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By

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ABSTRACT

EFFECT OF SIMULTANEOUS VERSUS SEQUENTIAL DISPLAY OF VISUAL INFORMATION ON DECISION ACCURACY: MODERATING EFFECTS OF DECISION CONTEXT

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This effort examined three avenues of research (i.e. decisionmakng; automatic versus effortful cognitive processes; visual cue characteristics) to predict patterns of decision error when complex information is visually displayed. Complex information is increasingly represented by perceptual cues configured to enhance an intuitive recognition-based response, through simultaneous display of visual cues configured as an overall pattern. These configural displays have been associated with better performance on divided attention tasks, when compared to cues that are usually perceived separately. However, it is proposed here that sequential presentation of cues that are part of a configural pattern will be more easily perceived as separate and will facilitate more effortful consideration of cue information and will result in higher accuracy when the decision context is favorable. Favorability of context is determined by both task characteristics (degree of time pressure, ambiguity of information, conflict among cues, irrelevant frame information) and individual characteristics (cognitive ability, cognitive style). In addition, while research participants in the sequential condition were predicted to perform more accurately than those in the simultaneous display condition when the decision context is favorable, they were expected to be less accurate when the decision context is degraded. Nine perceptual cues such as location, size, color, length and direction of arrows, and audio pitch/tempo were chosen to be easily interpreted, in this case to represent location, size, type of radar (red = hostile), speed and direction, and electronic signal. Results supported expectations when comparing performance under task conditions that were most favorable versus most degraded. Information display condition differed on type and degree of

decision error. Subjects in the simultaneous condition were more susceptible to error due to averaging cues inappropriately. In contrast, subjects in the sequential condition were more susceptible to anchoring-and-adjustment error, where preliminary information is weighted more than subsequent information. It was also found that subjects in the simultaneous condition made their judgements more quickly, even when they had more time to make their decision.

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INTRODUCTION

For the past 40 years, researchers used rational models of decisionmaking to describe and predict decision making behavior (Edwards, 1954; Einhorn & Hogarth, 1981; Hammond, 1955; Payne, Bettman, & Johnson, 1988; Savage, 1954). These models serve as criteria by which decisionmaking performance can be assessed when the decision task is essentially rational. Certainly, criticisms have been raised when the rational model is applied to decision situations which include nonrational and/or suboptimal elements. Such elements include variables such as values, commitments, personal impact, societal factors, and overarching goals (Beach & Lipshitz, 1993; Hernstein, 1990; Orasunu & Connolly, 1993; Thibaut & Walker, 1978; Zey, 1992); dynamic complexity (Beach et al., 1993; Cohen, 1993); tasks involving problem structuring and interpretation of ambiguous cues (Mintzberg, Raisinghani, & Theoret, 1976; Orasunu et al., 1993), social decision making (Fiske & Taylor, 1991), and organizational decision making (March & Shapira, 1992; Simon, 1955; 1990; 1992), among others (Jacob, Gaultney & Salvendy, 1986; Payne, Bettman, & Johnson, 1992; 1988). Nontheless, when the decision task is composed of quantitative elements which can be calculated to produce an unequivocally correct decision, the rational model serves as providing an "ideal" from which decision errors can be identified and described.

Individual limitations and biases. Within this boundary condition of rational tasks (i.e. tasks in which decision rules can be applied to ascertain a correct response), there is no doubt that systematic patterns of decision error occur (Edwards, 1954; Jacob, et al., 1986; Kahneman &

Tversky, 1972; Kahneman, 1991; Kahneman, Slovic, & Tversky, 1982; Massaro, & Cowan, 1993; Meehl, 1957; Payne, et al., 1988; Simon, 1955; Slovic, Fischoff, & Lichtenstein, 1977; Stevenson, Busemeyer, &Naylor, 1990; Tversky, 1972, 1977). These errors are usually attributed to limitations in human information processing capabilities such as working memory, long-term memory, and processing speed. The predictability of these errors suggests that these constraints result in simplifications, biases and distortions in individual information processing and decisionmaking, resulting in patterns of error such as overconfidence, representativeness, framing effects, availability, and illusory correlation (Kahneman & Tversky, 1972; 1982; Kahneman, Slovic & Tversky, 1982; Kleinmuntz, 1990).

Decision errors have also been associated with socio-cognitive and emotional factors. Thus decision errors can result from cognitive limitations such as a limited working memory capacity (Massaro & Cowan, 1993), and also from biases in social perception (Fiske & Taylor, 1991; Nisbett & Ross, 1980), differences in attitudes or values (Hammond, Harvey, & Hastie, 1992) and/or emotional distress (Parkinson & Manstead, 1992).

From these observations, alternative models of decisionmaking have arisen to better describe and predict individual decisionmaking. In order to explain decisionmaking in dynamic, complex situations, alternatives to the rational paradigm have been proposed that are more intuitive in nature (Hammond, Hamm, Grassia, & Pearson, 1987; Klein 1993; Klein, Orasunu, Calderwood, & Zsambok, 1993; Orasunu & Connolly, 1993; Zey, 1992). These alternatives focus on explaining decision processes and the role of cognitive ability and expertise, under conditions that are typically complex, ambiguous, and/or stressful.

Alternatives to the rational paradigm are generally simplified models of decisionmaking, to better reflect individual decision processes under conditions more representative of naturally occurring conditions of complexity, ambiguity, uncertainty, and time pressure. Many alternatives to rational models exist, such as image theory (Beach, 1990; 1993; Beach & Lipshitz, 1993; Beach & Mitchell, 1978), recognition-primed decisionmaking (Klein, 1993), satisficing (Simon, 1955), cognitive continuum theory (Hammond, et al., 1993), and various simplification strategies (Stevenson, Busemeyer, & Naylor, 1990). In support of the efficacy of these simplifying and/or satisficing strategies, Dawes (1982) demonstrated that simplifying heuristics such as averaging cue weights can still provide accurate estimates. The particular weighting scheme had less impact on accuracy; the deletion of one or more cues had a greater effect in producing error. Similarly, Gilliland, Schmitt, and Wood (1993), Kerstholt (1992), and Payne, Bettman, & Johnson (1988) demonstrate tradeoffs of different decision models and accuracy. Hogarth (1981) argues that biases assumed to be dysfunctional can actually be functional when decisions are made in a naturalistic and dynamic setting over a continuous length of time. It can be seen that alternative models have arisen in response to decision outcomes not well explained by traditional models of rational deliberation and from findings that alternative strategies can be effective in some circumstances. It is evident that we need to more fully develop and specify alternative models that fit these decision situations.

Investigation of visual displays. At the same time that human limitations and individual differences were investigated as sources of decision error, a complementary stream of research focused on effects of characteristics of the decision task that elicit systematic errors in decisionmaking performance. Thus characteristics such as information complexity, volume, tempo, ambiguity, and differences in how the information is presented are studied as manipulations. This perspective drives the field of cognitive engineering, where artificial intelligence, decision aiding, and information presentation displays are designed in order to create a decision context which maximizes advantages of computer driven analysis of data versus reliance on human cognitive processes.

The manner in which decisionmakers are presented with information has been related to systematic differences in decisionmaking performance. The results regarding relationships among visual cue characteristics and performance suggest performance can be enhanced by matching these characteristics with the cognitive demand of the task. Visual display characteristics have been related to decision processes and performance (Andre & Wickens, 1992; Bennett & Flach, 1992; Boles & Wickens, 1987; Coury, Boulette, & Smith, 1989; Coury, & Boulette, 1992; Hammond et al., 1987; Sanderson, Flach, Buttigieg, & Casey, 1989; Wickens, 1986; 1990; Wickens & Andre, 1990). Visual cues have been found to affect to differentially affect performance, depending on whether the decision was to be based on focused attention, divided attention, or the integration of all cues. In general, it has been found that cues which are easily distinguished results in higher accuracy in tasks requiring focused attention, and cues configured as an overall pattern are better when cues must be integrated (Bennett & Flach, 1992; Pomerantz & Pristach, 1989; Sanderson, et al., 1989).

Theories relating information display characteristics to decision performance are mainly based on relationships among basic cognitive processes such as attention and working memory and performance on visual search and discrimination tasks. Triesman (1986) provides a review of the literature on findings related to object perception and performance. Decision performance is enhanced when the information is presented in such a way as to reduce cognitive effort in data collection, working memory, and integration of cue information.

Visual representation of information usually accomplishes integration of information by capitalizing on the human capability of pattern recognition. In their discussion of graphic displays and cognitive processes, Bennett and Flach (1992) state:

"There appears to be a clear consensus that performance can be improved by providing displays that allow the observer to utilize the more efficient processes of perception and pattern recognition instead of requiring the observer to utilize the cognitively intensive processes of memory, integration, and inference. Thus this type of display (geometric object formats) has the potential to improve decision-making performance by shifting the burden of responsibility from cognitive processes that are severely limited (e.g., working memory) to cognitive processes that, with learning, are virtually unlimited (e.g., object perception and pattern recognition)" (p. 514).

Studies of visual display characteristics support the use of cues configured as a pattern when cue attention must be divided or when information must be integrated. However, in this study, an argument will be presented that separable cues can be more effective, and that the favorability of the decision context is an important moderating variable. Simultaneous presentation of visual cues has been associated with a more intuitive decision process (Hammond, et al., 1987). While descriptions of intuition vary, intuitive decision processes in general have been characterized as less effortful, less rational, and more prone to error. Thus, there appear to be conflicting evidence regarding the efficacy of visual pattern displays and the more intuitive decision process which has been associated with it.

Visual displays are extensive in aviation and military settings, such as air traffic control, aircraft cockpits, and command-and-control centers. They are also common in business, academic, and recreational settings. As distributed units with unique perspectives (e.g. military theater of war, global corporations, multi-national scientific research) become more extensively linked, coordination will be even more dependent on visual representation of strategic information. Given the widespread prevalence of visual display of information, questions naturally arise regarding the impact of task characteristics and individual characteristics on decision performance within this context.

Purpose of the Present Study

This study examines the impact of individual and task characteristics on decision accuracy in a rational task where information is presented in a visual display format. It is predicted that sequential versus simultaneous display of visual information would affect the degree of cognitive effort in the decisionmaking process, and would be typified by different patterns of decision error. In addition, it is further predicted that the patterns of error would be affected by the favorability of the decision context, as indicated by characteristics of the decisionmaker and of the decision task. Given an objective decision task which requires integration of several information cues, the sequential display of visual cues is predicted to result in higher performance than simultaneous displays when conditions are favorable. Sequential display of visual information is expected to direct attention to each cue and the decision rules associated with cue interpretation, resulting in more effortful processing of information.

Sequential consideration of each cue is expected to lead to more accurate assessments when the process is allowed to occur under favorable conditions, that is, when there is complete and certain information, and sufficient time to consider all information and decision rules. Favorable conditions also include characteristics of the decisionmaker; that is, decisionmakers who are highly capable for the task. Capability can be a function of skill, expertise, cognitive ability, and/or cognitive style.

If decisionmakers base their decisions on an overall impression, as predicted to occur with simultaneous presentation of a pattern of visual information, the impression can usually be modeled by an averaging or "summing up" strategy--when cues are highly intercorrelated, this stratgey would be very effective. Even when cues are not usually intercorrelated, the averaging strategy woud be effective when all cues are in agreement. However, if complex decision rules must be considered, such that the value of one cue cannot be interepreted without knowing the value of one or more other cues, an averaging strategy can be quite ineffective. Of course, if decisionmakers have memorized all possible patterns, the averaging strategy would be minimized--the decisionmakers would respond with certain recognition. When the number of possible patterns is small, recognition is easily achieved; however, when there are numerous patterns, it is more difficult.

When the decision context degrades, research participants in the sequential display condition are expected to be more vulnerable to error than those in the simultaneous display condition. The higher amount of cognitive effort expected to occur in this condition would also be more likely to be disrupted when conditions are unfavorable. Thus, characteristics such as time pressure, information ambiguity, and information conflict were expected to interfere with sequential and rule-based consideration of cues. In contrast, research participants in the simultaneous display condition are expected to react quickly with a more automatic response, less vulnerable to time pressure or considerations regarding missing information.

In this study favorability of decision context is indicated by four task characteristics and two individual difference variables. Task characteristics expected to affect favorability include time pressure, information ambiguity, information conflict, and irrelevant frame information. A favorable task context occurs when there is low time pressure, no ambiguity, no conflict, and no irrelevant information. Favorability of the decision maker will be measured by cognitive ability and cognitive style. A desirable decisionmaker in this context is one who has high cognitive ability and a deliberative, fact-based style of information processing.

Background

It is predicted that simultaneous presentation of visual cues will be perceived as a holistic pattern and will facilitate intuitive, recognition-based assessment. In research regarding visual information display, the simultaneous display created for this study is consistent with the concept of a configural visual display. A configural display has emergent properties such that an overall pattern can be perceived.

In contrast, sequential presentation of the same cues is expected to focus attention on individual cues and the decision rules by which these cues interact to determine the correct assessment. Sequential presentation is therefore expected to enhance decision accuracy when this more deliberate and effortful process can occur, with complete information, explicit decision rules, and no interuptions or limitations to the infomation processing required to apply the decision rules. When the decision context is degraded, deliberation is hampered, interupted, or stopped; consequently decision performance is degraded. These effects are expected to be less degrading for decisionmaking in the simultaneous condition. The following section reviews existing knowledge related to information display characteristics and task performance.

Visual Cue Characteristics and Task Performance

As decision tasks become more cognitively demanding, individual differences in abilities such as processing speed, working memory, and dual task capability define the limits of decision performance. At the same time there has been corresponding effort to analyze decision tasks for their cognitive demands, to (a) predict performance given a particular task and (b) redesign the task to facilitate performance.

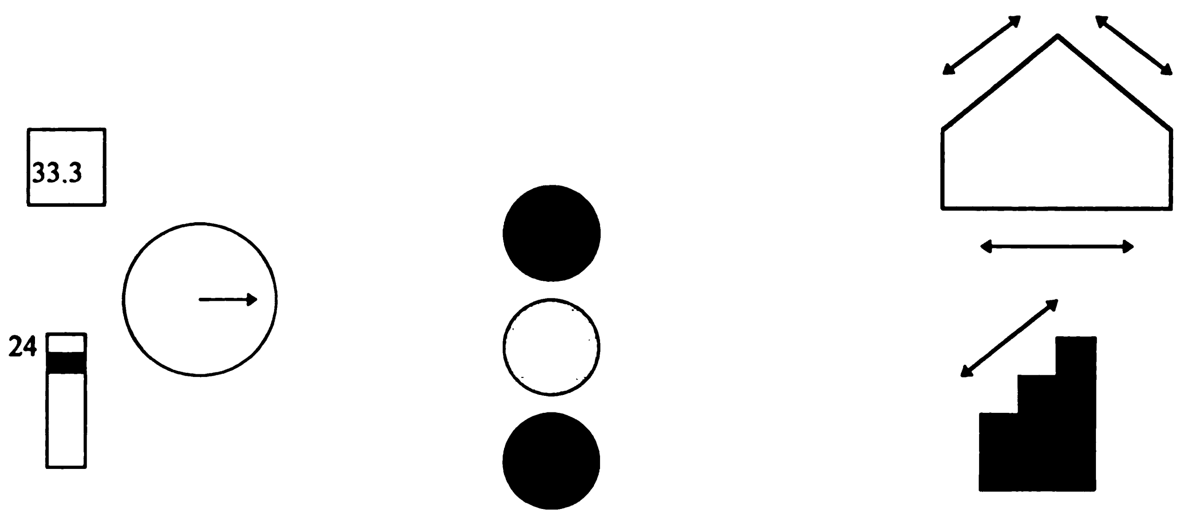
Many studies have been performed which demonstrated that decision performance is affected by the manner in which information is presented to research participants (Barnett & Wickens, 1988; Boulette, Coury & Bezar, 1987; Carswell & Wickens, 1987 1990; Coury & Pietras, 1989; Woods, Wise, & Hanes, 1981). These findings have been explained by relating display characteristics to cognitive aspects of the decision task.

Perception of visual cues. Bennett and Flach (1992) reviewed findings regarding the congruence of visual display characteristics and the cognitive demands of the decision task. Several theories relate visual display characteristics to types of cognitive task (Barnett & Wickens, 1986; Casey, 1986; Pomerantz & Pristach, 1989; Sanderson, Flach, Buttgieg, & Casey, 1989; Wickens, 1986), predicting higher performance when the visual display characteristics are congruent with the cognitive demand of the decision task.

The visual representations of information are often distinguished on the basis of the separability of individual information cues. Separable cues are defined by a lack of interaction among the stimuli, such as color versus shape. With these cues, the cognitive demand is characterized by ease of selective attention, somewhat more effort for divided attention, and no gain from redundancy. In contrast, integral cues are redundant, such that a change in one cue results in a change in the other perceptual cue, such as a traffic light having "stop" represented by both color (red) and location (top). This results in a redundancy gain, but makes it difficult to focus attention on one cue only, thus making selective attention and divided attention more effortful.

A third category, display of configural cues, is a mix of separable and integral characteristics. With a configural display, each cue can be perceived as a separate entity, but new emergent properties are created when these cues are perceived together (See Figure 1). For example, if the length of five individual lines were separate cues configured in a geometric shape, the overall shape is an emergent property. Changes in the shape of the overall figure can be more easily perceived than changes in individual line lengths. Bar graphs can also contain an emergent feature, if there is attention to general trends in the graph (e.g. attending to whether the bars increase or decrease in a particular pattern). Changes in the emergent property may better elicit perceptions of change as opposed to attending to the individual cues separately. Figure 1 provides examples of each type of visual cue and the cognitive processes which are best accommodated by each type of cue. The next section discusses the matching of visual cue characteristic and cognitive task demand in further detail.

Figure 1. Types of Visual Cues.



Separable Cues
(Control Task)
(Selective Attention Task)

Integral Cues
(Redundant Task)
(Correlated Task)

Configural Cues
(Divided Attention Task)
(Integration Task)

Type of visual display and performance. The effectiveness of these three types of cue display has been related to the type of cognitive task being performed. Bennett and Flach (1992) describe four types of cognitive tasks which should be considered when designing displays. They differ in the focus of attention which is required.

In the control task, the individual need only attend to one cue which varies, and the other cues are held constant. For this type of task, displays of separable cues are considered most conducive to effective performance. In the selective attention task, the individual still focuses on one cue, but the other cue(s) varies. In this type of task, separable cues are also most appropriate. In the correlated or redundant task, cues vary simultaneously and discrimination can be made by attending to either or all cues. For this task type, integral cues would provide a redundancy gain. In the divided attention task or cue integration task, variations in all cues must be considered, and Bennett suggests that a configural display, with its separable elements and emerging qualities, would facilitate performance (Bennett et al., 1992), based on the cumulative findings of many studies.

Consistent with Bennett's conclusions, Wickens' compatibility of proximity theory predicts effects of visual displays based on perceptual aspects of divided and focused attention (Wickens, 1986; Wickens & Andre, 1990). He states that if the task requires focused attention on a single cue, the display with separable cues would be more effective, but if the task requires integration, an object (configural) display is better. For example, Wickens and Andre (1990) found that when indicators of aircraft stall danger were distinct in color focused attention was improved but integration of information was disrupted. If the cues were presented as an object rather than a bar graph, information integration was improved but focused attention performance degraded.

Research supports the finding that when the task is one that requires cue integration, the use of a configuration of cues (object) is effective. Coury et al. (1989) found that such displays are particularly effective when the decision task is based on multiple cues where the values of these cues are correlated. In these circumstances object displays have been found to be consistently superior to alphanumeric displays. This is explained as the result of enabling the subject to recognize a unique object configuration for a particular decision response category. The physical representation of these cues creates a configuration with unique features which can be mapped to the underlying state represented by the cues. According to Wickens (1986) object displays enable rapid holistic integral processing of system cues.

Sanderson et al. (1989) adds that the display does not need to be an object per se, such as a geometric shape, but any figure can be configural if it contains an emergent feature. For example, if one uses a configuration of three lines formed as a triangle, if the lines represent values which must be monitored, when the lines change in length, so do the angles of the triangle. In this way the angles of the triangle are emergent features which represent additional or consolidated information. Sanderson points out that even bar graphs (separable cues) can have emergent features. To illustrate, the viewer may attend to a configuration of the bars (increasing to the right or left) rather than the values of the bars per se. According to Garner (1978) emergent properties may be functions of symmetry, repetition, intersections, conjoining, and angular separation. The attention to the emergent features is enabled by the pattern recognition capability of the viewer (Bennett & Flach, 1992; Sanderson et al, 1989).

