiority" (p. 880). Eye dominance has direct relevance to the HMD situation in which only one eye is presented the symbology. The key issue is whether performance differences result from viewing the HMD with the dominant eye as compared to the nondominant eye. At present, the U.S. Army AH-64 IHADSS system is placed over the right eye. Proposed systems appear to permit placement of the HMD before either eye. Does choice of viewing eye make a difference?

No empirical data appears available to answer this question. However, a variety of studies have explored the issue of eye dominance suggesting that eye dominance may play a role in the efficient use of information provided in the HMD. Porac and Coren (1976) reviewed this eye dominance research. Findings of potential relevance to HMD use are summarized here.

Porac and Coren (1976) identified at least two dozen different eye dominance tests. They report one study that administered 13 of these tests and then factor analyzed the results. Three forms of eye dominance emerged: sighting, sensory, and acuity dominance. Sighting tests accounted for 67% of the common variance of all the tests. Sighting dominance is the habitual favoring of one eye in monocular sighting tasks, such as looking into a microscope, or the use of one eye when the binocular images are discrepant or infusible. A large number of studies of sighting dominance reveals that about 65% of observers sight with the right eye, 32% sight with the left eye, and 3% show no consistent preference.

Sensory dominance is generally observed in binocular rivalry situations in which two discrepant monocular images alternate in consciousness. If the image appearing in one eye remains in consciousness for longer periods of time, this is taken as sensory dominance for that eye's input. Norms for sensory dominance are less well established but appear to be on the order of 48% preference for the right eye, 32% for the left, and 19% with no consistent preference.

Acuity dominance is the third form of eye dominance. Because both eyes rarely have the same acuity, the eye that measures greater acuity may appear dominant. However, Porac and Coren (1976) failed to find any clear evidence of the behavioral implications of acuity dominance.

Because Porac and Coren (1976) regard sighting dominance as the best documented and most fully understood form of the three basic kinds of eye dominance, they concluded that "... sighting dominance is the only significant form of eye dominance" (p. 886). Implications of eye dominance that they enumerate in their review, and which are extracted here, are related to sighting dominance.

1. There is no neurological or physiological evidence to link ocular dominance with cerebral dominance. Moreover, there is no correlation between measures of handedness and eye dominance. Handedness measures are frequently used as measures of cerebral dominance. Investigations of cerebral dominance using visual hemifield techniques have found no evidence of a relationship between visual field superiority and sighting dominance.

2. The dominant eye may play a more important role under binocular, as contrasted to dichoptic, viewing conditions. The evidence, however, is equivocal.

3. Eye dominance is relatively immutable (i.e., resistant to attempts to train the nondominant eye or otherwise attenuate the reliance on the dominant eye). Tampering with eye dominance relationships causes discomfort.

From these generalizations, two conclusions about possible HMD research directions may be drawn. The first is that eye dominance is a factor independent of cerebral laterality. Differences in performance that are not related to eye dominance but that are related to cerebral laterality are associated with the nature of the visual stimuli, task demands, and the visual hemifield of presentation. The second conclusion is that eye dominance is a relatively fixed functional characteristic of the pilot. It should be assumed that eye dominance will affect the efficiency with which the HMD is used. However, what that effect might be is still unknown.

Individual Differences

Traditionally, the study of individual differences in cognitive abilities has been the domain of psychometricians, although learning theorists have had a long-standing interest in individual differences in psychomotor skill acquisition (Ackerman, 1987; Marteniuk, 1974). Recently, the discipline of psychometrics has begun to close ranks with the domain of experimental cognitive psychology (Carroll & Maxwell, 1979), a collaboration that has contributed much to the recent literature about attention (reviewed in the preceding sections). One result of this collaboration is the recent appearance of research and analysis of systematic individual differences related to cognitive skills (Kyllonen & Woltz, 1989).

Individual differences in cognitive abilities and cognitive skill acquisition are being examined using theory and experimental paradigms drawn from the yet larger, multidisciplinary arena of cognitive science and information processing. An example is shown in the studies of Keele and Hawkins (1982) that explored whether time-sharing and attentional flexibility were general abilities. These investigators framed the ability versus skill debate in the following way:

> Consider fast action skills such as piloting a jet plane.... What accounts for the enormous success enjoyed by some people...? One assumes the extraordinarily successful person has exceptional perceptual or motor capacities.... But the perceptual-motor view has not been very useful for predicting individual differences in capability. Factors such as reaction time, movement time, and perceptual sensitivity seem not to correlate much, if at all, with skill success (Marteniuk, 1974). With practice, skill in a task appears to become more specific to itself, and less predictable by other perceptual-motor factors....
>
> An alternative view posits that task success largely results from practice.... In essence, practice yields both an increasing number of patterns or situations that people recognize and patterns which automatically prompt specific routines or sets of procedures.... This view of practice is quite consistent with the notion of task specificity. The

> gradual acquisition of patterns and procedures would render skill specific to the task practiced. (pp. 3-4)

Keele and Hawkins (1982) examined the abilities position using an information processing approach. This approach, rather than comparing global task performance, looks to the constituent processes that produce global performance differences. If the constituent processes that underlie tasks are isolated, then process scores from different tasks "should correlate highly because only the features common to the tasks are compared" (p. 5).

Using this approach, Keele and Hawkins (1982) found no evidence of a general time-sharing ability. However, the search for a flexibility of attention (attention switching) ability met with more success. They found a moderate correlation (*r* = .48) between scores on two different task pairings that differed in signals, responses, difficulty, and alternation of attention.

At the time of their report, Keele and Hawkins (1982) had not correlated this attention switching factor with fast action skills. They raised a cautionary note, however.

> We have not made successful inroads on this problem; the task is rather formidable. First, given that the correlations among different measures of flexibility are themselves moderate in magnitude, it is unlikely that any one of them would correlate highly with performance on some particular fast action skill. Second, most skills undoubtedly are influenced by numerous abilities. Ideally, predictions would be based on a battery of predictive variables, but up to this point, attentional flexibility is the only cognitive factor for which we have found construct validity. (p. 16)

The joining of skilled performance, attentional, and differential psychology research areas under the information processing umbrella has produced a number of studies that are relevant to HUD and HMD issues. The purpose of some of these studies has been to validate performance-based assessment tests for pilot selection.

Assessment of attention as a predictor of pilot performance has a history of about twenty years, in contrast to other forms of pilot selection instruments and performance assessment that extend back almost fifty years (Dolgin & Gibb, 1989). In part, the recent interest in attention-based tests is due to the realization that attentional factors play a part in cockpit tasks. In addition, the dynamic nature of attention assessment lends itself to computer-presented tasks, many drawn from experimental cognitive psychology. The widespread use of computers in experimentation and test administration is also a recent development. Thus, assessing attentional factors has been encouraged by the current preference for automated selection testing in general (Pellegrino, Hunt, & Yee, 1989) and within the aviation community in particular (Dolgin & Gibb, 1989).

The early research into attentional factors in pilot selection did not use computers. An experimental study of selective attention by Gopher and Kahneman (1971) was combined with the practical problem of selecting pilots for the Israeli Air Force. A test was designed to assess errors such as omissions and intrusions as student pilots listened to a series of dichotic messages--that is, messages in which different information is presented simultaneously to each ear. Part I of the test consisted of a cue to signal the relevant ear to monitor for messages, followed by the presentation of 2 or 4 digits interspersed in a stream of words. The subject had to repeat the digits immediately on presentation. Part II began with a cue signalling which ear was relevant (which could remain the same as in Part I), followed by three pairs of simultaneous digits to the two ears. The subject's task was to repeat the digits from the relevant ear only.

Errors on Part I were either omissions (i.e., failures to detect digits) occurring with equal frequency in both ears or intrusions that occurred predominantly in the left ear. This latter finding is consistent with findings of right-ear dominance in dichotic listening. The Part II test results are of greater interest from a selection point of view. This test involved either maintaining attention in one ear or switching attention to the other. Subjects demonstrated high error rates when initially listening with the left ear and failing to remain in the left ear when signalled to do so. The subjects tended to switch to the right, or dominant, ear.

The criterion of student pilot success in flight training was a three-point scale consisting of (a) rejected during initial training, (b) rejected early in jet aircraft training, and (c) attainment of advanced training status on jet aircraft. Statistically significant correlations were obtained with this criterion and Part I "omissions" ($r = .26$) and Part II switching ($r = .36$). Using the same criterion, intelligence and mechanical/psychomotor tests completed by student pilots revealed correlations of .21 to .29, respectively.

A second sample of 95 experienced pilots was dichotomized into two groups: either flying transport planes and slower aircraft or flying high performance and attack aircraft. The two groups were administered the same dichotic listening test. With the two group criterion, significant correlations were obtained for omissions ($r = .21$) and for Part II switching ($r = .32$). Given the higher correlations of the switching task with operational proficiency, the authors concluded that this was the more important of the pair of attention variables.

This conclusion was supported when the test was administered to bus drivers (Kahneman, Ben-Ishai, & Lotan, 1973). A three point scale of accident-proneness showed a correlation of .51 with the switching measure. A more comprehensive validation of the dichotic listening test with pilots was conducted by Gopher (1982). Omissions, intrusions, and switching errors all discriminated significantly with a pass-fail criterion in a sample of 2000 flight cadets. The most apparent differences, however, were shown with the switching task.