Simultaneous versus Sequential Display of Visual Cues

The simultaneous presentation of visual/audio cue information in this study provides a configural display with strong emergent features. The visual representations were chosen to be easily interpreted--size is indicated by size; location by location; speed and direction by length and direction of arrows, etc. (see Figure 10). In the sequential display the same cues are presented beginning with one cue (location) and adding cues one at a time such that when all cues are presented the display is equivalent to the simultaneous condition.

I expect that sequential presentation of the same information produces more separable information cues, because they are presented one at a time in a cumulative fashion. Thus, in contrast to conclusions that configural displays are best for divided attention tasks (Bennett et al., 1992; Wickens & Andre., 1990), it is argued here that sequential presentation will lead to greater accuracy when decision rules are complex and conditions for decisionmaking are favorable.

The task in this study requires consideration of all cues, according to interactive decision rules. Because the cues are not redundant, and because simply averaging the information cues can result in error, in this situation the more configural (simultaneous) display does not have a strong advantage. The emergent feature in the simultaneous condition is the overall impression one perceives from the pattern of cue information. However, an appraisal based on an overall impression is expected to be associated with increased error compared to assessment based on systematically considering each cue. Sequential presentation of cue information is expected to facilitate more effortful and systematic consideration of cues and decision rules.

This task has nine information cues and four decision rules, and thus systematic and effortful consideration of each cue will result in more accurate assessments. When there are many cues and cue interactions to consider, a large variety of possible patterns can result, making it difficult to easily recognize each unique pattern. Thus reliance on an overall impression by an inexperienced decision maker is likely to result in increased error. In contrast, the sequential display of these cues should facilitate more effortful consideration of each cue and decision rule, and thereby lead to more accurate assessments.

Resistance to degraded circumstances. While the sequential display of visual information is expected to result in higher decision accuracy, it is also predicted that more deliberate consideration of cues will be more vulnerable to degrading task conditions such as time pressure, ambiguity, and conflict and to degraded information processing due to differences in individual cognitive style or cognitive ability. When conditions are degraded, the sequential display condition is expected to result in lower accuracy due to greater interference. In contrast, the simultaneous display condition is expected to be more robust to degrading conditions.

The rationale for this expectation may be better understood within the context of the cognitive task demand of the decision. The decision task used in this study is complex, such that many different visual patterns can arise, making recognition more difficult. In addition, interactions among the cues must be considered in order to calculate the correct assessment. The task demands analytical deliberation of the cue information in order to calculate the correct assessment.

It is expected that sequential presentation of cue information will be associated with a higher degree of effortful deliberation on the part of the decision maker, and this match with the task demand will facilitate performance. On the other hand, it is expected that simultaneous presentation of cue information will be associated with a higher degree of intuitive, recognition-based decisionmaking. This recognitional process is expected to be less accurate than effortful deliberation of complex information, but more resistant to detrimental effects. Thus, while research participants in the sequential condition are expected to perform more accurately under favorable conditions, research participants in the simultaneous display condition are expected to perform more accurately under degraded conditions, due to the type of decision error elicited by these displays. Decision processes and associated decision errors are discussed in chapter 2.

Chapter 2

VISUAL DISPLAYS, PERCEPTION, AND DELIBERATION

In this study, it is expected that simultaneous versus sequential visual display of information will be associated with differences in amount and type of decision error. These errors are thought to arise from elicitation of decision processes that differ in degree of deliberate versus automatic processing of information. Sequential presentation of visual cues are expected to elicit a more controlled cognitive process, while simultaneous presentation is expected to be perceived as a holistic pattern, initiating a recognition response which varies in level of certainty. When recognition is certain, the response is fast and accurate. When recognition is uncertain, the response is more intuitve and less accurate.

Effortful delibertion of information cues and decision rules should result in higher accuracy than intuitive processing when information cues are certain and decision rules are explicit. Sequential presentation of cue information is expected to result in higher accuracy than the simultaneous display condition. However, effortful processing requires more cognitive resources and thus requires accurate information, an explicit algorithm, and enough time to process all information according to rules. Thus, it is more vulnerable to conditions such as time pressure, uncertainty, and conflicting information. A recognition-based response is expected to be more resistant to degrading contextual factors such as time pressure. The following section reviews the current thinking regarding the conceptualization of these different processes, and the impact of information display characteristics on decision processes.

Display Characteristics And Decision Process

As noted previously, researchers investigating effects of visual displays of information expect to enhance decision accuracy through design of displays which allow ease in perception and pattern recognition (Bennett & Flach, 1992). Similarly, in this study, it is proposed that the automatic and/or intuitive processing of information elicited by visual display features have different patterns of associated errors when compared to more effortful deliberation of information. Further, aspectes of the decision context are expected to moderate the impact of visual display characteristics and decision performance.

The proposal that visual display will affect type of error is not new. Hammond (1987) included display features as one of the task characteristics affecting the manner in which information is processed. He predicted that congruence between the process (intuitive or analytical) required by the underlying cognitive demand of the decision task and the process elicited by surface characteristics of the decision task, such as information display features, would facilitate decision performance. Similarly, in this study the cognitive demand is expected to be associated with differing requirements for effortful and deliberate analysis of information and that task characteristics are expected to affect the level of cognitive effort in the decisionmaking process. However, specific mechanisms and predictions differ from Hammond's.

This study distinguishes between display conditions and other characteristics of the decision context. Cognitive demand and display of information are expected to be of fundamental importance in influencing the process by which the decisionmaker responds. Other characteristics, such as time pressure, ambiguity, conflict, and capability of the decision maker, formulate the decision context. The favorability of the decision context is distinguished from display condition and are instead proposed as important moderator variables affecting the relationship between display and performance.

While these decision context characteristics are included in Hammond's list of decision task characteristics affecting decision process, they are distinct from the cognitive demand of the task. The underlying cognitive task demand can be represented by the complexity and specificity of decision rules used to assess and integrate information cues. Thus, if a decision task had explicit and complex rules by which information should be considered, the cognitive demand indicates that systematic deliberation is congruent with the task. Other characteristics are proposed to be characteristics of the decision task context. These variables may include many aspects, such as time pressure, incomplete information, conflicting information, consequences of error, and requirements for sustained performance over a long period of time; or as characteristics of the decisionmaker, such as expertise, experience, fatigue, cognitive ability, and cognitive style.

Congruence between cognitive task demand and cognitive process is expected to be an important predictor of decision accuracy, as predicted by Hammond (1987), and it is predicted here that effortful and analytical processing of information in a task comprised of complex and explicit decision rules will result in higher accuracy, but only when the decision context is favorable. When the decision context in unfavorable, attempts at effortful processing is impeded and interrupted, resulting in lower accuracy compared to a more intuitive, less effortful approach to decisionmaking.

First, Hammond's cognitive continuum theory will be described, followed by a section discussing the existence and differentiation of effortful analysis versus more intuitive cognitive processes. Chapter 3 describes and discusses specific predictions made in this study.

Cognitive continuum theory. Hammond's cognitive continuum theory maintains that human information processing varies along a continuum that ranges from very analytical to very intuitive. Within the middle of this continuum lies "quasirationality," which he states is similar to "common sense" or "bounded rationality" (Hammond, 1987). His cognitive continuum theory is based on the assumption that characteristics of the decision task will elicit analytical or intuitive decision processes, which in turn are associated with different types of decision error. He related task characteristics such as type of information (perceptual or quantitative), time pressure, uncertainty, etc. (see Table 1) to elicitation of analytical versus intuitive decision processes.

According to Hammond, if many or all of the task characteristics are those that elicit one form of decisionmaking, that type of decision process will be elicited. For example, he states that if the task includes (a) many redundant cues, (b) the cue values are continuous, (c) the cues are measured perceptually, and (d) there is no underlying principle for assessing the cues, the subject will respond with intuition, with the corresponding decision weighting scheme characterized by a simple summation of the cues.

Table 1.

Task Characteristics Associated with Intuitive and Analytical Responses (Hammond et al., 1987)

	Intuition	Analysis
1. Number of cues	> 5	< 5
2. Measurement of cues	perceptual	objective
3. Distribution of cue values	Continuous	Unknown
4. Redundancy among cues	High	Low
5. Decomposition of task	Low	High
6. Degree of certainty	Low	High
7. Cue-criterion relation	Linear	Nonlinear
8. Weighting of cues	Equal	Unequal
9. Organizing principle	Unavailable	Available
10. Display of cues	Simultaneous	Sequential
11. Time period	Brief	Long

The characteristics of a decision task were combined to form a task continuum index, described as the extent to which a decision task will elicit analytical to intuitive responses. A cognitive continuum index was generated to represent the degree to which a decision response was analytical versus intuitive. Congruence between the task continuum index and the cognitive continuum index was investigated for impact on decision performance. Hammond reported that task characteristics did elicit predicted variations in intuitive and analytical decision strategies.

While Hammond reported a direct comparison of analytical versus intuitive response, there is little knowledge as to the relative importance of these task characteristics in this elicitation, and alternative explanations can be generated for the results. For example, his manipulation crossed three clusters of task display thought to elicit intuition (visual pictures under high time pressure), quasi-rationality (bar graphs under time pressure), and analysis (requirement to produce formulas to derive and justify responses, no time pressure) with three types of task content corresponding with intuition (highway aesthetics), quasirationality (highway safety), and analysis (highway capacity). Research participants were experts with these tasks.

Contrary to predictions, performance was often higher when the display was intuitive (i.e. visual picture) even when the decision content was analytical (assessment of highway capacity). This may also be by reason of familiarity and experience in that research participants are used to using visual pictures for these determinations, and have already associated visual representations of highways to aspects such as safety and capacity. While results were not entirely as predicted, they demonstrate the interesting aspect of this study, that visual display elicited an intuitive response as measured by Hammond, and that the visual display manipulation resulted in higher performance even when the task was analytical.

Analytical Versus Intuitive Processes

Predictions from display theories assume that intuitive decision processes can be elicited and differentiated from more analytical processes. While Hammond's cognitive continuum theory has intuitive decision process as a primary construct, the construct is not specifically described. At this time the construct of "intuition" is almost useless due to the lack of a consistent definition.

Existing definitions were reviewed in order to identify inconsistencies and clarify the construct as used in this study. Because inconsistencies were found, a framework was generated to identify the differentiating characteristics of the intuitive decision process.

This section will discuss the existence of intuitive versus analytical processes, with the intention of organizing the various descriptions of intuition, and specifying what is meant by intuition in the context of a rational task. Many researchers have discussed distinctions between an effortful, deliberate, analytical decision process versus one that is nonanalytical, or intuitive. While most agree on what is meant by an analytical process, there are various and somewhat contradictory definitions of intuitive processes. Intuition at this time is a very fuzzy notion.

General definitions. What Hammond (1987) refers to as an "analytical" process, others have referred to as "rational" in nature. When compared to the nonanalytical "intuitive" process, a primary distinction is the cognitive effort involved in the process. This distinction can be captured by the use of the term "deliberative" process, which is descriptive of the effortful deliberation inherent in a rational or analytical task. In this discussion, the process described as the effortful, analytical, sequential processing of information will be referred to as the "deliberative" process.

Intuition has been described as the counterpoint to rational thought (Epstein, 1994). For example, Beach and Mitchell (1978, Mitchell & Beach, 1990) refer to "non analytical" strategies, where deliberate consideration of all alternatives is bypassed. Similarly, Kahneman and Tversky (1982a; 1982b) describe intuitive judgments as composed of an unstructured process which includes no deliberate calculation or analytical method. However, it is not very precise to define the intuitive process by what it is not.

Most researchers will agree that intuition is not deliberate, effortful, or analytical. There is growing agreement that unconscious, implicit processing of information does occur (Reber, 1993; Schacter, 1987; Seger, 1994). However, this still does not provide us with a succinct definition of intuition. Definitions of intuition cover many different phenomena, ranging from scientific insight to parapsychic prophesy (Agor, 1989; Vaughan, 1989). The following section reviews existing formulations of intuition, followed by the conceptualization adopted for this study.

Some authors have equated intuition as any human decision process that is not a specific decision algorithm (Denes-Raj & Epstein, 1994; Kleinmuntz, 1990). For example, Epstein (1994) proposed two fundamental processes, the rational system and the experiential system, as means by which individuals assess the environment and make judgments. According to Epstein, the experiential system includes heuristics, intuition, and affect. Epstein represented intuition as holistic, affective, associationistic, and more automatic than the separate process of objective reasoning. The intuitive process was also represented as the source of all deviations from rationality. In contrast, the rational system was presented as an information processing capability that is conscious, analytic, and logical, with more highly differentiated responses.

Many other researchers have proposed multiple information-processing systems that include a process which is unconscious, automatic, and/or affective in nature. These proposals range from the historical contributions of philosophers such as Aristotle (experiential versus rational knowledge) to conceptualizations from psychodynamic, experimental-cognitive, developmental, and social-cognitive perspectives (Epstein, 1994). Epstein provided a compelling network of arguments that these variations on multi-modal processes converge on the identification of a conscious, rational, deliberative system and a second system that has characteristics of automaticity, experiential knowledge, and emotionality.

It is proposed here that the intuitive decision process associated with configural visual displays is based on the cognitive process of recognition. This recognition process is expected to differ from deliberation by the manner in which cue information is processed. Recognition is based on simultaneous processing of cue information such that the decision object is perceived as a whole, without conscious deliberation of each cue. Research reported within the field of cognitive science supports this view.

Intuition as an automatic process. Certain recognition is an automatic process. Logan (1988) provides a clear discussion of automatic processes, and while there are intriguing discussions as to the explanatory mechanisms underlying automaticity, there is agreement that automaticity is fast, effortless, consistent, and unavailable to conscious awareness. Processes described as automatic include procedural knowledge (Anderson, 1983), implicit or tacit knowledge, and implicit learning (Reber, 1993). These processes are considered to be automatic, entailing little conscious effort.

Cognitive scientists have proposed a model of information processing, based on cognitive architectures that enable simultaneous processing of information (Lord & Maher, 1991). Lord and Maher provide an extensive review of cognitive theory in decisionmaking. In their review they outline the differences between symbolic and connectivist cognitive architectures in describing information processing, and relate intuition to expert problem solving and parallel processing. They state "implicit knowledge such as intuition may be more aptly explained by connectivist architectures."

Lord and Maher also stated that problem solving by individuals with expertise appears consistent with the parallel processing described within connectivist architectures (Kosslyn & Anderson, 1992). The lack of articulation commonly associated with experts attempting to explain their decisions or procedures may be due to the mismatch in using a symbolic process, that is, articulation, to describe an essentially connectivist process (Lord & Maher, 1991).

Several similarities can be drawn between the intuitive/deliberative distinction and the concepts of controlled versus automatic processing of information (Shiffrin & Shneider, 1977; Schneider & Shiffrin, 1977). According to their theory, automatic processing results from activation of a learned event, without conscious effort, and without reducing attentional capacity.

In contrast, controlled processing requires attention, is capacity-limited, usually serial in nature, and is controlled by the subject. This theory is focused on attention and search mechanisms, particularly search of familiar targets among distracters. The authors demonstrated differences and dynamics in the elicitation and performance of automatic detection versus controlled search processes. In the same way, the intuitive process has the fundamental features of automatic processing, that is, of low subject awareness and rapid parallel processing without deliberation. The deliberative process shares the same features as controlled processing--the subject actively and serially processes the information. In this proposal the concepts of automatic versus controlled attention and search mechanisms are extended to more complex cognitive functions of assessment, judgment, and decisionmaking.

In their review of current literature regarding information processing, Massaro and Cowan (1993) distinguished between fully serial information processing (only one item at a time), capacity-limited parallel processing (a limited number of items at a time), and capacity-free parallel processing. They drew an analogy of information processing capacity as a bridge, the width of which (a) determines how many items can "cross" at a time and (b) is affected by the automaticity of the process. Massoro also portrayed information processing theory as including "continuous representations similar to activation in many connectionist models." (p. 387)

Because recognition is often explicit and intentional, one may argue that it does not fit the criteria used for an automatic process (i.e. unintentional, involuntary, effortless, autonomous, occurring outside of awareness). However, as Bargh (1989) noted, there are automatic processes that have one but not all of the characteristics. Using his categorization, recognition processes can be explicit and intentional (goal-directed), yet still be an essentially automatic process. Ashby and Maddox (1990) discussed various theories of the recognition mechanism, stating that general recognition theory is one based on "experienced categorization." They add, "Although it may be at times difficult to determine which decision region an exemplar is in, the theory predicts that once this is established, categorization is essentially automatic" (p. 601.).

Some have described intuition as an implicit process (Lord & Maher, 1991), but one can distinguish between implicit processes versus recognition-based judgments. An implicit process by definition refers to acquisition of knowledge without explicit awareness (Seger, 1994). Similarly, Reber (1993) states, "Implicit learning is the acquisition of knowledge that takes place largely independently of conscious attempts to learn and largely in the absence of explicit knowledge of what is acquired." In contrast, according to Simon, recognition is explicit (Cooper, Schacter, Ballesteros, & Moore, 1992; Simon, 1989; 1986).

This overview of cognitive research reveals great progress in defining cognitive processes that are automatic and based on simultaneous processing of information. It has even been suggested (Reber, 1993) that automatic, unconscious cognitive processes are the default condition. Rather than proving an intuitive process was utilized, Reber challenges that the burden of proof should be to prove that conscious deliberation has taken place.

Two dimensions to classify intuitive processes. The diversity of constructs or perspectives on intuition appears to differ on two basic dimensions: the degree of certainty of the response, and the degree to which information or knowledge is consciously held, ranging from explicit awareness of facts (priming recognition-based responses) to implicit/subjective knowledge characterized by gut feelings or spiritual experiences (see Table 2).

Some definitions of intuition draw upon or are consistent with the notion of subjectivity and implicit processes, in that he subject is not aware of the rationale of the decision, it was based on a “feeling”, the rationale cannot be articulated, etc. This perspective can be contrasted with definitions of intuition based on recognitional processes that arise from expertise, explicit training, which can be associated with a high degree of certainty even if the subject did not process the information in a systematic, effortful manner.

Table 2

Framework for Diverse Conceptualizations of Intuition

Awareness	**Level of certainty**	
	Low	**High**
Implicit	**"Feeling of knowing"** (Rowan, 1989) (Barnard, 1938)	**"Transcendence/Belief"** (Rowan, 1989)
Explicit	**"Best Guess"** (Barnard, 1938) (Hammond, 1993) (Simon, 1992)	**"Insight/Aha"** (Goldberg, 1989) (Klein, 1993) (Simon, 1992)

When information regarding cues and decision rules is certain and explicit, intuition is that of automatic or semi-automatic cognition (as opposed to affect or parapsychic phenomena). Recognition can be conceptualized as ranging in certainty, from an amorphous "feeling of knowing" to "particular certainty." Of course, some researchers (Allwood & Montgomery, 1987 as an example) would not agree, as they distinguish intuition from recognition, stating that intuition is a function that is inarticulate, a simple "feeling of knowing" that occurs somewhere between a random guess and certain recognition. Their definition of intuition is limited to uncertain events, certain recognition would not be considered intuitive, even though it is automatic. It is apparent that intuition is not a precise term; rather, it is commonly used to refer to diverse characteristics. The two dimensions of explicitness and certainty appear to capture basic differences among the descriptions of intuition.

Fitting diverse descriptions of intuition into the framework. Researchers with different views on intuitive processes can be placed within Table 2, according to descriptions of level of conscious awareness of information/rationale, and the level of certainty of the response.

Many researchers agree upon the theme of intuition as rapid and unconscious cognition. Rowan (1989) described intuition as "knowledge gained without rational thought" (p. 84). In further describing intuition, he stated:

> Elusive as it is, we do know certain characteristics of this inner impression or hunch. It concerns relationships, involves simultaneous perception of a whole system, and can draw a conclusion--not necessarily correct--without proceeding through logical intermediary steps. That's why intuition comes with that queasy feeling of almost but not quite knowing. (p 85)

According to Rowan, intuition is perceived as arising from subconscious processing of information. The process itself was described as a spontaneous flash of insight which cannot be articulated by the decision maker. This lack of articulation is a common theme in definitions of intuition.