Gopher (1982) examined the contribution of the attention measures (omissions, intrusions, switching) to a selection battery that included eight other tests. The attention measures showed moderate zero-order intercorrelations (.49 to .57) and very low correlations with the other tests. Of the attention measures, switching errors contributed the most to the multiple correlation between a seven-point training criterion and the selection battery. However, the improvement in variance accounted for was 2.1%. Although statistically significant, Gopher (1982) did not regard this result as sufficiently substantial for the purposes of predicting success in training. On the other hand, switching errors did emerge as a significant training elimination criterion. A multiple regression cut-off score that included the switching error improved the identification of marginal and unsuccessful trainees from 27.2% to 48.5%.

One purpose of Gopher's 1982 study was to validate a group administered form of the dichotic listening test for use in pilot selection. In the same vein, the dichotic listening test was included in a developmental version of a pilot selection battery developed by the Navy (Griffin, 1988). This test battery is computer-administered, requiring little administrative support for test instructions, task presentation, and performance scoring. The test battery consists of two tasks: the Gopher dichotic listening task and a stick-and-rudder psychomotor task. The difficulty of the latter task is increased by reversing the control-input relationship (e.g., left joystick movement moves a cursor to the right). Both tasks, in single- or dual-task portions of the test, showed significant correlations with grades in the primary flight portion of the Navy flight training program. However, the score from the single-task trials of the stick-and-rudder task was the first to enter the multiple regression of all test scores with the criterion. The second measure was the Flight Aptitude Rating (FAR) composed of spatial, mechanical, and biographical measures.

Neither the dichotic listening task nor the dual-task combinations made significant contributions to warrant inclusion into the equation. This failure does not support the author's conclusion that "a series of automated DLT (dichotic listening) and PMT (psychomotor) tasks ... are valid predictors of Navy flight training performance" (p. 816). Other researchers from the same laboratory (Blower & Dolgin, 1990) likewise disagree with Griffin's conclusion. They reported that the DLT and PMT had no predictive capacity when combined in a prediction equation that included a risk-taking, visual information processing, and tracking task test score.

North and Gopher (1976) examined the selection potential of an alternative to the dichotic listening task for attention assessment using a familiar dual-task test. One task was a compensatory tracking task similar to the one used by Damos and Wickens (1980; see Figure 1). The other task was a digit-processing, reaction time task. This task presented subjects a single digit on the CRT and required the subjects to quickly press the corresponding digit on a keypad. Single-task performance on these two tasks (Phase 1) determined subject-specific performance standards for use in dual-task trials in Phases 2 and 3. Phase 2 required both tasks to be performed simultaneously, with the subject giving equal priority to performing each task. Phase 3 altered the priorities associated with each task, creating four conditions in which demand was increased or decreased by 20% for one task. Priority changes were introduced to assess the subject's ability to adjust and reallocate attention. The test battery took about 45 minutes to administer.

Subjects in the test development portion of the study (Phases 1 through 3) were flight students. Large individual differences were found in single-task tracking and digit-processing performance. However, single-task performance was uncorrelated with, and not predictive of, dual-task performance. On the other hand, dual-task performance under equal and altered priorities was highly correlated (ranging from .76 to .93), indicating subjects were highly consistent in dual-task performance.

North and Gopher (1976) developed "attention manageability scores" for the altered priority conditions. They reasoned that the ability to manage attention would be related to proficiency in both the single- and dual-task situations. Although they discovered a considerable degree of linearity in the subjects' performance adjustments to the demand changes for dual-tasks, the manageability scores did not show robust correlations with other performance measures. The most plausible explanation appeared to be that subjects over performed (invested more effort or attention) in the altered priorities condition as compared with the equal priorities condition.

North and Gopher (1976) concluded that individual differences could be divided into three categories: (a) single-task performance differences, (b) dual-task performance (i.e., time-sharing) differences, and (c) differences in the adjustment to changes in task demands. One aspect of the validation portion of North and Gopher's study looked at the relationship between test performance scores and flight proficiency. The subjects in this case were flight instructors and student pilots. In comparisons of these two groups on dual-task proficiency, instructors performed better on the tracking task, showed better transfer between single- and dual-task tracking performance, and demonstrated better time-sharing than did flight students. No group differences were found for the digit-processing task.