Rowan's conceptualization of intuition is more in alignment with intuition arising from implicit processing. This description of intuition as spontaneous, inarticulate insight is consistent with the notion of insight arising from processing of implicit cues. Other researchers, discussed below, will describe intuition with characteristics more consistent with explicit cues

Barnard (1938) provided a description of intuition consistent with that of Rowan's definition of intuition as spontaneous insight, Barnard distinguishes between what he called "logical" and "nonlogical" processes:

> By "logical processes" I mean conscious thinking which could be expressed in words or by other symbols, that is, reasoning. By "non logical processes" I mean those not capable of being expressed in words or as reasoning, which are only made known by a judgment,

> decision, or action. This may be because the processes are unconscious, or because they are so complex and so rapid, often approaching the instantaneous, that they could not be analyzed by the person within whose brain they take place. The sources of these non-logical processes lie in physiological conditions or factors, or in the physical and social environment, mostly impressed upon us unconsciously or without conscious effort on our part. They also consist of the mass of facts, patterns, concepts, techniques, abstractions, and generally what we call formal knowledge or beliefs, which are impressed upon our minds more or less by conscious effort and study. (p.302).

Barnard's conceptualization of intuition also includes characteristics of rapid, unconscious processing. It is interesting that he specifically distinguished and included both implicit and explicit cues as eliciting intuitive processes. He also distinguished between implicit and explicit processes as resulting in intuition when he stated that cues "impressed upon our minds more or less by conscious effort" can also result in intuition. Thus, deliberate learning of explicit knowledge is described as a source of intuitive phenomena.

Goldberg, (1989) described intuition as comprised of deliberate as well as spontaneous components. Factual knowledge and logical analysis are considered along with more non rational inputs such as feelings, dreams, hunches, and spontaneous insight. Thus a scientific discovery may be realized in an apparently instantaneous patterning of knowledge already attained by the individual. Goldberg describes how a number of scientists attribute their discoveries to spontaneous insight, and how these "sudden leaps to understanding" relate to processes of discovery, creativity, evaluation, operation, prediction, and illumination. This representation of intuition can be said to rely more on explicit cues (knowledge already attained by the individual) resulting in an intuitive insight with a high degree of certainty.

Hammond (1989) proposed several factors as differentiating intuitive decisionmaking, such as low cognitive control, rapid information processing, low conscious awareness, and low confidence in the answer (low level of certainty). There is a common theme that intuitive decision processes can difficult to articulate when decisionmakers are asked to describe their decision process. Thus, one may have a "gut feeling" that a decision is correct, but be unable to systematically describe the basis for the decision. Hammond's definition of intuition also states they are typified by decisions rapidly made at a low level of explicit awareness.

Hammond's conceptualization supports the notion of intuition as rapid and automatic. His assertion that intuition is marked by low confidence, however, may not be the case for all instances. The framework provided here allows intuitive processes to lead to certain responses. Low confidence in response typified by lack of articulation is consistent with intuition derived from subjective / implicit cues.

Klein and his associates (Klein, 1993; Klein, Calderwood, & Clinton-Cirocco, 1988; Klein, Orasunu, Calderwood, & Zsambok, 1993) presented a model of intuitive decisionmaking based on recognition that also describes intuition as rapid and automatic. He has reported several studies focused on decisionmaking of experts under time pressure. From his investigations of military officers in combat and ground fire crews, Klein has observed that complex decisionmaking under time pressure does not follow a deliberate process. Experts faced with stressful decisions with significant consequences under high time pressure do not report having generated more than one option at a time. The situation is "recognized", a solution is brought to mind, and that solution is utilized or rejected without generating alternative solutions. Within Klein's recognition-primed decisionmaking, expert decisionmaking under conditions of time pressure relies on intuitive assessments, based on the recognition of a scenario, rather than a deliberate sequential assessment of relevant factors.

Klein's conceptualization of intuition is more in alignment with explicit cues. His focus was on individuals explicitly trained to a high degree of expertise. The result is rapid and automatic decisionmaking that appears intuitive, yet arises from explicit cues and conscious processing of information. The decisionmaking behavior of these experts under time pressure is rapid and automatic, yet the underlying rationale for each decision could be articulated afterwards.

In his discussion of intuition, Simon (1992) succinctly states, "Intuition is nothing more and nothing less than recognition." While we may be unaware of the process of recognition, we are conscious of the fact that recognition took place. According to Simon (1990) recognition processes underlie cognitive processes such as grand master chess playing, medical diagnosis, and reading. Simon does not differentiate between intuition and rational thought:

> "When the problems to be solved are more than trivial, the recognition processes have to be organized in a coherent way and they must be supplied with reasoning capabilities that allow inferences to be drawn from the information retrieved, and numerous chunks of information combined. Hence intuition is not a process that operates independently of analysis; rather, the two processes are essential complementary components of effective decisionmaking systems (p.33). It is a fallacy to contrast "analytic" and "intuitive" styles of management. Intuition and judgment are simply analyses frozen into habit and into the capacity for rapid response through recognition" (p.38).

While Simon may not distinguish between intuitive and rational decision processes, one can argue that "recognition" is a process more instantaneous and less conscious than deliberative analysis, and is consistent with the category offered here regarding explicit cues. Simon distinguishes between intuition as recognition and insight, defined as spontaneous understanding on a deeper level than recognition. This distinction may be difficult to maintain. Within the framework, Simon's definition of insight would also fit as an intuitive process resulting from simultaneous processing of explicit cues leading to a high level of certainty.

Recognition versus deliberation. If intuition is based on recognition, the intuitive decision process is quite different from a deliberative approach. In contrasting the deliberative process with recognition, two distinguishing characteristics are apparent. First and primary, recognition is fast and relatively effortless. As stated earlier, recognition is a process that can occur instantly, when the cue is deeply familiar. In contrast, the deliberative process requires time and effort to process each cue, apply decision rules, generate possibilities and probabilities, evaluate each and identifiy the correct or optimal decision. The second characteristic distinguishing recognition from deliberation is that recognition is based on a holistic perception. Deliberation, in contrast, is by definition a sequential process. This often involves consideration of each information cue, application of decision ruels, and generation of possible solutions and outcomes, performed in a step-by-step fashion. On the other hand recognition usually occurs in an instantaneous fashion, and is thus likely based on parallel, rather than serial information processing, to enable simultaneous processing of many cues.

In summary, visual display characteristics have been differentially associated with performance on different types of cognitive tasks. When the task requires integration, configural represeentation has been recommended. However, configural displays have been associated with intuitive decisionmaking. The intuitive process elicited by these configural displays is argued to be a type of recognition-based response, which is faster and less effortful, but less accurate than systematic deliberation of all information, when decision rules are complex.

Intuitive processes have been associated with an averaging error; that is, performance can be modeled by a unit-weighted linear model. While averaging strategies can be robust, they can also lead to large errors when the decision rules are interactive and the information cues are not correlated.

When the decision task has complex rules by which information must be processed, more effortful and systematic analysis should lead to more accurate assessments than will an intuitive process. However, effortful deliberation is expected to be more vulnerable to degradation by unfavorable context characteristics, such as time pressure or low capability of the individual. Thus, decision context is offered as an important moderator variable in modeling the effect of visual display on decision process and patterns of decision error. These predictions are described in detail in chapter three.

Chapter 3

PREDICTIONS

Effect Of Information Display

The preceding section discussed the various conceptualizations of intuitive processes in order to clarify the intuitive construct that is often stated to be elicited by configural displays of visual information. The conclusion is that the intuitive response that is referred to is based on explicit recognition processes that can vary in degree of certainty.

Simultaneous display of visual cues. Using the framework provided by Hammond (1989) the primary eliciting factor for an intuitive recognition-based response is proposed to be the simultaneous presentation of perceptual information, that is, presentation of a "pattern". Simultaneous presentation of multiple perceptual cues is expected to induce a more intuitive attempt to recognize the overall pattern in the display.

Intuitive decision making is thus presented as an automatic, recognition-based decision process (Simon, 1992). It is this ability to recognize complex patterns which is most human, and most difficult for linear computer programs to emulate. This pattern recognition process would result rrom deliberate learning processes; however, once the cues become familiar, the judgment process transitions from one of deliberation to that is more automatic and recognition-based.

It is expected in this study that simultaneous display of visual cues will facilitate an intuitive, pattern recognition response, varying in degree of certainty. Even though the decision task requires deliberation of interactions, it is expected that the simultaneous display of visual information easily perceived as a holistic unit will induce a more intuitive, pattern-recognition response. If the recognition response is uncertain, the decision maker may then consider cue information more deliberately, to verify the overall impression, if time permits. Even so, the assessment would likely be less systematic than when cues are deliberately considered to formulate a judgment. Instead, the cues would be scanned for consistency with the overall impression, and the impression adjusted accordingly.

Sequential display of visual information. The underlying cognitive task demands systematic deliberation of information. In this study, the task was constructed such that information cues must be considered separately and systematically, in accordance to four decision rules. For this type of task, it is expected that sequential display of visual information will in general result in higher accuracy than simultaneous displays.

It is expected that serial presentation of cues would induce a deliberate, sequential approach to information processing. This is counter to some previous research (Matin & Boff, 1988) which suggested that serial presentation of information is processed more rapidly and automatically. However, in their study, the stimuli consisted of single digits, presented serially (same location on screen) or all at once, and it is a recall task. Research participants had to recall the information in order, and this would be easier when serially presented than when the information had to be processed in a spatial manner (the first digit is in the upper left window, the second in the upper right window, etc.). Thus their task differed in (a) nature of the task (recall versus decisionmaking), (b) nature of the stimulus (quantitative versus perceptual) and (c) number of cues (3 versus 9). While their conclusion was that sequential presentation of information is more automatic, the difference can be attributed to differences in task demands. The task used in this study provides the simultaneous display of information with strong emergent features, that is, the image can easily be comprehended as a whole. In addition, the previous study was a recall task, whereas this task will require more effortful considerations of separable but interacting cues.

Sequential presentation of these perceptual cues is expected to facilitate consideration of individual cues and their interactions. Research participants are told to consider each cue as it related to its interacting cue. If one cue is safe the interaction is safe regardless of the threat level of the other cue; therefore each threatening cue must be considered in light of the other interacting cue. When cues are presented sequentially, in order of interacting cues, the subject will more easily be able to interpret each specific interaction.

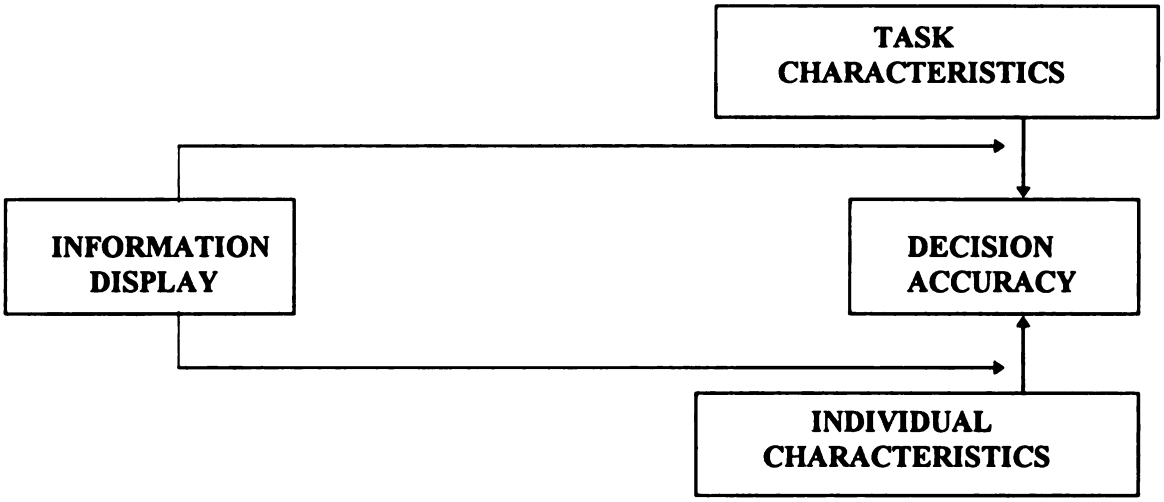
If the cues are presented sequentially, the "pattern" cannot be ascertained until all cues are presented. Also, when the cues are presented singly, it is expected that the decision maker will consider each cue as it is being presented. Hammond (1990) has reported results consistent with these expectations. According to Hammond deliberative cognition will result if a decision task presents nonredundant cues in a sequential fashion, along with an explicit principle, scientific theory, or method for organizing cues into a judgment.

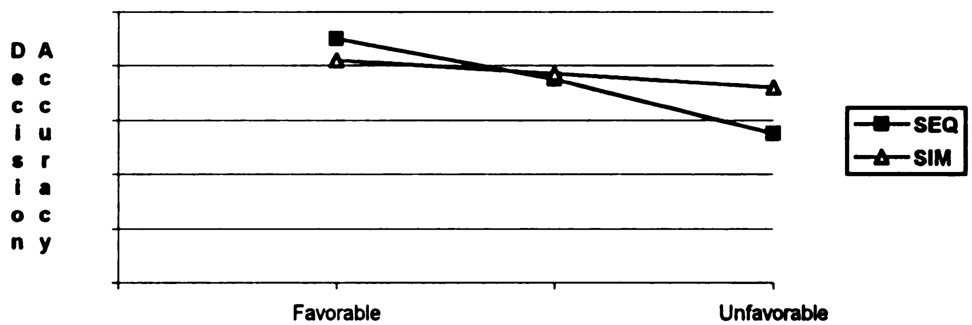
Additional support for the expectation that sequential cues would elicit a deliberative response is supported by research regarding integral versus separable cues. It has been demonstrated that displays with separable cues require the subject to serially process the information, and the additional mental workload results in greater time and effort to process the cues (Coury & Boulette, 1992). Sequential presentation of cues should also have the same effect as separable cues. While a perceptual pattern is built, and can be seen at the very end, I expect that sequential presentation of cues minimizes the perception of the whole, and focuses attention to the separate cues.

Thus, two factors serve to elicit deliberation in this task. One is the underlying demand that research participants consider cue interactions; a cue that is in itself threatening may not be correctly assessed as threatening if the interacting cue is safe. In addition, sequential display is expected to result in a more deliberative response. Serial presentation is expected to induce serial processing of cue information and reduce parallel processing of the pattern of cue configurations. Simultaneous presentation of multiple channels of cue information is expected to be more readily perceived as a holistic pattern leading to recognitional responses. Presentation of cues based on a variety of perceptual stimuli--location, color, size, sound, etc., is expected to facilitate parallel processing and recognition of the pattern of cue configuration.

Interactions between display and decision context. The major proposition of this dissertation is that decisionmaking performance will depend on the interaction between display type and characteristics of the task and the decision maker. It is proposed here that intuition as a holistic recognition process can be effective, even in a decision task with objective cues and algorithms for accuracy, depending on the favorability of decision context. When conditions are ideal, the sequential analysis of information is expected to be associated with greater accuracy. However, when situational conditions are degraded, due to factors such as time pressure, conflicting cues, and/or low cognitive ability, then sequential presentation of information, with its requirement to systematically deliberate the information, is expected to be associated with a higher rate of error. In contrast, simultaneous presentation of perceptual information is expected to be less affected by degraded conditions. The nature of this interaction is such that these conditions can result in greater accuracy resulting from recognition-based responses. Figure 2 provides the overall model of the predictions made in this study.

Figure 2. Overall Model





FAVORABLE	**UNFAVORABLE**
Low time pressure	High time pressure
Certain information	Ambiguous information
No conflict	Conflicting cues
High cognitive ability	Low cognitive ability
Analytical cognitive style	Intuitive cognitive style

Task Characteristics Affecting Favorability: Main Effects

Figure 2 includes main effects of task characteristics on performance across both conditions. The main effects for these characteristics are expected to be as follows.

Time pressure. Time pressure is known to have a negative effect on performance, due to constraints on attentional and processing resources (Coury & Boulett, 1992). According to

Hogarth (1975) the time required for decisionmaking is a function of task complexity. Other characteristics influencing the effect of time pressure include extent of attentional resources, mapping of stimuli to resources, task pacing, and type of display (Coury & Boulette, 1992).

In this study time pressure will range from having sufficient time to complete the task to high time pressure, where research participants report perceptions of time pressure. As time pressure is increased, the cognitive demand of the task is increased, as decision makers will have to process information more rapidly. Time pressure is expected to degrade accuracy by interrupting and/or not allowing sufficient processing of information.

In addition, the need to make an immediate judgment will increase vulnerability to biases such as central tendency (judgments are less varied in assessment). Directional bias can also occur, if the decisionmaker has a preference for reducing error due to overly safe assessments (increasing chance that the aircraft is really threatening and consequently takes hostile action) or to overly aggressive assessments (increasing chance that the aircraft is really nonthreatening and is wrongly attacked). Time pressure is expected to degrade accuracy in the simultaneous condition as well, but to a lessor degree compared to the sequential display.

Information ambiguity. It is reasonable to expect that information ambiguity, as defined by missing information, would be detrimental to performance. Decision makers will have decision situations where (a) no information is missing, (b) some information is missing, and (c) nearly a third of the information is missing. As information becomes more ambiguous, the decision maker will not be able to calculate the correct outcome with certainty, even if there is no time pressure.

A review of decision performance under uncertainty emphasizes the role of ambiguity as a source of error. Individuals are usually ambiguity-averse (Curley, Yates, & Abrams, 1986) and have been willing to pay to avoid ambiguity (Kahn & Sarin, 1988). They assess lower probabilities of occurrence for a single event, such as the probability of rain, but higher probabilities for an outcome based on a series of probabilistic events (Boiney, 1993; Gettys et al 1982). Even statisticians have been found to over-rely on small numbers (Tversky & Kahneman, 1982). Intuitive prediction of uncertain events relies almost exclusively on information particular to the event, rather than information regarding the population (Bar-Hillel, 1982; Kahneman & Tversky, 1982; Tversky & Kahneman, 1982).

Tversky and Kahneman (1982) list numerous errors in human judgment under uncertainty, such as anchoring and adjustment, availability, and representativeness. While there has been a great deal of research regarding decisionmaking under ambiguity or risk, most of it has been for choice decisions involving probabilities such as gambling decisions (Kahneman et al, 1982). In those situations, individuals are likely to violate SEU predictions by choosing the alternative with a lower payoff that is more certain. Models have been offered to accommodate this phenomenon of ambiguity aversion (Einhorn & Hogarth, 1985; Kahn & Sarin, 1988) within the paradigm of SEU theory. However, they do not provide direct implications for the type and degree of decision error that can arise from unavoidable ambiguity within an objective task, beyond that of increased error. Frisch et al (1988) did provide a prediction similar to "regression to the mean" in that, given extreme but limited information, the decision maker will assume the missing information will provide a less extreme judgment, if the decision maker cannot delay the decision.

A common assumption is that ambiguity leads to intuitive judgment (Kahneman et al, 1982 Mahan, 1992; 1994). Discussion of error under ambiguity is therefore taken to be a discussion of intuitive error. Tversky and Kahneman use this definition of intuition, stating "The reliance on heuristics and the prevalence of biases are not restricted to laymen. Experienced researchers are also prone to the same biases - when they think intuitively" (p. 18). That may be so if one defines intuition as any human judgment process which is not favorable. The overall finding here is that ambiguity has been related to higher error in decisionmaking, and is thus expected to degrade accuracy in general.

Information conflict. Conflict among information cues is expected to be detrimental to performance in general, as it also creates ambiguity during information assessment. Conflict is defined as a decision situation where some of the cues indicate one level of assessment, and other cues indicate a very different level of assessment. In the sequential condition, the conflicting cues will be presented such that preliminary cue information will conflict with subsequent cues. In the simultaneous condition, the decision maker will also see the same conflicting cues, rather than seeing a more easily recognized pattern with consistent cues. Conflict among cues is expected to lower decision accuracy.

Irrelevant frame information. Irrelevant background information is also expected to have a detrimental effect on decision performance in general. It has been demonstrated that research participants will respond differently to a decision problem depending on the manner in which the problem or alternatives are phrased (Frisch, 1993), such as when the decision outcomes are worded as a gain or a loss (Kahneman & Tversky, 1982). In this study background information which describes a previous error (with disastrous consequences) is expected to have a frame effect, where research participants will be more inclined to avoid the error previously described, and be more likely to make errors in the opposite direction.