The predictive validity of the test was examined using flight student data. Criteria consisted of a pass-fail score in a flight certification checkride and a subjective evaluation of each student by a flight instructor. Only two measures, digit-processing scores from the dual-task test and tracking manageability scores, resulted in reliable differences between high and low performance students using these criteria. North and Gopher (1976) concluded that:

> The preliminary investigation of the discriminative validity of the various attention measures appears, therefore, to yield encouraging support for the usefulness of divided attention measures as predictors of flight-training success. No such support was found for single-task measures.... As the results indicate, the main difference between flight instructors and students in the dual-task situation appeared on the tracking task, while the performance differences within the student sample were on the digit-processing task. (p. 12)

Other studies have sought factors other than attention switching to account for individual differences in multi-task situations. Damos (Damos, Smist, and Bittner, 1983) retreated from her earlier espousal of a general time-sharing ability and reconfirmed an earlier discovery (Damos & Wickens, 1980) that response strategies are a significant factor in dual-task performance. In a replication of the 1980 experiment, Damos, Smist, and Bittner (1983) again found that within five minutes of dual-task performance, subjects revealed a strategy to perform dual tasks in an alternating, massed, or simultaneous fashion (see page 8). Two possible explanations could be posed to explain these strategy differences. One is that a subject's "natural" strategy could reflect a true individual difference in information processing. The other is that the subject chooses a strategy at random and maintains it throughout the dual-task trials. Damos, Smist, and Bittner (1983) examined these alternative explanations by first identifying strategies among their subjects, and then instructing some of them to adopt a specific alternative strategy. If strategies are "natural," then switching would result in disrupted performance.

Subjects initially using a massed strategy (i.e., responding repeatedly to one task before turning to the other), when instructed to use either a simultaneous or alternating strategy, performed more poorly than subjects spontaneously using either a simultaneous or alternating strategy. Subjects switching to a simultaneous strategy from an alternating strategy evidenced no disruption of performance. Because a simultaneous strategy represents optimal performance, subjects were not tested in switching from a simultaneous to an alternation strategy. Damos, Smist, and Bittner (1983) concluded that massed response subjects do not choose their strategy at random and that they appear to process their information differently than simultaneous or alternating strategy subjects. The subjects who were switched from alternating to simultaneous responding do appear to choose their response at random, given the ease of their transition. The experimental design did not provide evidence on the strategy selection process for the simultaneous subjects. Overall, the results point to both "natural" and "choice" selection factors as sources of individual differences in dual-task response strategies.

The propensity of subjects to either focus or divide attention was investigated by Johnston, Hawley, and Farah (1988). Subjects were presented a long series of briefly presented 4-word arrays. After each array, the subject was presented a probe word that had appeared in one of the array positions and was then asked to indicate in which location the word had been presented. In the focused attention condition, subjects were instructed to attend to a prespecified location of the 4-word array. In the divided attention condition, subjects were instructed to distribute their attention across all four locations. The within-subjects design used 513 Air Force nonpilot recruits.

Subjects were classified into groups of attentional styles dependent on whether they were scored above or below the median in the divided attention and focused attention conditions. The results are presented in Figure 8. Seventy-two percent of the subjects were classified as either divided or focused attenders. A small percentage of subjects were flexible attenders, and about the same percentage were unable to adopt either attentional set. The relevance of these findings is summarized by the investigators:

> Although focused attenders were relatively inaccurate in most conditions, they may be better suited than other subjects to tasks that place a heavy premium on focused attention, that is, on the ability to both <u>attend</u> to some environmental locations and <u>ignore</u> others [authors' emphasis]. These subjects were as proficient as any subjects in terms of their ability to attend to cued locations and were clearly superior in terms of their ability to ignore noncued locations. This ability to ignore certain locations may be beneficial when the stimuli that arise from those locations are always irrelevant and potentially distractive. Divided attenders may be poorly suited to such tasks because of their apparent inability to ignore irrelevant locations and, consequently, their vulnerability to distraction. On the other hand, divided attenders may be better suited than other subjects to tasks that require either complete division of attention or only partial focusing of attention. (pp. 8-9)

		Divided Attention	
		High	Low
Focused Attention	High	Flexible Attenders 13%	Focused Attenders 37%
	Low	Divided Attenders 35%	Non- Attenders 15%

Figure 8. Percentage of subjects classified into four attentional styles.

These subjects were not tracked through training, so correlations with performance measures are not available. Validation of the test awaits a practical selection problem. The test is easily administered on a personal computer, and software and other test materials are available from the University of Utah.

The factors of selectivity and resistance to distraction, considered to underlie the focused-divided attention dichotomy by Johnston, Hawley, and Farah (1988), and the attention switching factor evident in dual-task arrangements (e.g., Damos & Wickens, 1980), had earlier been considered to be separate, identifiable attention processes. Sack and Rice (1974) used a battery of psychological tests to investigate this hypothesis.