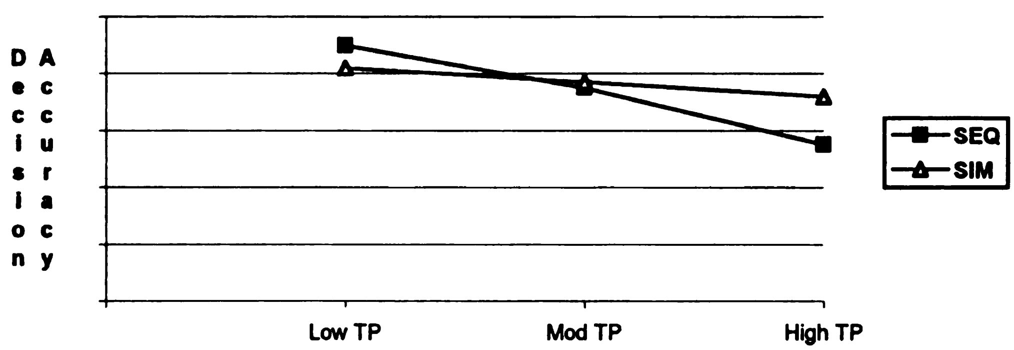
Task Characteristics: Interaction Effects

The main effects of display and task characteristics, while included in the overall model, are of secondary interest in this study. The main premise of this dissertation is that the effect of visual display conditions will be moderated by task and individual characteristics. The graph displayed in Figure 2 indicates that task characteristics will moderate performance in sequential versus simultaneous display conditions. Degraded conditions are expected to have a more detrimental effect on performance in the sequential display condition. In this section, predictions regarding the interaction of display type and task characteristics of time pressure, ambiguity, conflict, and frame are discussed.

Display and time pressure. Time pressure is expected to be more detrimental in the sequential condition, due to greater detrimental effect on effortful deliberation. If the decision makers are striving to be deliberative and are not given enough time to sequentially analyze all cues and their interactions, increased error is expected. Simultaneous display of information is expected to induce a more automatic, less effortful recognition-based response. The overall impression occurs immediately, therefore this process is expected to be less vulnerable to effects of time pressure.

One study supporting this expectation compared the accuracy of recognition-based judgments versus explicit deliberation on speeded performance. The group that was explicitly trained was affected by time pressure, in that performance declined under time pressure. In contrast the group that was implicitly trained to rely on memory had no difference due to time pressure (Turner & Fischler, 1993).

Figure 3. Predicted Effect Of Time Pressure



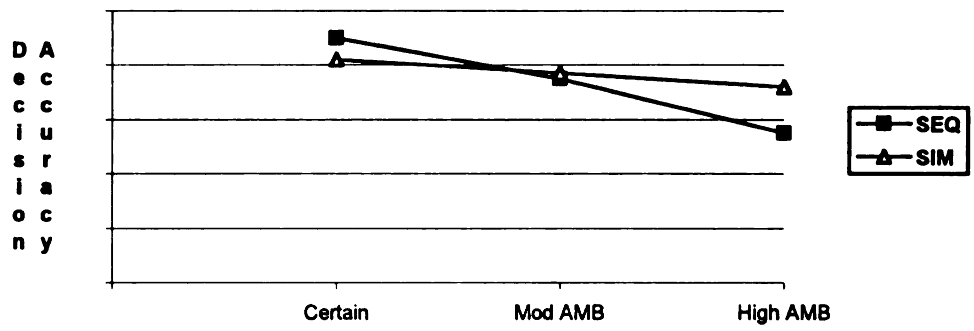
In a study comparing digital display or a polygon display, Coury and Boulette (1992) trained research participants to monitor and interpret cues related to the overall state of a hypothetical system, under varying conditions of time pressure. First, research participants were well trained

(384 training trials) and it was noted that decision accuracy was higher for subjects in the digital display, until the last few training blocks, when performance in both display conditions were equally accurate. By the time they were finished with training, the participants were performing more quickly in the polygon display condition, with accuracy equal to that of the digital display condition. Research participants then made system diagnoses under conditions varying in time stress. Research participants using the digital display were more accurate than research participants in the polygon display condition when there was no time pressure. However, research participants in the polygon display condition were more accurate when time pressure was high.

Display and information ambiguity. It is expected that ambiguity will be more detrimental to the deliberative process, as the missing cues are expected to be more salient in the decisionmaking process. Deliberate consideration of complex information breaks down when the decision maker encounters uncertain information (Kahneman, Slovic, & Tversky, 1982; Moser, 1990). Moser defines decisionmaking under ambiguity as situations in which the decision maker lacks complete information regarding relevant facts or outcome probabilities, and points out that decisionmaking under certainty is quite rare. When the decision object is ambiguous, the subject will have to make a best guess as to assessment (Gettys, Kelly III, & Peterson, 1982; Kahneman & Tversky, 1982) or delay the choice if possible (Frisch & Baron, 1988; Shafir & Tversky, 1992; Tversky & Shafir, 1992).

The proposition that ambiguity will be more detrimental to the deliberative process is based on an expectation of higher interference within the deliberative process. If the deliberative process depends on a sequential analysis of information cues and their interactions, the deletion of particular cues is expected to cause more cognitive distress and higher error than when judgments are based on an overall impression. The intuitive process, which considers all cues as a gestalt, is not expected to be as detrimentally affected by the deletion of particular cues, as individual cue information is not as salient (see Figure 4).

Figure 4. Predicted Effect Of Information Ambiguity



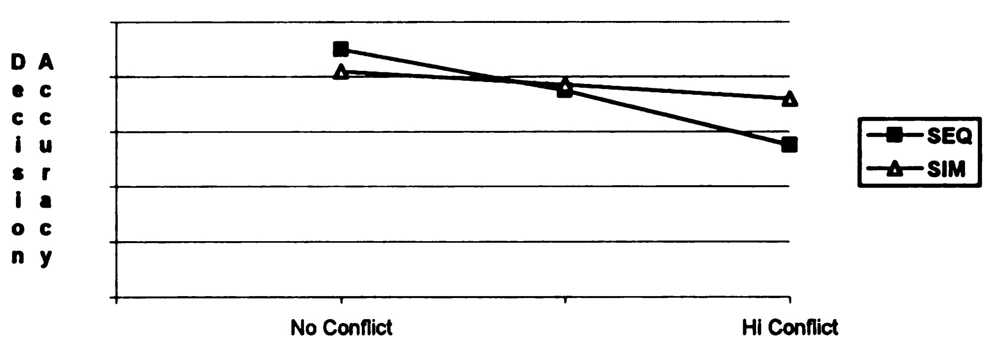
As ambiguity increase, it is expected to more negatively affects deliberation, such that under highly ambiguous conditions, decision accuracy will be higher in the simultaneous condition. Decisionmakers in the simultaneous condition will be more experienced with making judgments based on overall impressions, and may not even notice that a few cues are missing. On the other hand, decisionmakers using a deliberative process will be more aware of missing information, less able to systematically determine a judgment, and less experienced with making a judgment based on an overall impression.

Coury and Boulette (1992)investigated interactions of ambiguity and digital versus polygon displays, at different levels of time pressure. Research participants using the digital (separable) display were unaffected by uncertainty until the time pressure was very high. Responses of research participants using the polygon (integral) display had a more linear relationship with uncertainty, with increasing amounts of uncertainty leading to more error; however, they performed more accurately on uncertain targets than research participants in the digital condition when time pressure was high.

Display and information conflict. Conflict among cues is expected to be more detrimental when cues are presented sequentially. Conscious and deliberate processing of cues will make the conflict more salient. In addition, sequential consideration of cues has already been demonstrated to result in decision error due to order effects.

In this study, information conflict will be presented in a sequential order, in the sequential display condition. When information is presented sequentially, two types of error have been reported, where information is weighted more or less depending on the order in which the information is presented (Anderson, 1981; Hogarth & Einhorn, 1992; Jarvenpaa, 1990; Kahneman, Slovic, & Tversky, 1982; Slovic & Lichtenstein, 1971). This additional order effect is expected to result in more error for the sequential display condition (see Figure 5).

Figure 5. Predicted Effect Of Conflict



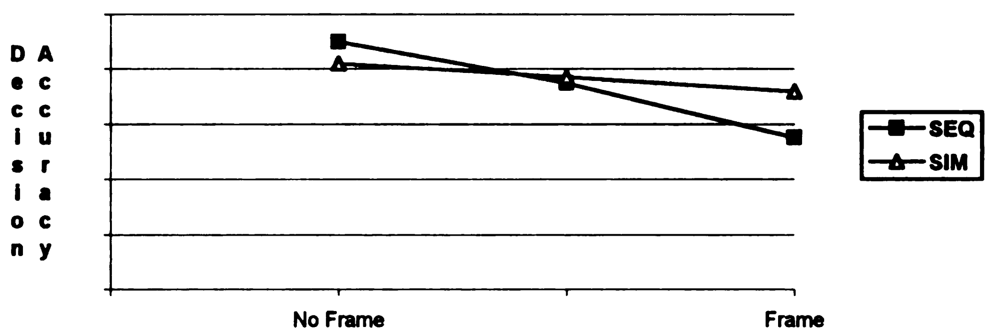
Two order effects have been noted in sequential presentation of information. One is belief-updating, predicting a general recency effect in that information presented last is weighted more heavily than justified, particularly in the case of social cognition over time--assessments of individuals appear to rely most on most recent information (Hogarth & Einhorn 1992). This belief-updating response has been reported for analytical tasks as well (Adelman & Bresnick, 1992). In contrast, a type of primacy effect have also been found (Block & Harper, 1991; Cohen, 1993; Payne et al, 1992; Switzer & Sneizek, 1991; Tversky & Kahneman, 1974), where information presented first is more heavily weighted than it should have. A particular example of primacy is described by Tversky and Kahneman (1974) as anchoring and adjustment. Preliminary information provides an "anchor" or reference point, from which subsequent information, if conflicting, results in an adjustment of the assessment, but the adjustment is usually not sufficient for accuracy.

An order effect occurs when the final judgment of decision makers will differ according to the order that information cues are presented. Hogarth and Einhorn (1992) reported several task characteristics which influence whether order effects occurring during sequential presentation of cues is typified by anchoring and adjustment or belief updating. These authors found that anchoring effects were more likely to occur when information cues were complex and when there was a large number of cues (over 18). It was also more likely to occur when research participants were requested to make a judgment after all cues were presented (end-of-sequence), as opposed to providing a judgment after each information cue (step-by-step judgments). Matching these characteristics to the characteristics of the decision task in this study leads to the expectation of primacy effects in the sequential display condition.

Display and frame. Kahneman and Tversky (1982) stated that intuitive assessments rely almost exclusively on singular information; that is, information that is descriptive of the particular event to be assessed, as opposed to population distribution of events. Consideration of the differences between deliberative and intuitive processes leads to the proposition that deliberative processes are in general, more reactive to the influence of framing, that is, the manner in which the decision context is explained.

Research participants in the sequential condition are expected to more effortfully process information and as a result, are expected to incorporate additional background information, such as past experience, feedback, or background information. Usually, the additional information is useful, and deliberation is enhanced when considering this contextual information. However, if the additional information is irrelevant, the deliberative process is disadvantaged. For example, when faced with an ambiguous stimuli such as a written report which is neither very good or very bad, the past performance of the writer may influence the perception of the quality of the written report. One could say that the "base rate" performance of the writer was considered along with the current report, in the evaluation of the report.

Figure 6. Predicted Effect Of Irrelevant Frame Information



The assertion that deliberation includes more contextual information is not new. Kahneman and Tversky (1982) stated that intuitive processes rely on information particular to a decision event (singular data) to the exclusion of distributional data. Distributional data was defined as "information that characterizes the outcomes that have been observed in cases of the same general class." (p 415). This phenomena was listed as a source of error for intuitive decisionmaking, but there may be instances where the influence of incidents outside the event of interest may be detrimental. When the additional information is useful and easily incorporated, deliberative processes may be improved; however, when the information is independent of the decision event, deliberative processes, it is expected to introduce more error.

Decision context within this proposal is defined as information serving as background or reference to a specific decision incident. For example, the outcomes of prior similar decisions formulates a background for a particular decision. As another example background information also forms a decision context (Tversky & Kahneman, 1981). If intuitive processes do not incorporate contextual information to the same degree as deliberative processes, it is expected that intuitive processes are more immune to contextual effects.

Kahneman and Tversky (1982) describe the reliance on singular information as a source of error, but in this study the background information is extraneous to the assessment of information. It is proposed here that knowledge of previous incidents can serve as a frame which can subsequently bias the analysis of a decision problem. In this way, knowledge of previous events can affect deliberative processes more so than intuitive processes. Thus if deliberation is more likely to incorporate contextual information decisionmakers in the sequential condition are expected to be more affected by the frame manipulation.

Individual Characteristics: Main Effects

Cognitive ability. Cognitive ability is expected to be positively related to performance in this task, in both display conditions. It is established that cognitive ability predicts learning and performance in general, and this task is essentially cognitive in nature. Determination of the correct response requires perception of cues, and application of rules in order to make correct decisions. It would be surprising if cognitive ability were not related to performance in this task. Cognitive ability was included as a variable in this study is in order to investigate proposed interactions between cognitive ability, display condition, and decision context.

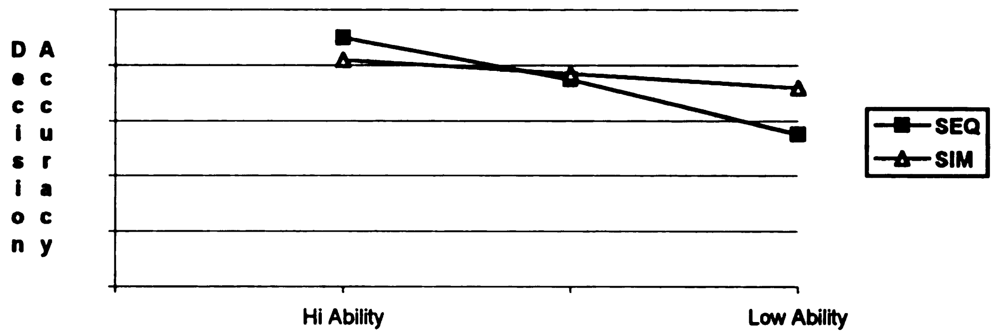
Cognitive style. Cognitive style refers to the preference for concrete and specific facts/rules versus a preference for concepts, theory, and intuitive processing. Jung (1923) described this difference as the most fundamental individual difference in distinguishing personality type. Jung described individuals with a preference for concrete facts and rules as "sensing types", while individuals with a preference for concepts, theory and intuitive judgments as "intuitive types." Within his information-processing approach to classification of personality type, this preference was regarded as most fundamental in that it describes how individuals perceive their surroundings. Conflict among individual differing in this preference was predicted to be most difficult to overcome.

Cognitive style is expected to be related to performance as a function of the underlying cognitive task demand. In this task the demand is for analytical and effortful processing, based on decision rules, which would be more congruent with the sensing preferences than the preference for intuitive, holistic information processing. Thus, congruence of cognitive style and cognitive demand should be more effective in general. However, an interaction is expected with display condition and decision context, such that the preference for intuitive processing can be beneficial when the decision context is degraded.

Individual Characteristics: Interaction Effects

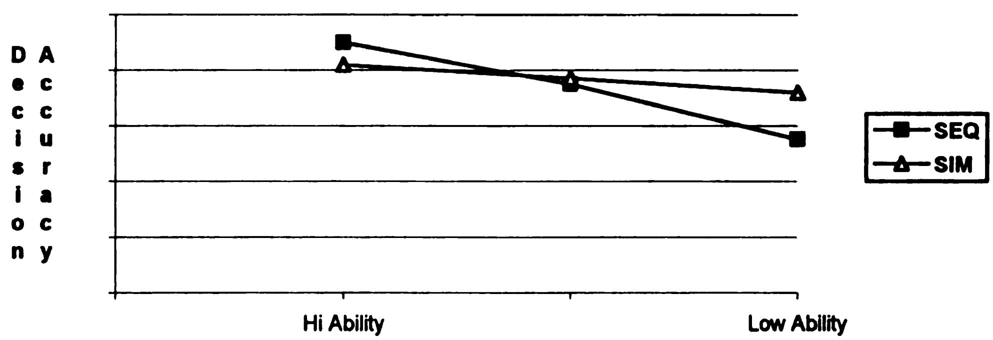
Display and cognitive ability. A significant interaction is predicted between cognitive ability and display condition. Individuals high in cognitive ability are expected to perform more accurately in the sequential display condition. Individuals high in cognitive ability are expected to more effectively manage the processing demand inherent in analytical decision tasks. Simultaneous presentation of information is expected to invoke a less effortful process, based on a holistic impression of the visual pattern. This impression is expected to be an immediate reaction which can vary in degree of certainty. The response is not a result of effortful processing, thus cognitive ability is not expected to be as influential in predicting decision accuracy in the simultaneous condition.

Figure 7. Expected Effect Of Cognitive Ability And Display Condition.



Display and cognitive style. A significant interaction is expected between decision style and display condition. Individuals with a preference for analytical processing are expected to perform more accurately in the sequential display condition than in the simultaneous condition. Individuals with a high preference for intuitive decisionmaking are expected to perform more accurately in the simultaneous condition. Individuals with a high preference for intuitive decisionmaking, faced with a sequential presentation of multiple cues, are expected to be less effective in the deliberative process, and demonstrate increased decision error associated with deliberation.

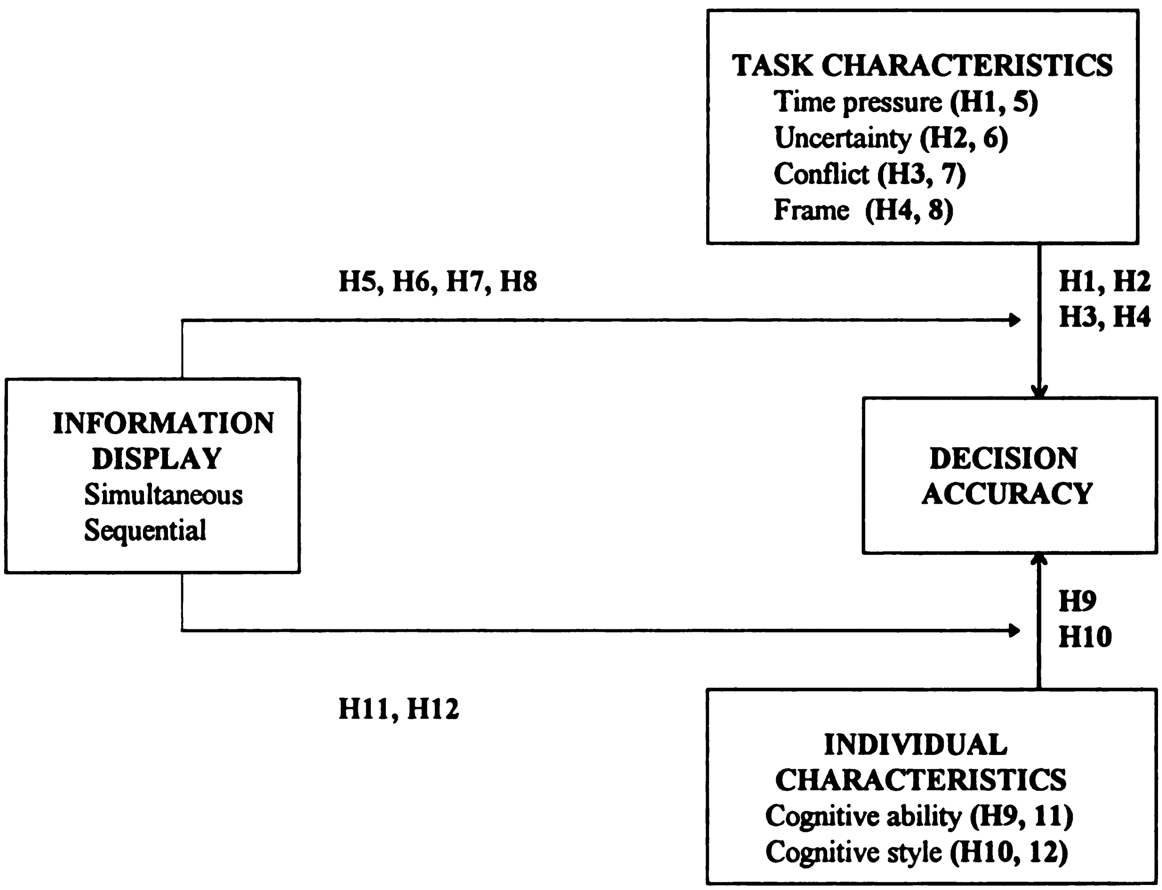
Figure 8. Expected Effect Of Cognitive Style And Display Condition.



Summary

Figure 9 provides the overall model of predicted relationships discussed within this study. Hypotheses are grouped by (a) main effects of task characteristics (H1-H4); (b) interactions of task characteristics and display condition (H5-H8); (c) main effects of individual characteristics (H9-H10) and (d) interactions of individual characteristics and display condition (H11-H12).