Three tests were assumed to measure selectivity of attention: the Group Embedded Figures Test, an adaptation of the Gottschaldt Concealed Figures test, and the Hidden Figures Test V. Sack and Rice (1974) interpreted the "field articulation" defined by performance on the embedded figures tests as a form of selectivity in attention. A person high in attentional selectivity is a high field-articulator (i.e., field independent); a person low in attentional selectivity is a low field-articulator (i.e., field dependent). High field-articulators are presumed to make very sharp distinctions between what is relevant and what is irrelevant in problem-solving situations, whereas low-field articulators attend in a global, undifferentiated fashion in such situations (Sack & Rice, 1974).

Sack and Rice (1974) defined distraction as "an involuntary change in an established attentional focus, as such occurring later in time than selectivity, which refers to the act of establishing a focus" (p. 1004). The three tests used to measure distraction were the Arithmetic Operations Test (math problems interspersed with irrelevant text), the Distracting Contexts Test (locating relevant geometric figures in a matrix of irrelevant figures), and the Cancellation Test (crossing out selected letters on a densely printed page of letters).

Sack and Rice (1974) differentiated attentional shifting (attention switching) from selectivity "which is the very act of establishing the focus in the first place, and hence, occurs earlier in time; it differs from distraction in terms of volition, distraction being involuntary while shifting is not" (p. 1005). A form of the Stroop Color Word Interference Test, an Anagrams test, and the Reversed Triangle Test (requiring reorientation of triangles drawn in freehand) comprised the attentional switching portion of the test battery.

Test scores were predicted to load on three factors extracted using a factor analysis method that compares the obtained matrix against a hypothesized matrix. The hypothesis of three attentional factors was supported by high congruency coefficients of the factor structure and low correlations among the oblique factors. All tests assumed to measure a specific attentional factor revealed high factor loadings on their respective factors. The Stroop test loaded on both the selectivity and switching factors, and the Triangles test loaded on both the distraction and switching factors.

The predictive validity of tests of field independence and selective attention has also been demonstrated in accident rates among drivers. For example, Mihal and Barrett (1976) chose the Rod and Frame Test and the Embedded Figures Test to evaluate attentional capacity in a group of utility company drivers. Included in the test battery were the Gopher Dichotic Listening Test and tests of simple and complex reaction time. Scores from these tests were correlated with a 3-point driving performance scale of no accidents, one accident, or two-or-more accidents during the preceding 5 years. Correlations of the Rod and Frame Test and the Embedded Figures Test with number of accidents were statistically significant at .38 and .24, respectively. Significant correlations were also obtained for the dichotic listening test (r = .40) and complex reaction time (r = .27). Tests of simple reaction time were uncorrelated with number of accidents. The dichotic listening task showed moderate, statistically significant correlations with the Rod and Frame Test and Embedded Figure Test (.46 and .44, respectively). Unfortunately, a multiple regression was not performed on the complete test battery.

A recent development in individual differences research has been the investigation of specific abilities involved in the coordination of separate information processing tasks. Interest in this area is motivated by the need to better understand (and develop predictive tests for) real-life situations in which people are performing several subtasks at once. Real situations, such as flying an aircraft, are characterized by situations in which information must be integrated and coordinated in the pursuit of solving a problem (Pellegrino, Hunt, & Yee, 1989).

Most laboratory investigations using the dual-task paradigm have specifically avoided task combinations that involve coordination in order to understand processes such as time-sharing (see quote by Damos and Wickens on page 9), functional issues such as brain laterality, or the characteristics of attentional resources.

In setting out to research this area, Pellegrino, Hunt, and Yee (1989) established the following goal:

> ... characterizing individual differences in real-time, multitask situations that require the coordination of verbal, motor, and visual-spatial information. We shall refer to such situations as *multicomponent coordination tasks.* We wish to establish patterns of individual differences in performance on multicomponent coordination tasks and, if possible, to relate these patterns to the process models now used in cognitive science to explain performance in a variety of problem-solving tasks, including ones with a real-time component. (p. 176)

The domains of their research effort are the human abilities of verbal comprehension, visual-spatial reasoning, and motor responding. The focus, however, is whether there is an ability to coordinate information received from these domains over and above the ability to process information within each domain. Their model for this coordination ability is shown in Figure 9.

One example of their research is an experiment that presented the subject with a single display with two information areas (see Figure 10). The top portion of the display presents a dynamic display in which the black and white "ships" are moving towards the vertical line. The difficulty of this visual task can be varied in two dimensions: arrival times of the two objects and their speed ratio. The bottom portion of the display presents a message that the subject must comprehend. The message can be made more or less difficult to comprehend by manipulating its syntax. The multicomponent task is to estimate when the ship is to arrive at its destination and answer the question about this judgement. The person can answer only by coordinating the visual observation with a verbal interpretation. Individual differences in coordination ability are provided by varying the difficulty levels of the two tasks. Individual differences in visual or verbal ability are generated by varying the difficulty of one task while holding the difficulty level of the other constant.

Not surprisingly, errors and response time increase as both the spatial and verbal task difficulty increases. What is significant about this research methodology is the regression analysis that enables variance to be partitioned into meaningful components. Pellegrino, Hunt and Yee (1989) report that 72% of the variance on the combined task was stable across periods of practice. For each period, less than 50% of the combined-task variance could be predicted by performance on the individual tasks. Most important with regard to coordination ability,

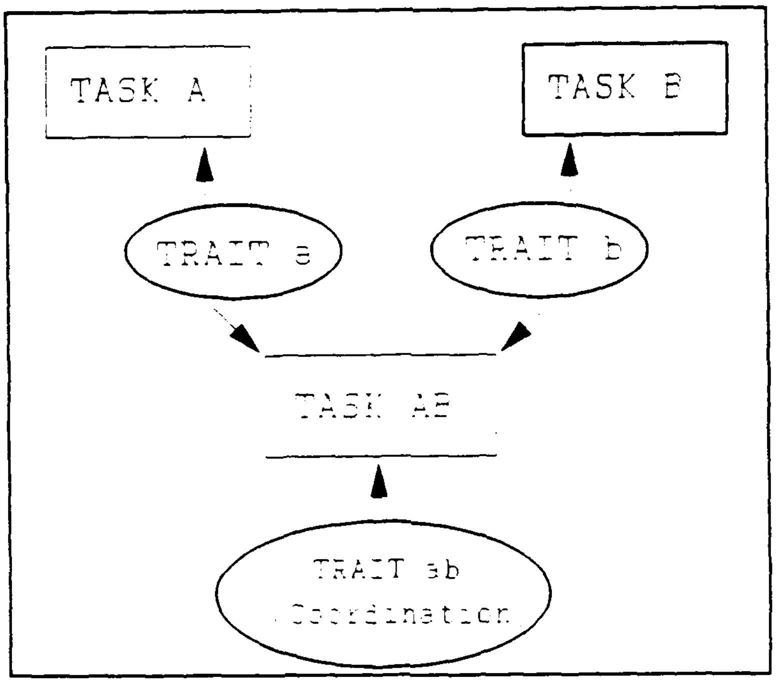

Figure 9. A model for performance on two single domain and one multiple domain task postulating domain specific abilities and a general coordination ability (from Pellegrino, Hunt, & Yee 1989).

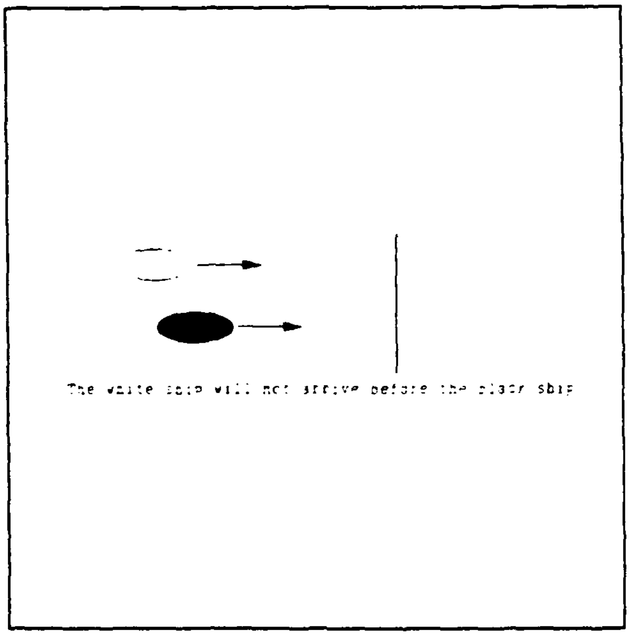

Figure 10. Illustration of the combined visual movement-verbal task (from Pellegrino, Hunt, & Yee 1989).

however, is the finding that 30% of the variance for the combined-task appears to be unique to the combination.

Because this multicomponent research approach is new, its methods and findings need to be investigated with respect to validity and reliability. However, studies have begun to appear to fulfill this requirement. For example, Morrin (1990) used the above tasks and reported finding evidence of coordination ability in females but not in males. He interpreted these results in terms of greater load on the females who demonstrated more difficulty with the spatial task. The results of this study, however, echo a caution that the testing situation may be particularly sensitive to the simplicity of the tasks used (Pellegrino, Hunt, & Yee, 1989).

Conclusions and Research Recommendations

This literature review of information processing and attentional research relevant to HUD and HMD usage was organized around two issues: (a) whether the combined HUD and OTW image evokes serial or parallel processing of the total visual array, and (b) how spatial and object perception affects the processing of information from the combined HUD and OTW image.