Figure 9. Overall model



Task and individual characteristics comprising favorability of decision context are predicted to have a main effect on decision performance (Hypotheses 1-4; 9-12). The degree of effect will by moderated by visual display condition (Hypotheses 1,2; 5,6,7,8).

Hypotheses 1 through 4 indicate expected main effects of task characteristics on decision performance. H1 states that as time pressure increases, performance will decline. Similarly, H2 and H3 predicts that as information ambiguity and information conflict is increased, performance will decline. Similarly, H4 predicts that irrelevant frame information will have a negative effect on performance.

The next four hypotheses (H5-H8) predict interaction effects between task characteristics and display condition. The sequential display condition is expected to be more vulnerable to degrading task characteristics of high time pressure, information ambiguity, information conflict, and frame information. Correspondingly, research participants in the sequential display condition are expected to perform less accurately than research participants in the simultaneous display condition when (H1) time pressure is high, (H2) information is ambiguous, (H3) information is conflicting, and/or (H4) irrelevant frame information is provided.

The next group of variables are the individual characteristics expected to have main effects (H9, H10) on decision performance, that is, cognitive ability and cognitive style. Research participants who are lower in cognitive ability and/or who have an intuitive decision style are expected to perform less accurately when conditions are favorable. Research participants with high cognitive ability and/or analytical cognitive style are expected to perform more accurately in the sequential display condition when conditions are favorable. Research participants who are lower in cognitive ability and/or have a preference for intuitive processing are expected to be perform more accurately in the simultaneous condition.

Chapter 4

METHOD

Sample

Research participants consisted of undergraduate students in an introductory course in management at a large midwestern university. 600 students were recruited, in order to ensure an N of 500 and thus achieve sufficient (80%) power for statistical analyses (Cohen, 1992; Cohen & Cohen, 1987; Kraemer & Thiemann, 1987). Incentives to participate in this study consisted of course credit in lieu of other coursework, and the opportunity to earn money contingent upon task performance.

Task

The task was a computer-administered team decision task based on simplified military air surveillance decisions. Research participants were trained to form judgments of threat on hypothetical incoming aircraft based on nine information cues, such as speed, direction, altitude, etc. This task was created using TIDE^2 software (Team Interactive Decision Exercise for Teams Incorporating Distributed Expertise) for team and individual decision making simulations. Documentation for the original TIDE^2 software can be found in Ilgen and Hollenbeck (1993).

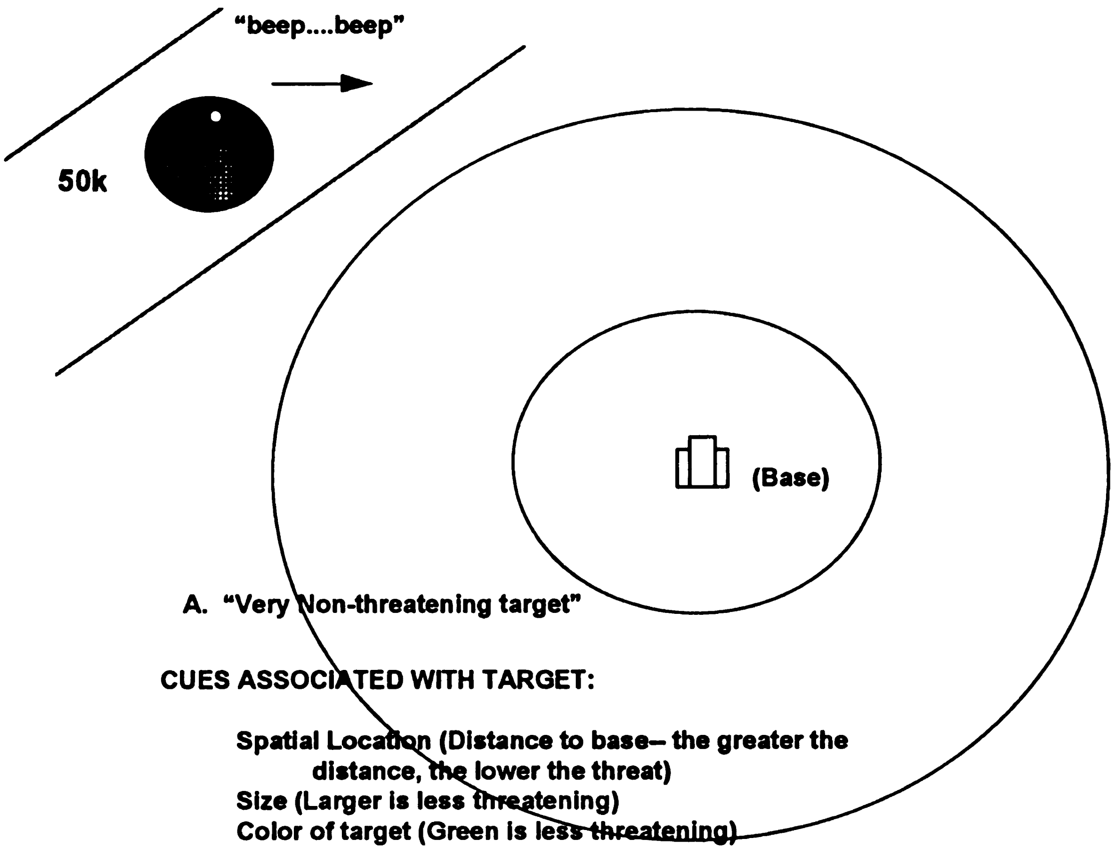
The TIDE^2 task enables investigation of decision processes through multiple presentations of decision events which require the individual to make a decision based on up to nine information cues. Usually, the same cues are considered in each decision event, while cue values are varied. This allows investigation of processes consistent with the brunswick lens model of decisionmaking (Brunswick, 1955). Cue weights can be estimated by regression weights, when there is finite and stable set of cues which vary. In addition, the traditional TIDE2 task is networked such that several individuals can perform as a team, and the software is configured to capture core constructs of the multi-level theory of team decisionmaking.

Research participants were trained to assess the level of threat based on 9 characteristics of the aircraft. These characteristics include speed, size, angle of ascent/descent, range from base, altitude, corridor status (whether the aircraft was within a corridor designated safe for civilian aircraft), direction, radar (hostile to friendly), and IFF (Identify Friend or Foe) electronic signal.

Research participants completed 180 judgments, each judgment taking no more than 20 seconds to complete. Previous pilot tests revealed 20 seconds was considered to be ample time for decision making by research participants. Most participants completed the session, including the interactive training, within 90 minutes.

Information cues. Research participants played the role of an air patrol officer responsible for monitoring a sector of airspace for incoming aircraft. They were presented with up to eight visually presented cues and one audio cue representing attributes of each hypothetical aircraft. There is great contrast between configuration of totally nonthreatening versus the configuration comprised of all threatening cues. The nonthreatening configuration presents a large green circle (representing size and friendly Identify Friend or Foe (IFF) signal), far away from the base, within a safe civilian flight corridor, headed slowly away from the base, at high altitude and ascending, and emitting friendly radar (low pitch slow tempo audio). In contrast, the threatening display shows a small red circle, very near the base, outside the safe civilian corridor of airspace, heading straight in at fast speed, at low altitude and descending, and emitting hostile radar (high pitch high tempo audio) (See Figures 10 and 11). Table 3 describes the nine cues. Each had three levels of threat: safe, moderately threatening, and threatening. Figure 12 provides the representations of the

Figure 10. Graphic Display Of Aircraft With All Nonthreatening Cues.

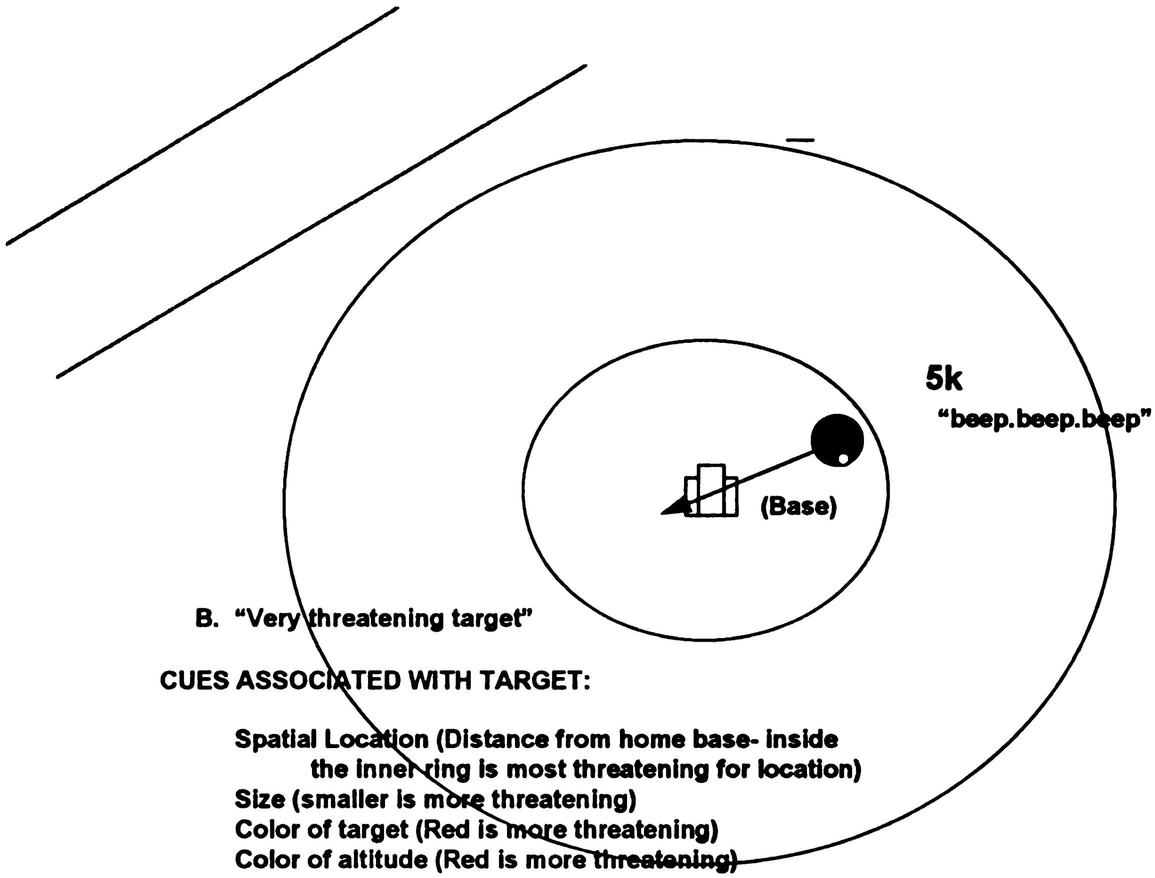


A. "Very Non-threatening target"

CUES ASSOCIATED WITH TARGET:

Spatial Location (Distance to base– the greater the distance, the lower the threat)
Size (Larger is less threatening)
Color of target (Green is less threatening)
Color of altitude (Green is less threatening)
Corridor status (inside the dual lines is safe)
Sound (low pitch/freq is non threatening)
Arrow (length = speed; short is slow) (direction = away from base is safe)
Location of dot (if dot is toward top of target target is ascending, non threatening)

Figure 11. Graphic Display Of Aircraft With All Threatening Cues.



B. "Very threatening target"

CUES ASSOCIATED WITH TARGET:

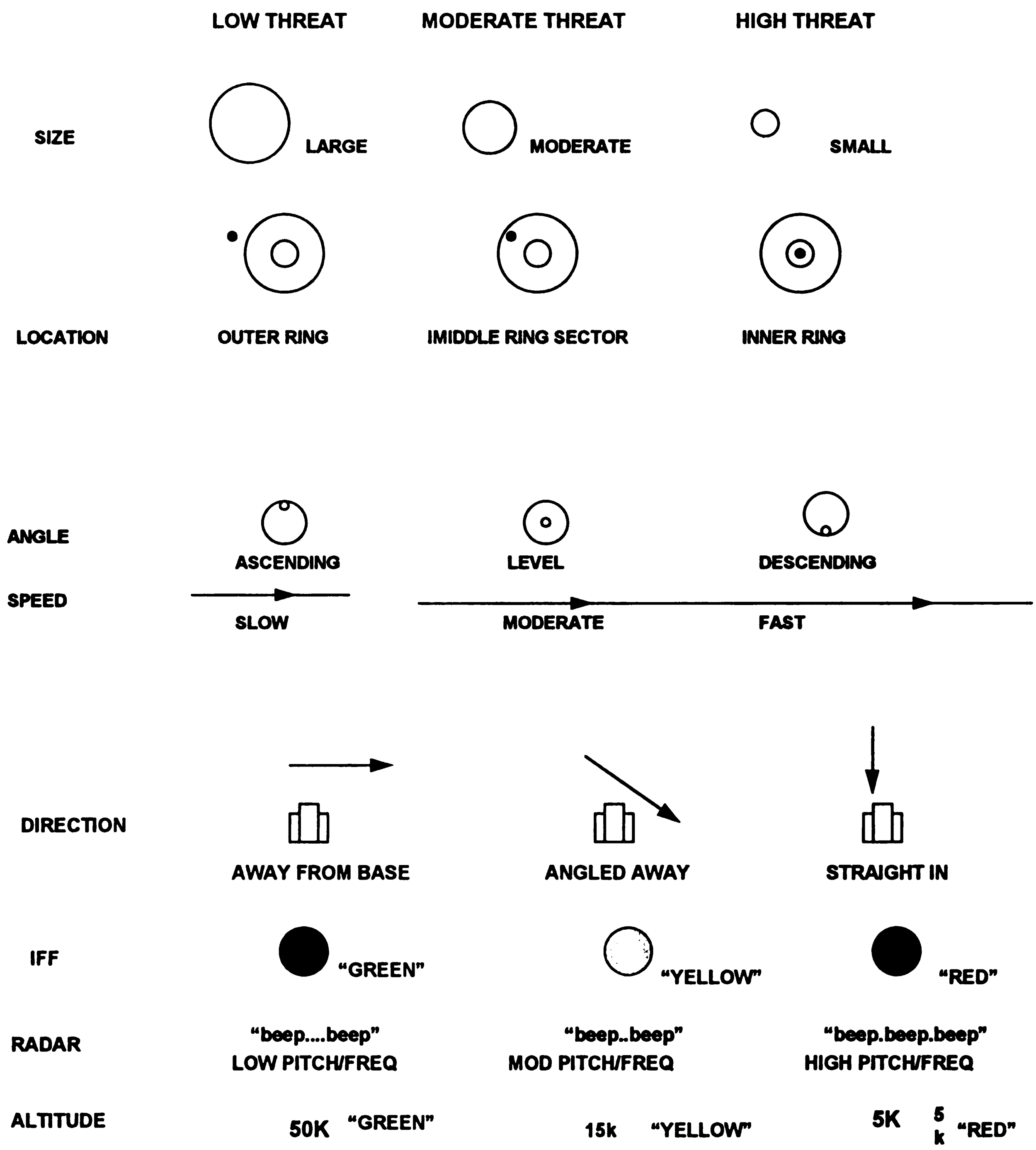
Spatial Location (Distance from home base- inside the inner ring is most threatening for location)
Size (smaller is more threatening)
Color of target (Red is more threatening)
Color of altitude (Red is more threatening)
Corridor status (far outside the dual lines is most threatening for corridor status)
Sound (high pitch/freq is threatening)
Arrow (length = speed; long is fast) (direction = toward base is threatening)
Location of dot (if dot is toward bottom of target target is descending, threatening)

Table 3

Attributes and Ranges Underlying Perceptual Cues

Attribute	Description	Cue (3 levels)
Speed	Miles per hour	**Length of arrow**
Altitude	Feet	**Number, color**
Size	Meters	**Size**
Angle	Degrees: Descent to Ascent.	**Graphic**
IFF	Identify Friend or Foe: Megaherz. A radio signal that identifies civilian (low), para-military, or military (high) aircraft.	**Color**
Direction	Degrees: Angle of flight ranging from passing far to the east (+40) to coming straight in (0).	**Direction of arrow**
Corridor Status	Miles: A corridor is a 20 mile wide lane open to commercial traffic. The status is expressed in miles from the center of the corridor.	**Graphic lines**
Radar Type	Class: Classes of radar ranging from weather to weapons.	**Auditory**
Range	Miles: Distance of the aircraft from the operator.	**Spatial location**

Figure 12. Threat Values Associated With Each Cue.



three levels of threat for each cue. Perceptual cues represented quantitative information. For example, instead of a number, the size of the aircraft was indicated by a circle which was large, medium, or small in size depending on the size of the aircraft. Similarly, the range from the base was indicated by the location on the another example, three lengths of the arrow representing speed (short, medium, and long) signify speed (no threat, moderate threat, high threat).

Decision alternatives. Research participants assessed the overall threat of each aircraft, based on seven choices ranging from no threat to very threatening (see Table 4). Each threat level was associated with a specific action. For example, if the aircraft was judged as having no threat, the associated action was "ignore." If the aircraft was judged as having the highest degree of threat, the corresponding action was "defend", that is, to shoot the aircraft down.

Table 4

The Seven Decision Alternatives

(1) **IGNORE**: The aircraft is assessed as posing no threat. The operator would devote no further attention to the aircraft.

(2) **REVIEW**: The aircraft poses little threat. The operator would leave this aircraft momentarily, but would return to the aircraft after a short period of time to update its status.

(3) **MONITOR**: The operator decides to continuously track the aircraft on radar.

(4) **WARN**: The operator sends a message to the aircraft to steer clear.

(5) **READY**: The operator sets defensive weapons on automatic. A ship in a readied position is rarely vulnerable to attack. This stance should not be taken for non-threatening aircraft due to the possibility of firing mistakenly at innocent aircraft that fly too close.

(6) **LOCK-ON**: The operator decides to synchronize the ship's radar and attack weapons such that the weapons are fixed upon the aircraft. An operate may then use offensive weapons at a moment's notice. This should be reserved for aircraft almost certain to be threatening.

(7) **DEFEND**: The operator decides "weapons away" and attacks the aircraft. A defend decision cannot be aborted once initiated and must only be used when attack by the aircraft is imminent.

This task does not reflect actual military guidelines, but the rules were generated to appear reasonable. For example, a large aircraft, all other things equal, was described as less threatening than a small aircraft because fighter aircraft were smaller than civilian airliner aircraft. Perceptual cues were chosen to be easily interpreted. For example, the cue for aircraft size was a large circle for large aircraft, and a small circle for small aircraft. As another example, the type of weapons signal can be civilian, demonstrated by a green color (safe), or military, demonstrated by a red color (threat).

The rules of engagement required the research participant to consider interactions among the cues which affect the determination of cue threat. For example, speed and direction make one interaction, so that one cue could be threatening in itself (high speed) but should not be considered threatening if the other cue was considered safe (i.e. if direction was safe). Table 5 provides the rules that guide the correct assessment of each aircraft.

Cue Interpretation Rules

This task has the advantage of a single correct answer for each judgment, calculated from a quantitative representation of the "rules of engagement" (see Table 6). Each cue takes on a potential threat value ranging from 0 (no threat) to 2 (very threatening). Interactions among the cues must be considered to ascertain the correct level of threat. The four interactions were represented by the multiplication of the individual cue values. Thus, if speed is threatening (2) and direction is nonthreatening (0), the interaction between speed and direction would be nonthreatening (0 x 2 = 0). The four interactions plus IFF considered alone, determined the threat of each of the aircraft. The threat level of the aircraft was an additive combination of the threat level of each cue set. Subjects were trained on the rules, but were not presented with the mathematical formula.

Table 5

Rules of Engagement

(1) ASSESSMENT OF IFF (Identify Friend or Foe). All else equal, aircraft with military IFF (red) are more threatening than ambiguous aircraft (yellow). Civilian (green) aircraft are nonthreatening for IFF.

(2) ASSESSMENT OF INTERACTIONS. Four rules must be considered in the assessment of the actual threat of an incoming aircraft:

1. **RANGE AND CORRIDOR STATUS** - go together, so that CLOSE aircraft that are WAY OUTSIDE THE CORRIDOR are most dangerous. If either range or corridor status is safe, the interaction is considered safe. An aircraft that has a threatening range (close) is not a threat if the corridor status is safe (inside), and vice versa.

2. **SIZE AND RADAR** - go together, so that SMALL aircraft with WEAPONS radar (high pitch sound) are most dangerous. If either size or radar is safe, the interaction is considered safe. An aircraft that has a threatening size (small) is not a threat if the radar is safe, and vice versa.

3. **SPEED AND DIRECTION** - go together, so that FAST aircraft coming STRAIGHT IN are most dangerous. If either speed or direction is safe, the interaction is considered safe. An aircraft with a threatening direction (straight in) is not a threat if the speed is safe, and vice versa.