With respect to the first issue, research conducted by aviation researchers has strongly suggested that parallel processing of symbology elements and the OTW scene does not occur in an effective way. Fixations on symbology and failure to integrate symbology information into flight control actions are cited as evidence that the activities of monitoring the symbology and viewing the scene outside the aircraft are occurring as serial processes. That is, the pilot attends to one task for some period of time before switching to another. Critical information (e.g., an altitude reading in the HUD, the appearance of an aircraft on the runway during a landing) is not apprehended when it appears, but awaits attention with the interruption of a task occurring in another frame of reference.

The evidence from research in time-sharing also strongly suggests that complex tasks such as reading text while taking dictation do occur in parallel, or in such rapid alternation that performance is effectively parallel. Accumulating experience with multi-task (generally dual-task) situations has resulted in general guidelines in how to facilitate time-sharing performance of two distinct tasks. In contrast, guidance in how to create coordinated tasks that share common information or response requirements is less well established. Dual-task and coordinated task research provide issues and methods that can be of use in determining the problems and potential solutions of HUD/HMD use. These are discussed in the following sections.

How spatial and object perception affect processing of HUD and OTW information does not emerge as an immediate area of research for rotary wing applications at this time. One reason is that the fundamental problem in HUD usage is the switching between the HUD and OTW frames of reference. It appears likely that spatial and object perception are more closely related to the form and arrangement of elements within the HUD than they are to the switching issue. Secondly, at this stage of HUD research, it is important to determine the elements of the HUD or HMD display that pilots look at and for how long (i.e., determination of scanning patterns). Answering these basic questions should precede investigations of the arrangement of elements or how to configure them for maximum information value.

Consequently, using spatial and object attention research issues to explore HUD and HMD issues was not pursued in this review. Other areas of research, however, appear to be more germane. Specifically, the influence of dichoptic viewing, individual differences, and practice effects in coping with the HUD and OTW scene show promise of being potentially important determinants of performance for rotary wing pilots. The importance of brain laterality as a determinant of performance also emerged as a potentially fruitful area of inquiry. Therefore, the review focused on these areas of research.

In the following sections, conclusions drawn from the research literature are focused on potential problems worthy of further research, and the methodologies that appear the most appropriate for conducting the research. The discussion is organized under the topics of research strategies, brain laterality, dichoptic viewing, learning and practice, and individual differences.

Research Strategies

Dual-tasks. Time-sharing of attention resources between the dynamically changing HUD or HMD contents and scene outside the cockpit should provide the overall conceptual framework for an initial series of empirical investigations. The dual-task paradigm has been the predominant structure for implementing laboratory research in time-sharing, and it appears appropriate for HUD and HMD investigations. In contrast to the information processing tasks performed in the laboratory, the primary tasks to be performed should be piloting tasks performed during flight simulations. Concurrent tasks should involve HUD symbology that conforms to current standards and information processing activities similar to those performed during actual flight.

Prior research within the aviation community has taken this approach, but flight simulation has been implemented on workstations with relatively low level graphics. The availability of videotapes of actual helicopter flights affords the opportunity to present the pilot with realistic OTW scenes. In addition, high fidelity Army flight simulators with large terrain data bases provide another research platform. Either means of presenting the OTW view can be instrumented to present superimposed symbology images. Pilots should, of course, serve as the experimental subjects. The need to continue HUD/HMD research in the most realistic operational setting requires this, but it also adds an advantage generally not available with naive subjects. Pilots have developed a variety of schemata and mental models of the aircraft and flight procedures that are integral to performance in the multi-tasking environment of the cockpit. Although it is too early in this research to suggest the role of schema constructs in HUD/HMD usage, the activation, selection, or reprogramming of schemata may be involved in effective use of the symbology.

Wickens' multiple resources model is currently the most fully articulated attention model. In particular, its formulation about the nature of central processing codes (spatial versus verbal) is germane to the processing of the OTW scene and the contents of the symbology display. The other dimensions of the Wickens' model may offer less certain avenues for experimental manipulations. For instance, information input to the pilot will be limited to visual channels and will not be divided between vision and hearing. Likewise, mode of responding will probably be limited to manual responses as the pilot controls the aircraft or acknowledges experimentally manipulated stimuli. However, introducing a verbal versus manual response alternative into the experimental situation may offer the means to determine whether HUD-related interference occurs at the central processing or response generation stage.

Task integration. The dual-task paradigm offers the means of determining performance effects when independent tasks are performed concurrently. Initial research should maintain this independence between a task involving the environment external to the cockpit and a HUD/HMD monitoring task. However, this independence is artificial from an operational point of view because the HUD or HMD symbology presents information that is assimilated into other visual information obtained by looking out of the cockpit. The pilot makes a judgement based on a combination of these immediate sources of information (and other information held in short- and long-term memory), and then executes a response. Therefore, the pilot performs tasks that require information integration in preparation for response execution.