4. **ALTITUDE AND ANGLE** - go together so that LOW-FLYING aircraft that are DESCENDING are most dangerous. If either altitude or corridor status is safe, the interaction is considered safe. An aircraft that has a threatening altitude (low) is not a threat if the angle is safe (ascending), and vice versa.

(3) ASSESSMENT OF THE ENTIRE AIRCRAFT. Assessment of the aircraft as a whole is based on a quantitative combination of threat assessments of each interaction and the IFF cue.

Table 6

Underlying Quantitative Model

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(1) ASSESSMENT OF IFF. (Color of aircraft)

RED =	2	points (military IFF, threat level high)
YELLOW =	1	point (moderate threat)
GREEN =	0	point (civilian, non threatening IFF)

(2) ASSESSMENT OF INTERACTIONS. Four rules must be considered:

A. **RANGE AND CORRIDOR STATUS** - The threat level of range (0,1,2) is multiplied with that of corridor status (0,1,2) to provide a threat level for the interaction (0,1,2,4). This multiplicative approach applies to all interactions.

B. **SIZE AND RADAR** - The threat level of size (0,1,2) is multiplied with that of radar (0,1,2) to provide a threat level for the interaction (0,1,2,4).

C. **SPEED AND DIRECTION** - The threat level of speed (0,1,2) is multiplied with that of direction (0,1,2) to provide a threat level for the interaction (0,1,2,4).

D. **ALTITUDE AND ANGLE** - The threat level of altitude (0,1,2) is multiplied with that of angle (0,1,2) to provide a threat level for the interaction (0,1,2,4).

(3) ASSESSMENT OF THE ENTIRE AIRCRAFT. Assessment of the aircraft as a whole is based on the sum of threat levels of each interaction and for IFF. IFF is weighted by 2 so that it will have a range (0 - 4) equal to that of the interactions, resulting in an overall assessment ranging from 0 to 20. The correct decision for each aircraft depends on the number associated with the threat level of the aircraft as a whole, as follows:

IGNORE: 0 - 2	MONITOR: 6 - 8	WARN: 9 - 11	
REVIEW: 3 - 5	READY: 12 - 14	LOCK-ON: 15 -17	DEFEND: 18 - 20

<u>Ambiguous decision events</u>. Some of the decision events were ambiguous, that is, research participants did not see all nine information cues. When the level of threat associated with a particular interaction was unknown, a rational assessment can only determine a range of "correct" assessments. For example, if speed was unknown, the threat level for the interaction of speed and direction cannot be precisely determined. However, a range of "possibly correct" judgments can be determined.

In this study, ambiguous decision events have an underlying correct answer based on all nine cues, regardless of whether they were available to the decision maker. Research participants were informed that some decision events will have missing information and requested to make their best guess. They were told that their decision may be consistent with the available information, yet still be incorrect according to the feedback, because of the unknown information. Scoring was based on the correct assessment using all nine cues, even if some were not available to the decision maker, because the focus was on the impact of ambiguity on task performance outcomes as they can be generalized to realistic settings.

Feedback. After each decision event, participants entered their judgment of overall threat. If the research participant failed to provide a judgment within the time period a default judgment of "ignore" was assigned to that aircraft. Once the judgment was entered they were presented with feedback that provided the correct judgment and the number of points associated with the accuracy of their judgment.

The feedback screen provided the research participant's judgment and the actual correct assessment for the aircraft. Scoring was based on the absolute difference between the research participant assessment and the correct assessment. Scores range from hit (+2 points), near miss (+1 point), miss (0 points), incident (-1 point), and disaster (-2 points). If the participant achieved the correct decision, this was termed a "hit". Thus, if the research participant decided to correctly "ignore" an aircraft, this was considered a hit. In the same way, if the research participant decided to correctly "defend" against an aircraft, this would also be a hit. If the research participant was one level above or below the correct decision, it was termed a "near miss." Thus, if the research participant decided to "monitor" when the true decision was "warn", this would be a near miss. If the research participant was two levels above or below the correct decision, it was termed a "miss". An example of a miss would be deciding to "ignore" when one should have chosen "monitor."

Three levels above or below the correct decision was referred to as an "incident." An example of an incident would be choosing "defend" when the correct action was "warn." Four or more levels from the correct decision was termed a "disaster." Thus, if the participant chose to "review" when the correct decision was "defend" the feedback was that of "disaster" and the research participant loses 2 points (see Table 7).

Table 7

Scoring Of Accuracy

"Hit"	Correct threat assessment	+ 2
"Near Miss"	One threat level off	+ 1
"Miss"	Two threat levels off	0
"Incident"	Three threat levels off	- 1
"Disaster"	Four+ threat levels off	+ 2

Research participants were presented with feedback on their decision accuracy immediately after each decision was made. The feedback screen also provided the research participant's performance history (number of hits, near misses, etc.), and a projection of what the person's final total score would be given the performance up to that time. The feedback screen was presented for 3 seconds, followed by the next decision event.

Research Design

This study has four between-subject variables, two of which were manipulated, and two which were individual difference variables which were assessed but not manipulated. The two manipulated between subjects variables were display condition (simultaneous versus sequential display condition) and decision frame (passive versus aggressive previous error), resulting in four experimental conditions. In addition, there were 3 within-subjects variables (time pressure, ambiguity, and cue conflict) which were consistent throughout all experimental conditions. The two individual difference variables, cognitive style and cognitive ability, were obtained for each research participant. The Myers-Briggs Type Indicator was administered to all research participants and SAT/ACT scores were obtained for each research participant.

Experimental Manipulations

Sequencing of cue presentation. Research participants assigned to the simultaneous condition were presented with all nine cues within a single display, as demonstrated in Figures 4 and 5. Research participants assigned to the sequential condition were first presented with a blank screen followed by cues added one at a time in the same order: range, corridor status, size, radar, IFF, direction, speed, altitude, angle. When all cues were presented the research participants in the sequential display condition saw the same screen as the research participants in the simultaneous condition. Then in both conditions the screen goes blank, allowing research participants an additional three seconds in which they can make their judgment.

Decision frame. Decision frame was manipulated through background information which described a recent incident in the same area of responsibility which had disastrous consequences, in that 200 lives were lost. The manipulation consisted of the type of decision error described for the incident. In one frame the decision error was one of passivity: a hostile aircraft was assessed as safe and ignored, with the consequent loss of 200 civilian lives after the hostile attacked the base. In the other frame the decision error was of over-aggression: a peaceful aircraft was assessed as threatening and attacked, with the consequent loss of 200 civilian lives.

Each research participant was presented with background information which described the role they were to play as that of a member of a command-and-control team, recently assigned to be responsible for an unstable geographic area. The written information described the background scenario. According to the scenario, the area is a part of the middle east with a long history of political unrest, and the recent incident has made the situation even more unpredictable. The background information was identical in both conditions except for the description of the disastrous error made by the previous decision maker.

The error described in both frames resulted in 200 fatalities. The passive frame manipulation described an error of passivity: a hostile aircraft was not correctly assessed and defended against; consequently the hostile aircraft attacked and 200 civilians died. In the aggressive frame manipulation, the decision error was an overly aggressive judgment. In this scenario, the research participants were told that an aircraft was mistakenly identified as hostile, and consequently 200 civilians died from the shooting down of an airline aircraft.

In both scenarios, research participants were told that the previous incident should not affect their current decisionmaking task, which was described as demanding a very objective impersonal assessment of aircraft information. While this reduces the magnitude of the frame manipulation, it was important that decisionmakers be focused on achieving objective accuracy.

Time pressure. There were three levels of time pressure: high time pressure (5 seconds), moderate (10 seconds), and low time pressure (15 seconds). The time allowed for high time pressure was quite short in order to constrain deliberation. The time pressure was not expected to constrain the recognition process as Simon (1986) described the recognition process as immediate, that is, within a few seconds.

After each aircraft was viewed for its amount of time, a blank screen was shown for an additional 3 seconds. The additional 3 seconds allowed the research participant to view the cues for the total time, and still be able to send in a judgment. It compensated for the fact that the sequentially presented aircraft allow the research participants very little time to perceive the last cue.

Information Ambiguity. Ambiguity was manipulated by removal of 2 or 4 information cues. Certain decision events provided information on all nine cues. Decision events with moderate ambiguity were missing two cues, each related to separate interactions. Decision events with high ambiguity were missing four cues, where two of the cues comprise an entire interaction.

Information conflict. It was predicted that sequential display of information under time pressure was more likely to result in primacy error, that is, the information presented first would be more influential in the overall assessment. In order to ascertain whether primacy occurs, decision events had to be constructed where over-weighting of preliminary information would make a difference. If subsequent information was consistent with preliminary information primacy could not be ascertained. Decision events were constructed such that information provided first was in conflict with information provided last. Thus, preliminary information may indicate no threat, followed by information indicating high threat, or vice versa. In this way, if primacy is occurring, aircraft would be assessed as less threatening than the correct assessment, if the non threatening information was presented first. In the same way, aircraft would be assessed as more threatening than the correct assessment, if the threatening information was presented first.

Construction of decision events. Decision events were generated such that they systematically vary in time pressure, ambiguity, and cue conflict. Table 8 describes the strategy by which decision events were generated to examine these within-subjects variables. The manipulation and crossing of (a) three levels of time pressure, (b) three levels of ambiguity, and (c) conflict - whether the first three cues were indicative of subsequent cues, resulted in 18 different types of decision events. A single decision event was constructed for each of the 18 different configurations of time pressure, ambiguity, and cue conflict. These 18 decision events were presented 10 times in the same order, a total of 180 decision events assessed by each individual.

Table 8

Generation of Decision Events: Within-subject variables

Decision event	Time Pressure	Ambiguity	1st Three
1	1	0	0
2	2	0	0
3	3	0	0
4	1	1	0
5	2	1	0
6	3	1	0
7	1	2	0
8	2	2	0
9	3	2	0
10	1	0	1
11	2	0	1
12	3	0	1
13	1	1	1
14	2	1	1
15	3	1	1
16	1	2	1
17	2	2	1
18	3	2	1

* This chart signifies the manner by which these decision event sets were generated.

The repetition of the 18 decision events was expected to facilitate the recognition process. Bentin and McCarthy (`1994) noted that repetition facilitates recognition, and the repetition effect occurs primarily when the repetition was immediate. In this study, the 18 decision events were repeated 10 times in the same order, such that increased recognition of the decision events was expected, particularly for research participants in the simultaneous display condition.

Procedure

Research participants were recruited from an undergraduate management class at a midwestern state university. They were informed that participation in the experiment would provide extra credit, and would take about three hours of their time. Research participants who expressed a willingness to participate filled out the Myers-Briggs Type Indicator. Volunteers were scheduled to three-hour time intervals, in groups of 12-15 at a time.

When research participants reported to the laboratory they w re randomly assigned to experimental manipulations of display condition and decision frame. They were given written information describing the task. This background information varied consistent with their assigned decision frame. Experimental conditions varied randomly over the time period of the data collection period.

Research participant training. Participants were trained to interpret cue information and perform the computer task. Training consisted of written information, video training, and interactive training. The written information included a general overview of the task and information relating cue values to appropriate judgments. After 5 minutes of studying the written material, research participants were presented with video training. The video corresponded with the written script, so that research participants can read along with the video presentation. During the video presentation, research participants were first trained on each individual cue. A visual representation of the cue or information was presented, followed by the correct assessment. They were then shown how to operate the computer task. Operation of the computer task was very simple, as research participants were presented with each aircraft representation and only needed to enter a judgment with a keystroke.

After the video training, research participants completed a task knowledge questionnaire. Once the questionnaire was completed, they began the actual task. The first five decision events were for practice, where research participants were "walked" through the decision task for the first couple of decisions, and the experimenter remains present during this time. Once these practice decisions were completed the research participant was left to complete the set of decision events.

Hypotheses

The following section describes the hypotheses proposed in this study. Hypotheses are derived from the overall model depicted in Figure 7. The model describes expected effects of task and individual characteristics on decision performance, as moderated by display condition. Task characteristics and individual differences were predicted to affect optimality of decision context. Interactions were expected between these characteristics and display condition.

Task characteristics. The first four hypotheses follow from Figure 7 and predict main effects of task characteristics on decision performance. Time pressure, ambiguity, conflict, and frame were expected to be detrimental to decision performance in general, such that increased time pressure, ambiguity, and conflicting information create a suboptimal decision context.

H1. Time pressure. Time pressure was expected to have a significant main effect on decision accuracy. As time pressure was increased, decision accuracy was expected to decrease. This hypothesis was tested using measures ANOVA on mean accuracy scores for each level of time pressure (O'Brien & Kaiser, 1985; Winer, 1978). The F-test for the main effect of time pressure was expected to be significant at p </= 0.05.

H2. Information ambiguity. Ambiguity was expected to have a significant main effect on decision accuracy. As information becomes less certain due to missing information, decision accuracy was expected to decrease. This hypothesis was tested using repeated measures ANOVA on mean accuracy scores for each level of information ambiguity. The F-test for the main effect of ambiguity was expected to be significant at p </= 0.05.

H3. Information conflict. Conflict of information cues was expected to have a significant main effect of decision accuracy. Conflict of information cues was expected to have a negative effect on decision accuracy. This hypothesis was tested using repeated measures ANOVA, using mean scores for each level of conflict. The F-test for the main effect of conflict was expected to be significant at p </= 0.05.

H4. Decision frame. A main effect was expected for Frame 1 versus Frame 2 for all research participants. This hypothesis was tested using ANOVA. The F-test for the main effect of frame was expected to be significant at p </= 0.05.

Interactions between task characteristics and display condition. Interactions were predicted between display condition and each task characteristic, such that the effect of each task characteristic was expected to be moderated by display condition. It was expected that research participants in the sequential display condition would be more detrimentally affected by unfavorable task characteristics of increased time pressure, ambiguity, conflict, and frame.

H5. Time pressure and display. Time pressure was expected to be more detrimental to research participants in the sequential condition compared to research participants in the simultaneous condition. Research participants in the simultaneous condition were expected to be more likely to utilize a recognitional response that does not require as much effortful deliberation, and thus not be as detrimentally affected by time pressure. This hypothesis was tested using repeated measures ANOVA. The F-test for the interaction between display and time pressure was expected to be significant at p </= 0.05.

H6. Information ambiguity and display. Ambiguity was expected to be more detrimental to research participants in the sequential condition, who were more likely to be processing the information sequentially. Research participants in the sequential condition were expected to be more likely to attempt deliberate consideration of each cue which will make the absence of cue(s) more salient. Research participants in the simultaneous condition were expected to make a more holistic judgment, and the absence of a cue(s) was not expected to prevent a holistic impression from occurring. This hypothesis was tested using repeated measures ANOVA. The F-test for the interaction between display and ambiguity was expected to be significant at p </= 0.05.

H7. Information conflict and display. Conflict among information cues was expected to be more detrimental to research participants in the sequential condition, who were expected to process the information sequentially and be more susceptible to primacy error. Research participants in the simultaneous condition were expected to make a more holistic judgment based on all cues seen at once and the conflicting information was expected to be less difficult to integrate. This hypothesis was tested using repeated measures ANOVA. The F-test for the interaction between display and conflict was expected to be significant at p </= 0.05.

H8. Decision frame and display. Research participants in the simultaneous display condition were not expected to be affected by frame manipulations. However, research participants in the sequential display condition, were expected to demonstrate a significant mean difference in average decision assessment as a function of frame manipulations. The direction of average judgment was expected such that research participants in the overly passive condition would provide assessments that were higher in threat than research participants in the overly aggressive frame condition. This hypothesis was tested using repeated measures ANOVA. The F-test for the interaction between display and frame was expected to be significant at p </= 0.05.

Individual differences.

Individual differences among decision makers were also predicted to affect decision performance. Optimal characteristics of the decision maker were predicted to be those who are high in cognitive ability and have a cognitive style preference that is congruent with the decision task.

H9. Cognitive ability. Cognitive ability was expected to have a significant main effect on decision accuracy, such that research participants with high cognitive ability were expected to perform more accurately than those with low cognitive ability. This hypothesis was tested using ANOVA. The F test for the significance of cognitive ability as a main effect was expected to be significantly larger than would be expected by chance.

H10. Cognitive style. Cognitive style was expected to have a significant main effect on decision accuracy. Individuals with an objective, fact-based decision style were expected to perform more accurately on this task than those with a preference for intuitive, holistic decision making. This hypothesis was tested using ANOVA.

Interactions between display and individual characteristics.

Individual differences in cognitive ability and decision style are expected to affect information processing, such that low cognitive ability and/or an incongruent decision style should have a degrading effect on decisionmaking. Consistent with the previous predictions regarding task characteristics, the simultaneous display condition is expected to be more resistant to degrading influences.

H11. Cognitive ability and display. A significant interaction was predicted between cognitive ability and display condition. Individuals low in cognitive ability were expected to do less well in the sequential display condition. This hypothesis was tested using ANOVA. The F test for the interaction between cognitive ability and display condition was expected to be significant at p </= 0.05.

H12. Cognitive style and display. A significant interaction was expected between decision style and display condition. Individuals with a high preference for "sensing" (fact-based reasoning as opposed to intuition) were expected to perform more accurately in the sequential display condition than those with a preference for intuitive processing. This hypothesis was tested using ANOVA. The F test for the interaction between cognitive style and display condition was expected to be significant at p </= 0.05.

Chapter 5

RESULTS

Overview

A total of 537 research participants participated in this study, with 286 in the simultaneous display condition and 251 in the sequential condition. Also, 270 were in frame 1, where the previous error described was overly passive, and 267 were in the frame 2 manipulation, where the previous error described in background information was one of over-aggression (see Table 10).

Table 9

Between-subjects Variables

	DISPLAY		
FRAME	**Simultaneous**	**Sequential**	**Total**
Overly Passive			
N Ss.	142	128	270
N Decisions	25,418	22,912	48,330
Overly Aggressive			
N Ss.	144	123	267
N Decisions	25,776	22017	47,793
Total			
N Ss.	286	251	537
N Decisions	51,194	44,929	96,123

Performance was based on the absolute difference between the true score and the actual score. The range of this absolute difference spans from 0 to 6. In order to make this accuracy score such that a higher number reflects higher accuracy, the absolute difference was subtracted from six, resulting in a number that increases as accuracy increases. The overall mean for this performance score was 4.69 (s.d. = 1.24), based on a total of 96,123 decisions.

Task Characteristics

Characterictics of the decision task expected to enhance or degrade the information processing/decision making process include time pressure (three levels), ambiguity (three levels), information conflict (two lehvels) and decision frame (two categories).

Time pressure: Main effect (H1). Table 10 provides within-subjects ANOVA results for the impact of time pressure on decision accuracy. All ANOVA analyses reported within this study were performed using the General Linear Models (GLM) Procedure Repeated Measures Analysis of Variance procedure of SAS statistical analysis software. For within-subjects manipulations of task characteristics, such as time pressure, means were calculated for each level, o(i.e. low, moderate, and high time pressure) for each research participant, and the repeated-measures ANOVA procedure was run on these means. While there is no difference in the F-value using either procedure, the sums of squares reported are lower than if the ANOVA was run using scores for each individual decision.

Table 10

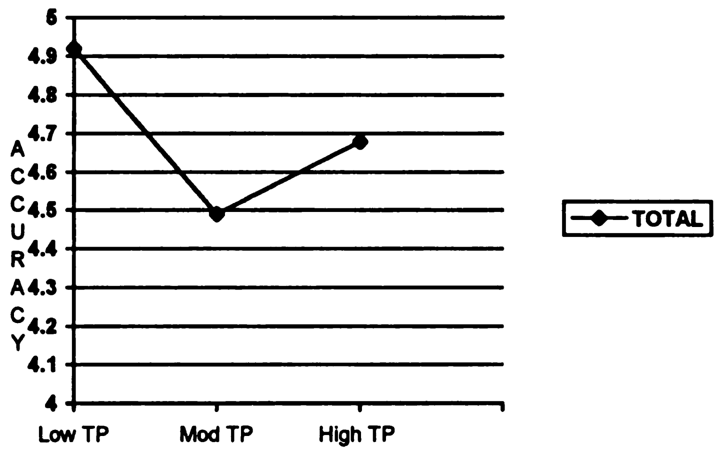
Impact of Time Pressure on Decision Accuracy

Source	DF	SS	MS	F	Pr	Eta2
TIM3	2	2967.04	1483.52	397.90	0.0001	0.43
Error	1072	3996.85	3.72			

* The ANOVA was calculated using means for each participant

Table 10, continued.