An intermediate goal for HUD and HMD research should be to develop experimental tasks that stress integration of the information from the symbology with other situational information. This will require determining integration strategies that pilots currently use, and combining these with strategies for dividing attention between sources of information.

Brain laterality

Brain laterality research suggests two areas for HUD and HMD research. The first is determining if any relationship exists between the degree of cerebral lateralization and performance associated with HUD or HMD use. Cerebral asymmetry can be determined by hand preference instruments such as the ARI Handedness Inventory (Morey & Simon, in preparation). Given the ease of administering a handedness assessment instrument, handedness data should be routinely obtained in all HUD or HMD experiments.

The second area has to do with examining the effect of HUD or HMD information appearing in visual hemifields. A considerable body of academic literature exists that demonstrates the interactive effect of stimulus material, task demands, and the side of the brain initially receiving the task input. It may be that differential performance effects result depending on which hemifield receives a particular kind of information. Previc's (1989) ideas about placement of information in the upper and lower portions, and especially the upper right-hand quadrant of the HUD, are also relevant.

Various placements of symbology objects in the field of regard may have operational and HMD design implications. One or more experiments could manipulate the forms of stimuli (i.e., text and graphics), and their positions in various quadrants of the display, to determine if any effects due to cerebral functional differences are obtained. These experiments would need to impose restrictions on eye movements to ensure that particular stimulus items were presented to one or the other hemifield.

Dichoptic Viewing

The scant amount of research that has examined attention factors associated with dichoptic viewing suggests that selective and divided attention operates similarly for one- and two-eye viewing situations. However, the question of whether eye dominance plays a role in efficient processing of HMD symbology has not been explored. Because sighting dominance, like handedness, can be easily determined, it appears that HMD-related experiments should routinely obtain sighting dominance data on each subject. If this data suggests an eye dominance effect, further manipulations of left and right eye symbology presentation could be pursued. Investigations into eye dominance might also include measurements of sensory and acuity dominance because the performance implications of these forms of eye dominance are not well documented.

Learning and Practice

Attention research results have shown that effective time-sharing requires sufficient practice with the specific tasks being performed. Because a general time-sharing ability has not been confirmed, experiments involving multiple tasks must provide a sufficient number of learning trials so that subjects can adequately perform the multiple-task requirements. Damos (1991) reviewed research studies that specifically looked at learning (practice) issues using traditional dual-task combinations with uncorrelated stimuli and two response channels. One issue experimentally tested was whether practice should involve single-task trials, dual-task trials, or a combination of both to efficiently attain dual-task proficiency. The answer is unequivocal with respect to single-task practice: the amount of single-task practice has little effect on subsequent dual-task performance. Although the answer to which combinations of single- and dual-task practice facilitate obtaining asymptotic performance is less clear, the best guidance is to provide nearly all practice under the dual-task condition. The same conclusion appears warranted for coordinated-task conditions.

Therefore, despite the fact that pilots are familiar with attending to both the instruments and the OTW scene, the HUD or HMD situation requires practice in dealing with the instrument symbology presented in head-up mode. Experiments using the HUD or HMD should start by providing familiarization and practice with the symbology display. The experiment should then provide sufficient trials with the superimposed symbology and OTW scene to collect reliable practice data.

Individual Differences

Individual differences in time-sharing strategies, attentional switching, and ability to divide and focus attention emerged as potential areas for HUD-related research. Time-sharing strategies occupy both the abilities and the acquired skills domains. Experimental subjects have been shown to "naturally" adopt a simultaneous, alternating, or massed strategy in dual-task experiments. On the other hand, time-sharing is amenable to training, as was shown in Gabriel and Burrows' (1968) study of pilot scanning patterns. In either case, HUD and HMD experiments should provide for observing the attentional strategies that pilots use spontaneously or report using the basis of their experience with the symbology displays. Visual scanning data is another potential source of information helpful in making these determinations and may be especially useful because they offer more empirical, objective evidence than do self-reports. Experiments specifically designed to study the effectiveness of strategy training would provide results having both theoretical and practical implications.

Attentional switching and the ability to divide or focus attention belong more clearly to the individual differences domain. Attentional switching has been recognized as a potential pilot selection variable since the publication of Gopher and Kahneman's findings in 1971. The question of the relative importance of divided and focused attention skills for rotary wing pilots is another potential area for further research. It appears that both skills are necessary, but there is no evidence of how both these skills are related to HUD or HMD usage in particular or to rotary-wing piloting in general.

Individual differences in attention should be examined as a part of any HUD or HMD experiment. Not only would this data help to account for variance in the dependent measures of the experiment, but it would help in the validation of attention measures as a useful pilot selection dimension.

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