	Low TP (15secs)	Mod TP (10secs)	High TP (5 secs)	Total
Mean Accuracy	4.92	4.49	4.68	4.695
S.D.	(1.08)	(1.29)	(1.30)	(1.24)
N Ss.	537	537	537	1611
N Decisions	32,220	32,220	31,683	96,123



The effect of time pressure on performance was consistent with predictions. Performance was expected to be adversely affected by time pressure such that the higher the time pressure the more detrimental the effect. This is reflected in the positive correlation between time pressure and decision accuracy ($r = 0.07$; $p < .001$). However, as reflected in the graph, research participants performed better under high time pressure than under moderate time pressure.

The decision events were examined in case decisions presented under high time pressure were less difficult than decisions presented under moderate time pressure. Difficulty was operationally defined as deceptiveness: when two interacting cues conflict in that one cue is safe and the other is threatening. The decision rule states that if one cue within an interaction is safe, the entire interaction should be considered safe regardless of the threat level of the other cue. When one cue is safe and the other is threatening, the aircraft will appear more threatening than it actually is. This is another variation of information conflict; however it differs from the planned manipulation of information conflict. The measure of information conflict used in this study has preliminary cues conflicting with subsequent cues, thus allowing investigation of order effects in the sequential presentation condition. Deceptive decision events differ in source of conflict: the conflict is not based on order, it is based on cues within a pair of interacting cues. In a deceptive target, there will be safe and threatening cues, and the target will appear more threatening than it is if judgment is based on a sum of safe versus threatening cues. Attention to and application of the decision rule will result in more accurate and "less threatening" assessments.

As it turned out, there were more deceptive targets in the high time pressure condition. When deceptive and nondeceptive targets are examined seperately, accuracy was no longer higher under high time pressure. Findings are further described in the description of exploratory results.

Time Pressure: Interaction with display (H5). Research participants in the sequential display condition were expected to be more negatively affected by time pressure. Research participants in the sequential condition would then have more accurate assessments for targets presented under low in time pressure, but would have less accurate assessments than research participants in the simultaneous condition under high time pressure. This hypothesis was tested using repeated measures ANOVA. The following table describes ANOVA results for the prediction of accuracy using display and time pressure as predictors.

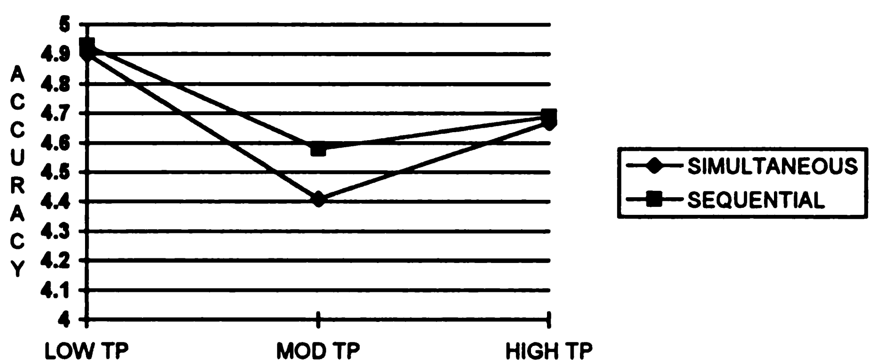
Table 11

Impact of Display Condition and Time Pressure on Decision Accuracy

Source	DF	SS	MS	F	Pr	Eta2
DISP	1	132.77	132.77	11.43	0.0008	0.02
Error	535	6215.59	11.62			
TIM3	2	2890.69	1445.34	398.91	0.0001	0.42
TIM3*DISP	2	120.00	60.00	16.56	0.0001	0.02
Error(TIM3)	1070	3876.85	3.62			

Table 11, cont'd.

Time pressure	Simultaneous	Sequential	Total
High (5 secs)			
Mean Accuracy	4.67	4.69	4.68
S.D.	(1.28)	(1.32)	(1.30)
N Ss.	286	251	537
N Decisions	16,874	14,809	31,683
Mod (10secs)			
Mean Accuracy	4.41	4.58	4.49
S.D.	(1.32)	(1.25)	(1.29)
N Ss.	286	251	537
N Decisions	17,160	15,060	32,220
Low (15 secs)			
Mean Accuracy	4.90	4.93	4.92
S.D.	(1.10)	(1.06)	(1.08)
N Ss.	286	251	537
N Decisions	17,160	15,060	32,220



The graph demonstrates the main effect of time pressure was similar for both display conditions in that research participants performed less accurately in the moderate time pressure condition. It was predicted that research participants in the simultaneous display condition would perform better than research participants in the sequential display condition as time pressure increased; however, the detrimental effect of moderate time was greater for research participants in the simultaneous condition.

Analysis were repeated separately for deceptive and nondeceptive targets. When analyzed seperately, decision accuracy is no longer higher under high time pressure. Results are described in further detail in the exploratory section. Deceptiveness of target accounts for the lower accuracy under moderate time pressure; it also accounts for lower performance of subjects in the simultaneous condition.

Information ambiguity: Main effect (H2). It was predicted that ambiguity from missing information would degrade the decision context such that research participants would do less well under ambiguous conditions. The correlation between degree of ambiguity and performance was positive as expected ($r = 0.08$; $p = .0001$), However, while performance was much worse on the highly ambiguous targets, the performance on the moderately ambiguous targets was better than on the certain targets.

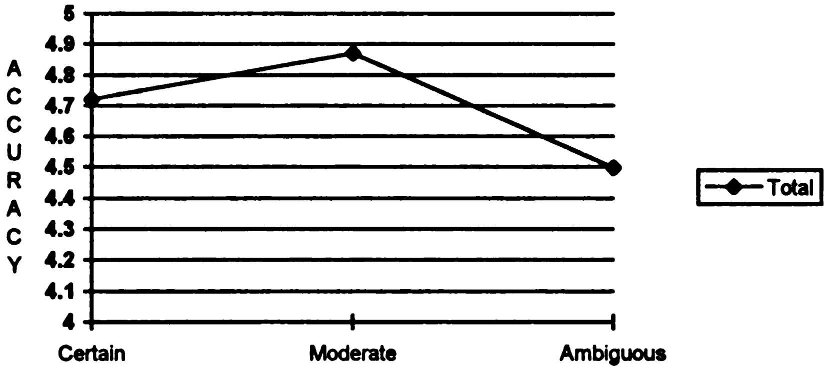
Table 12

Impact Of Ambiguity On Decision Accuracy

Source	**DF**	**SS**	**MS**	**F**	**Pr**	**Eta2**
AMB	2	2275.78	1137.89	275.64	0.0001	0.34
Error(TIM3)	1072	4425.34	4.13			

	Low (Certain)	**Moderate Ambiguity**	**High Ambiguity**	**Total**
Mean Accuracy	4.72	4.87	4.50	4.69
S.D.	(1.25)	(1.06)	(1.36)	(1.24)
N Ss.	537	537	537	1611
N Decisions	31,683	32,220	32,220	96,123

Table 12, cont'd



Decision events were examined for distribution of deceptive targets across levels of ambiguity, as done previously in the analysis of time pressure. There were more deceptive targets in the certain condition, and fewer deceptive targets in the moderate condtion. After controlling for deceptiveness, the effect of ambiguity was as expected. Analyses are further described in the section describing exploratory analyses.

Information ambiguity: Interaction with display (H6). It was predicted that research participants in the sequential display condition would perform less accurately as ambiguity increased. The next table provides ANOVA results for display, ambiguity, and the interaction term.

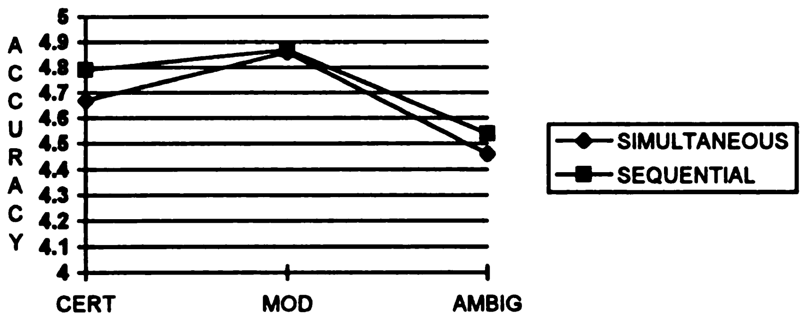
Table 13

Impact of Display Condition and Ambiguity on Decision Accuracy

Source	DF	SS	MS	F	Pr	Eta2
DISP	1	132.77	132.77	11.43	0.0008	0.02
Error	535	6215.59	11.62			
AMB	2	2250.27	1125.13	275.97	0.0001	0.36
AMB*DISP	2	62.87	31.43	7.71	0.0005	0.01
Error(AMB)	1070	3876.85	3.62			

Table 13, cont'd.

Certainty	Simultaneous	Sequential	Total
Low (ambiguous)			
Mean Accuracy	4.46	4.54	4.50
S.D.	(1.36)	(1.36)	(1.36)
N Ss.	286	251	537
N Decisions	17,160	15,060	32,220
Moderate			
Mean Accuracy	4.86	4.87	4.87
S.D.	(1.05)	(1.08)	(1.06)
N Obs.	286	251	537
N Decisions	17,160	15,060	32,220
High (certain)			
Mean Accuracy	4.66	4.79	4.72
S.D.	(1.30)	(1.18)	(1.25)
N Ss.	286	251	537
N Decisions	16,874	14,809	31,683



Results indicate significant effects of display, ambiguity, and the interaction term on performance, but not in the manner expected. All research participants performed better on targets that were moderate in ambiguity. Further, high ambiguity had a more negative influence on performance of research participants in the simultaneous condition, when it was predicted it would have a more negative effect within the sequential condition.

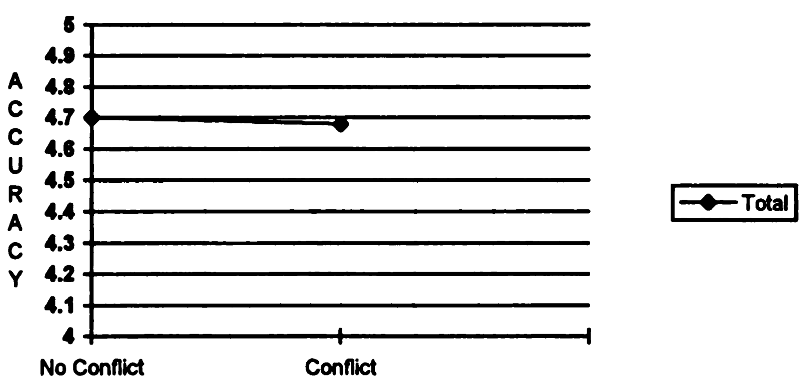
Information conflict: Main effect (H3). This hypothesis predicted that research participants would do less well when cues conflicted. However, results indicate no significant relationship between conflict and performance (r = -.005; p = .30).

Table 14

Impact Of Cue Conflict On Decision Accuracy

Source	DF	SS	MS	F	Pr	Eta2
CONF	2	0.98	0.98	0.19	0.67	0.00
Error(CONF)	536	2838.84	5.30			

	No Conflict	Conflict
Mean Accuracy	4.70	4.68
S.D.	1.36	1.11
N Ss.	537	537
N Decisions	48,330	47,793



It may be that information conflict only had an effect on decisionmaking in the sequential condition, as conflict was manipulated as an order effect: information presented first conflicts with subsequent information. This is demonstrated in the next analysis.

Another possible explanation is that conflict has more effect on the direction of decision error rather than the amount. In this study half of the conflicting decision events presented "safe" information first, followed by "threat" information; the other half was in reverse order. The data were then analyzed for impact of information conflict on the response mean. Analyses demonstrated significant relationship between conflict and response mean, and are described in the exploratory section.

Information conflict: Interaction with display (H7) The following table describes the interaction of display and conflict on decision accuracy.

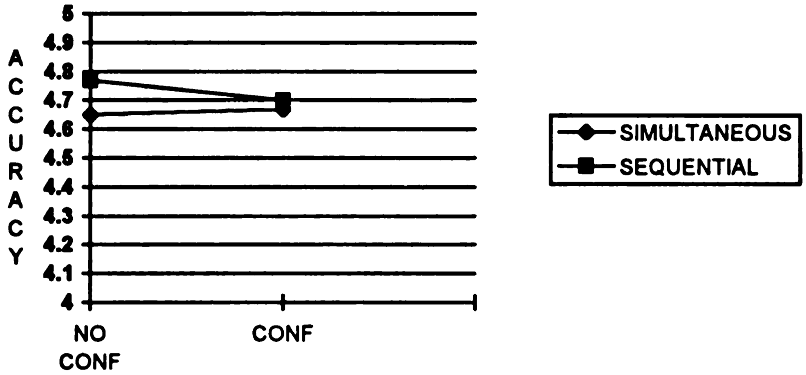
Table 15

Impact Of Display Condition and Information Conflict On Decision Accuracy

Source	DF	SS	MS	F	Pr	Eta2
DISP	1	132.77	132.77	11.43	0.0008	0.02
Error	535	6215.59	11.62			
CONF	1	1.97	1.97	0.38	0.54	0.00
CONF*DISP	1	40.49	40.49	7.74	0.005	0.02
Error(CONF)	535	2798.35	5.23			

	Simultaneous	Sequential	Total
No Conflict			
Mean Accuracy	4.65	4.77	4.70
S.D.	1.39	1.32	1.36
N Ss.	286	251	537
N Decisions	25,740	22,590	48,330
Conflict			
Mean Accuracy	4.67	4.70	4.68
S.D.	1.11	1.12	1.11
N Ss.	286	251	537
N Decisions	25,454	22,339	47,793

Table 15, cont.



This finding is consistent with predictions. It was predicted that research participants in the sequential display condition would perform better than research participants in the simultaneous display condition when the targets do not conflict. It was also predicted that research participants in the simultaneous condition would do better than research participants in the sequential condition for conflicting targets. While this is not the case, one sees the direction of the findings consistent with the predictions, in that conflicting targets had a detrimental effect only on decision making in the sequential display condition.

<u>Decision Frame: Main effect (H4).</u> Frame information was expected impact decision accuracy and direction of decision error. When the frame manipulation described the previous error as one of passivity (a hostile aircraft was not defended against when it should have been) research participants were expected to make somewhat more aggressive assessments. When the frame manipulation described the previous error as one of over-aggression, research participants were expected to assess aircraft as less threatening than research participants in the overly passive frame condition. Results indicate a small but significant effect of frame information on decision accuracy. When the previous error described in the frame was one of agression, accuracy is higher. This is likely due to an overall tendency of assessing targets as more threatening than they

actually are. When the previous error is that of over-aggression, the decision makers were supposed to be more cautious of agressive assessments. Analyses using accuracy as the dependent variable are described below, followed by analyses using the response mean as the dependent variable.

Table 16

Impact Of Decision Frame On Decision Accuracy

Source	DF	SS	MS	F	Pr	Eta2
FRAME	1	0.27	0.27	4.11	0.04	0.02
Error	535	34.99	0.06			

	Passive	Agressive
Perform	4.68	4.72
S.D.	1.25	1.23
N Ss.	286	251
N Decisions	48600	48060

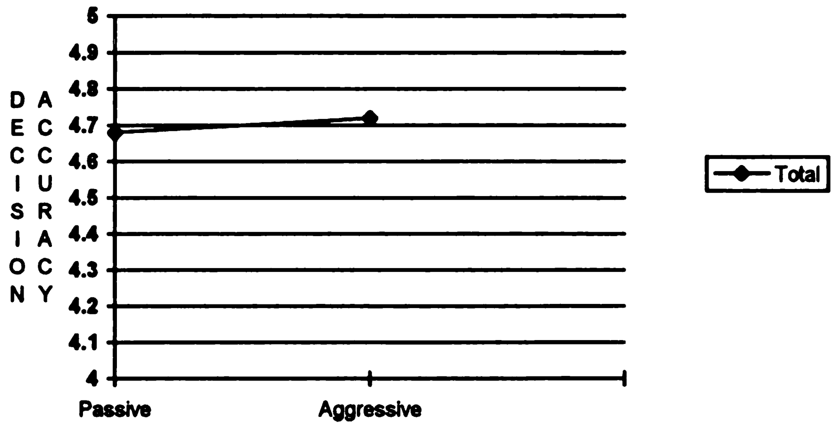


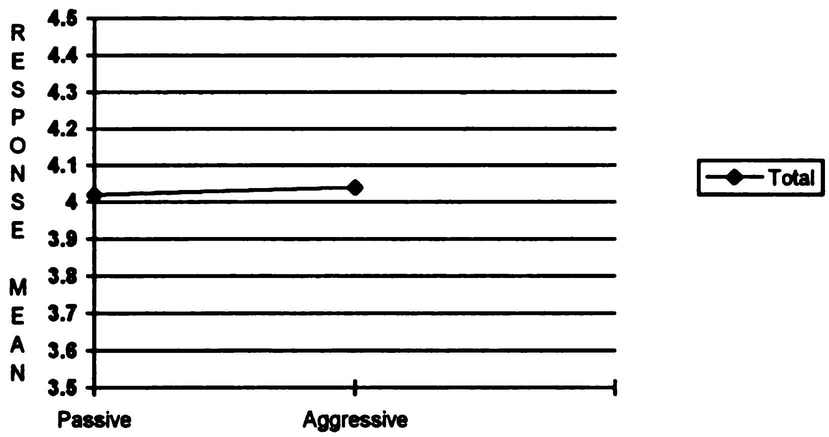
Table 17

Impact Of Decision Frame On Response Mean

Source	DF	SS	MS	F	Pr	Eta2
FRAME	1	0.04	0.04	0.46	0.49	0.00
Error	535	48.92	0.09			

Mean Decision Response for Frame 1 and Frame 2

	Passive	Agressive
Mean Response	4.02	4.04
S.D.	1.77	1.76
N Ss.	286	251
N Decisions	48600	48060



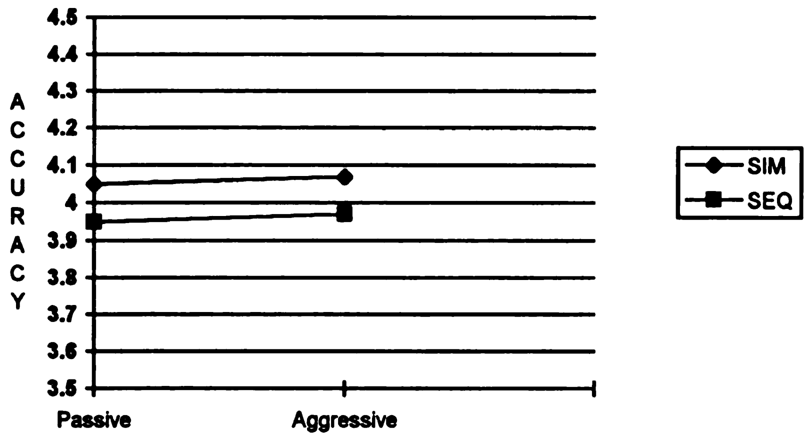
Frame: Interaction with display (H8). The following table describes ANOVA results for the relative impact of frame and display on decision responses. The graph provides the correct answer for each target, along with mean responses for research participants in Frame 1 and Frame 2.

Table 18

Impact of Display Condition and Frame on Decision Response

Source	DF	SS	MS	F	Pr	Eta2
DISP	1	234.12	234.12	14.56	0.0002	0.02
FRAME	1	6.48	6.48	0.40	0.5258	0.00
DISP*FR	1	0.01	0.01	0.00	0.9843	0.00
Error	533	8571.46	16.08			

	Passive	Agressive
Sequential		
Mean Response	3.95	3.97
S.D.	1.77	1.76
N Decisions	22,912	22,017
Simultaneous		
Mean Response	4.05	4.07
S.D.	1.75	1.73
N Decisions	25,418	25776



It can be seen that there is minimal difference between the frame conditions. There was no significant interaction between frame and display.

Individual Characteristics

Cognitive ability. SAT and/or ACT scores were obtained where possible on research participants (N = 375). The following table provides descriptive statistics for the total SAT (adding verbal and math) and the ACT composite score. Z-scores were also computed.

Table 19

Descriptives for SAT and ACT Scores

Variable	N	Mean	S.D.	Min	Max	Skew	Kurtosis
SAT-Total	139	954.32	145.25	620	1370	0.22	0.14
ACT-Composite	354	22.00	3.30	9	32	-0.29	1.18

A total of 114 research participants had scores on both the SAT and ACT measures. Comparison of these Z-scores indicated that research participants tended to have higher ACT Z-scores. For example, the Z-scores were computed for all research participants having scores. When we look at the mean Z-scores for research participants having both scores, the mean ACT Z-score is 0.19 while the mean SAT Z-score was -0.02. The cumulative percentiles for ACT and SAT Z-scores were examined, and differences in percentiles were found when equivalent Z scores of ACT versus SAT were compared. The distribution of the ACT and SAT scores were not the same (ACT skew = -.29; kurtosis = 1.18; SAT skew = 0.22; kurtosis = 0.14).

ACT and SAT scores were equated using an equipercentile equating procedure. One hundred and fourteen research participants had scores on both ACT and SAT scores. Using this set of research participants, data were arranged by cumulative percentile ranks to show the ACT and SAT scores corresponding to each percentile rank. The computational strategy to generate the corresponding ACT and SAT scores was based on the identification of the observation (ACT, SAT score) that is closest to that percentile rank. This data was used as a lookup table to identify the ACT score that corresponds to a particular SAT score at a particular percentile ranking. For example, an SAT score of 620 and an ACT score of 12 were identified at cumulative percentile of 1; an SAT score of 860 corresponded to an ACT score of 21 (percentile rank of 26); and an SAT score of 1370 corresponded an ACT score of 32 (percentile rank of 99). This enabled the transformation of SAT scores to ACT scores for those research participants who did not have ACT scores. ACT scores were then transformed to Z scores and these scores were used in the ANOVA analysis.

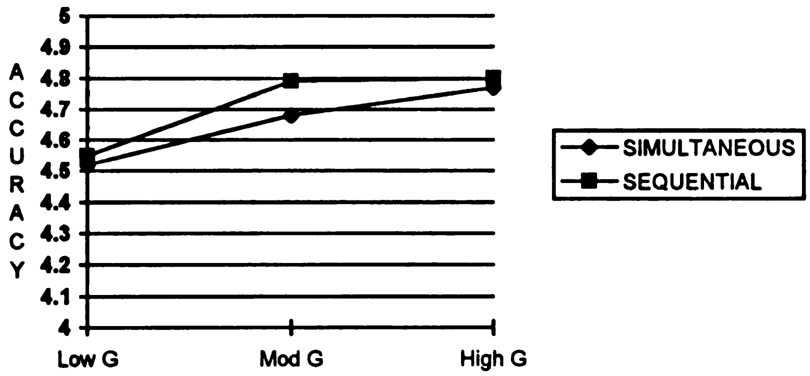
Table 20

Impact of ACT Z Scores and Display Condition on Decision Accuracy

Source	DF	SS	MS	F	Pr	Eta2
Display	1	135.91	135.91	13.98	0.00	0.03
Z_ACT	1	323.26	323.26	33.26	0.00	0.08
D*Z_ACT	1	0.04	0.04	0.00	0.94	0.00
Error	375	3644.55				

ACT Score	Simultaneous	Sequential
Low		
Mean Accuracy	4.52	4.55
S.D.	(1.35)	(1.33)
N Ss.	26	25
N Decisions	4,680	4,500
Moderate		
Mean Accuracy	4.68	4.79
S.D.	(1.24)	(1.20)
N Ss.	150	131
N Decisions	27,000	23,580
High		
Mean Accuracy	4.77	4.80
S.D.	(1.19)	(1.16)
N Ss.	26	20
N Decisions	4,860	3,600

Table 20, cont.



Results demonstrate a significant main effect overall on decision accuracy ($r = 0.28$; $p < 0.001$) but the interaction between ACT scores and display is not statistically significant.

Cognitive style. Scores were calculated for the "sensing" and "intuitive" scales of the Myers-Briggs Type Indicator. These scales are based on forced-choice items and are not completely independent; however, raw scores were transformed through a normed process as specified in the manual. While scores are calculated, the MBTI manual urges the reader not to use them as quantitative scales; they are for categorization only. The quantitative scores, while suggesting degree of preference, are ambiguous and cannot be interpreted with precision.

For this study, the scores were transformed as recommended in the manual such that a "0" indicated no preference; positive scores indicated an intuitive preference, and negative scores indicated a sensing preference. Research participants were categorized into three groups: (a) "sensing" types, (b) "intuitive" types, and (c) no decided preference. As can be seen in the table below, there was no significant main effect for decision style.

Table 21

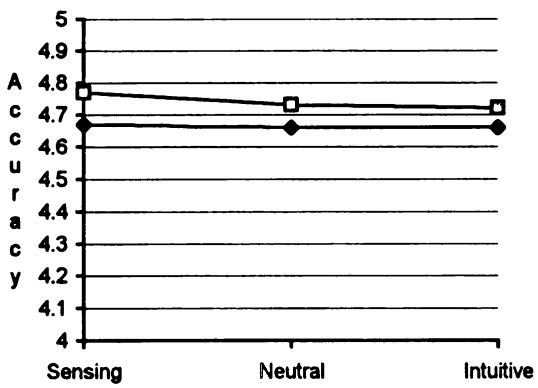
Descriptives for MBTI Sensing and Intuitive Scales

Variable	N	Mean	Std Dev	Minimum	Maximum
S	493	16.26	7.95	0.00	34.00
N	493	9.79	5.57	0.00	25.00
SN_SCORE	493	11.93	26.33	-51.00	67.00
SN_GRP	493	0.99	0.82	0.00	2.00

Table 22

Impact of Display and Cognitive Style on Decision Accuracy

Source	DF	SS	MS	F	Pr	Eta2
DISP	1	115.26	115.26	9.88	0.002	0.02
SN_GRP	2	15.43	7.71	0.66	0.52	0.00
DISP*SN_GRP	2	6.19	3.09	0.27	0.77	0.00
Error		487	5682.13	11.66		



Cognitive style and display. Table 22 also provides ANOVA results for the interaction between display and decision style. While it appears that individuals with a preference for sensing performed more accurately in the sequential condition, the interaction was not significant.

Exploratory Analyses

Several of the hypotheses were not supported by the data. The following section contains exploratory analyses to investigate post-hoc reasons for results. First, while a main effect for display was not predicted, results demonstrated a main effect, which is described here. Then, four issues are explored with further analyses:

1. Manipulation of favorability. The first set of analyses in this section addresses the predicted interactions between display condition and time pressure and uncertainty. The manipulation of favorability may not have been strong enough. Predicted effects may be more likely to occur when comparing "highly favorable" versus "highly unfavorable" targets. Therefore, performance between the two display conditions was compared on targets that were very favorable (i.e. low time pressure, certain information) with targets that were more unfavorable (i.e. high time pressure, uncertain information).

2. Deceptive targets. Decision events differed in degree of difficulty, operationalized as deceptiveness: Information was classified as deceptive if within a pair of interacting cues, one cue is safe and the other cue indicates threat. When one cue is safe, the entire interaction is considered safe; therefore, deceptive targets may appear more threatening than they actually are. The distribution of deceptive targets is not equal across conditions of time pressure and ambiguity. It was found that this unintentional and unequal distribution accounts for the curvilinear results found for the impact of time pressure and ambiguity on decision accuracy.

3. Performance over time. The third set of analyses investigates the possibility of differences between the display conditions over time. It was proposed that simultaneous display targets would elicit a more recognition-based decision process. In this case, the recognition response would be more likely to occur after the research participants had encountered several sets of targets. Hypotheses were reanalyzed using performance data on the last 54 out of 185 targets.

4. Order effect: Anchoring-and-adjustment versus belief-updating. The fourth set of analyses investigates performance on conflicting versus nonconflicting targets. Sequential display of targets was expected to result in less accurate performance when the first few cues conflicted with the last few cues. This was supported by the data. Further analyses, presented here, investigate whether the error was due to anchoring-and-adjustment (first cues weighted more) or belief-updating (more recent cues weighted more) for sequentially presented cue data.

Main effect of display. Display condition varied by sequential versus simultaneous display of cue information. The main effect of display was predicted to be moderated by time pressure and ambiguity, therefore no directional hypothesis was made for the main effect of display across all condtions. While results did indicate that research participants in the sequential display condition performed more accurately across all conditions, it should be noted that display condition did interact with task and individual variables such that more accurate predictions of performance can be attained if display, task, and individual variables are considered.

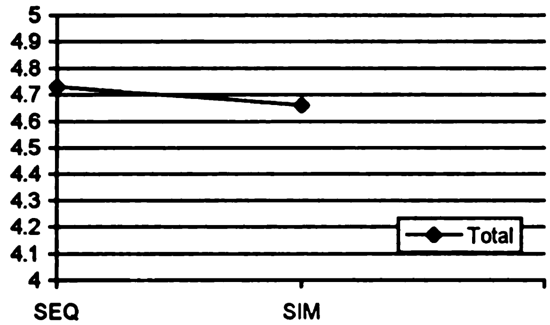
Table 23

Impact of Display Condition on Decision Accuracy

Source	DF	SS	MS	F	Pr	Eta2
DISP	1	132.77	132.77	11.43	0.00	0.02
Error(TIM3)	535	6215.59	11.62			

	Simultaneous	Sequential	Total
Mean Accuracy	4.66	4.73	4.69
Std. Deviation	1.255	1.225	1.242
N observations	51,194	44,929	96,123
N subjects	286	251	537

Table 23, cont.



Research participants in the sequential condition had a significantly ($F = 8.91$; $p = 0.00$) higher mean performance score ($4.74 > 4.66$) across all targets.

1. <u>Manipulation of favorability: time pressure and ambiguity</u> For this set of analyses, it was postulated that expected interaction effects between time pressure and and ambiguity with display were not as expected because the manipulation of favorability may not have been strong enough. Time pressure and ambiguity were analyzed separately as representing task-related aspects of favorability. Conflict was not included as conflict had no main effect on accuracy. When variables are analyzed separately, the set of targets in each condition were not fully favorable or fully unfavorable. That is, targets that were low in time pressure included targets that ranged in uncertainty and conflict. These targets are not completely favorable for deliberation, because of the targets with high uncertainty. In order to explore fully the effect of optimality, decision events which were favorable on both task characteristics were compared to decision events which were unfavorable on all three task characteristics.

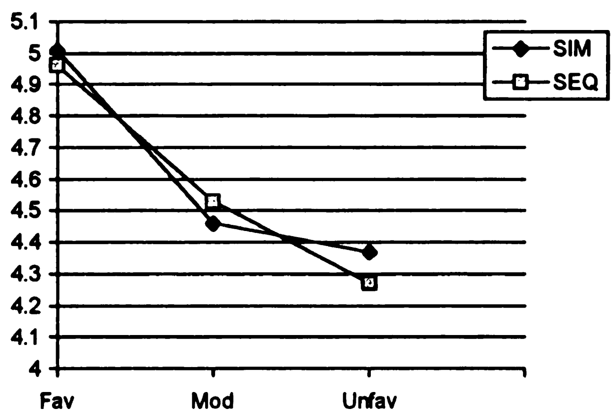
Targets which were highly favorable, that is, certain information and low time pressure, were labeled as "favorable". Targets which were highly unfavorable, that is, high in time pressure and ambiguity, were labeled as "unfavorable". An ANOVA was performed contrasting the favorable versus unfavorable targets, and any interaction with display.

Table 24

Impact of Favorability and Display on Decision Accuracy

Source	DF	SS	MS	F	Pr	Eta2
Display	1	0.25	0.25	0.06	0.80	0.00
Favorable	1	4101.64	4101.64	1082.66	0.00**	0.31
Optimal x Display	1	20.40	20.40	5.38	0.02*	0.01
Error (Favorable)	377	9166.56	4.28			

	Simultaneous	Sequential
Highly Favorable		
Mean accuracy	5.01	4.96
S.D.	0.78	0.70
Moderate Unfavorable		
Mean accuracy	4.46	4.37
S.D.		
Highly Unfavorable		
Mean accuracy	4.37	4.27
S.D.	1.26	1.31



Research participants in the sequential condition performed better than research participants in the simultaneous condition on the favorable targets, and research participants in the simultaneous condition performed better than research participants in the sequential condition on the unfavorable targets, although the effect size was small.

2. Deceptive Targets. Overall, all subjects were most inaccurate for the assessment of low threat targets. One possible explanation for the lower performance on these low threat targets may be the deceptiveness of the target. If a target is very threatening all cues are threatening. However, targets can be made that are very "safe" that contain dangerous cues. This is due to the interaction rules (if one cue in a paired interaction rule is safe, the entire interaction is safe regardless of the threat of the other cue), resulting in targets lower in threat more likely to be deceptive. This can be investigated by determining the level of deceptiveness in each target. A target that is not at all deceptive would be one in which either (a) all cues in an interaction are safe, or (b) there is no safe cue in the interaction. The nondeceptive targets would then be assessed more accurately if one were using an "equal weighted" strategy, which requires less effort to assess the threat level.

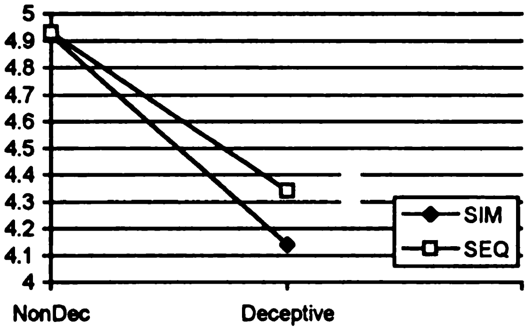
To investigate the impact of "deceptive" targets, a new variable was created to represent deceptive (decept = 1) and nondeceptive (decept = 0) targets.

Impact of deceptive targets on decision accuracy. The following graph presents mean decision accuracy for deceptive versus nondeceptive targets, by display condition.

Table 25

Impact Of "Deception" By Display Condition

Source	DF	SS	MS	F	Pr	Eta2
Display	1	6.86	6.86	16.65	0.0001	
Deceptive	1	196.15	196.15	785.88	0.0001	
Disp x Decept	1	4.06	4.06	16.28	0.0001	
Error (Decept)	535	220.39	0.41			



There was a significant effect of "deception" on performance, where subjects in both display conditions were less accurate when the targets were deceptive. Further, subjects in the simultaneous condition did less well than subjects in the sequential condition when targets were deceptive. This is not surprising as the deceptive targets required more attention to interactions. Decisionmakers in the sequential condition had the advantage of having the cues presented in an order where interacting cues were presented back-to-back, making it easier to attend to interactions.

The distribution of deceptive targets is not equal across conditions of time pressure and ambiguity. It was found that this unintentional and unequal distribution accounts for the curvilinear results found for the impact of time pressure and ambiguity on decision accuracy.

Deceptiveness, display, and time pressure. The following graphs illustrate the impact of deceptiveness as it moderates the effect of time pressure on decision accuracy. Results indicate that time pressure has no effect on accuracy when targets are not deceptive. When targets are deceptive, the impact of time pressure is large, and there is no difference between moderate and high time pressure. The pairing of deceptiveness and time pressure had a larger impact on subjects in the simultaneous condition.

Table 26

Impact of Time Pressure, Display, and Deceptiveness on Decision Accuracy

Source	DF	SS	MS	F	Pr
Display	1	6.86	6.86	16.65	0.0001
Error (Display)	535	220.39	0.41		
Tim3	2	211.70	105.85	838.85	0.0001
Tim3 X Display	2	2.66	1.33	10.56	0.0001
Error (Tim3)	1070	135.02	0.13		
Deceptive	1	196.15	196.15	785.88	0.0001
Disp x Decept	1	4.06	4.06	16.28	0.0001
Error (Decept)	535	220.39	0.41		
Tim3 X Decept	2	331.4	165.70	1125.79	0.0001
Tim3XDeceptXDisp	2	0.621	0.31	2.11	0.1217
Error (Tim3xDecept)	1070	157.49	0.15		

NonDeceptive Targets: Impact of Time Pressure on Decision Accuracy

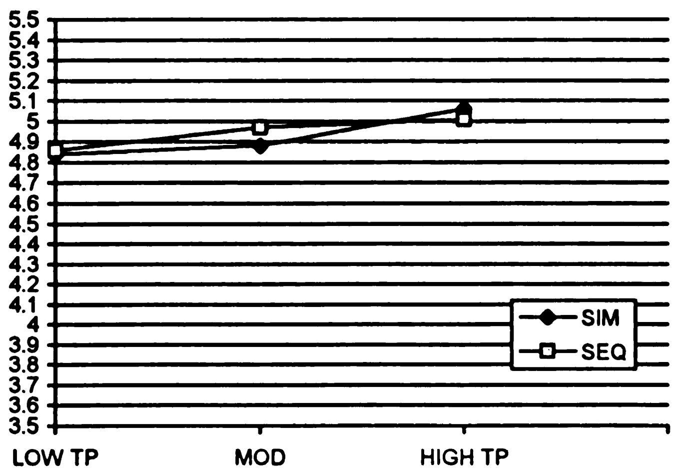
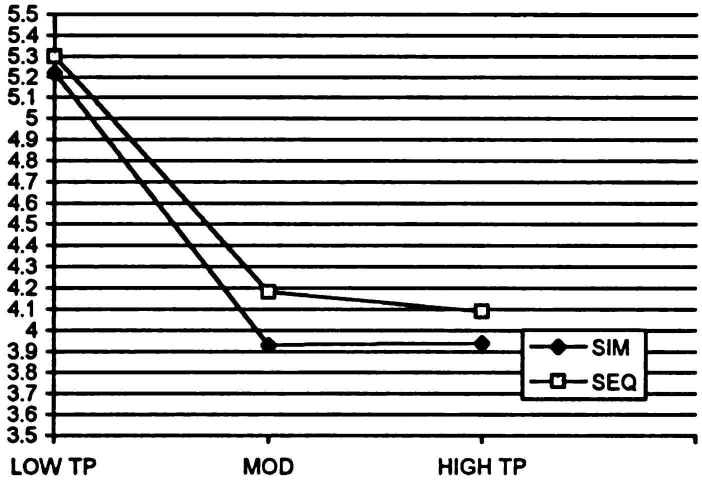


Table 26, cont.

Deceptive Targets: Impact of Time Pressure on Decision Accuracy



Deceptiveness, display and ambiguity. There was also an unequal distribution of deceptive targets across levels of ambiguity. The following graphs demonstrate the moderating effect of deceptiveness on the impact of ambiguity and display condition on decision accuracy. Deceptiveness of the decision event explains the initial finding that decisionmaking was more accurate when targets were moderately ambiguous. There were more nondeceptive targets in the moderately ambiguous condition.

Ambiguity had no effect on decision accuracy when targets were not deceptive, but had a strong degrading effect on targets that were deceptive. There was no difference between display conditions when targets were non-deceptive.

Table 27

Impact Of Ambiguity, Deceptiveness, and Display On Decision Accuracy

Source	DF	SS	MS	F	Pr
Display	1	4.62	4.62	10.68	0.0011
Error (Display)	535	231.58	0.43		
Cert	2	89.01	44.51	204.87	0.0001
CertX Display	2	2.01	1.00	4.62	0.0111
Error (Cert)	1070	232.45	0.22		
Deceptive	1	502.26	502.26	1602.82	0.0001
Disp x Decept	1	3.46	3.46	11.04	0.0010
Error (Decept)	535	167.65	0.31		
Cert X Decept	2	123.89	61.94	201.83	0.0001
CertXDeceptXDisp	2	5.81	2.91	9.47	0.0001
Error (CertxDecept)	1070	328.40	0.31		

27A: Non-Deceptive Targets: Impact Of Ambiguity On Decision Accuracy

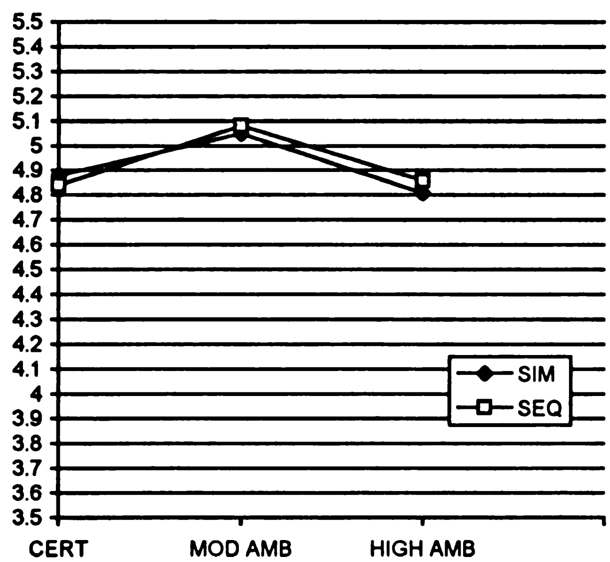
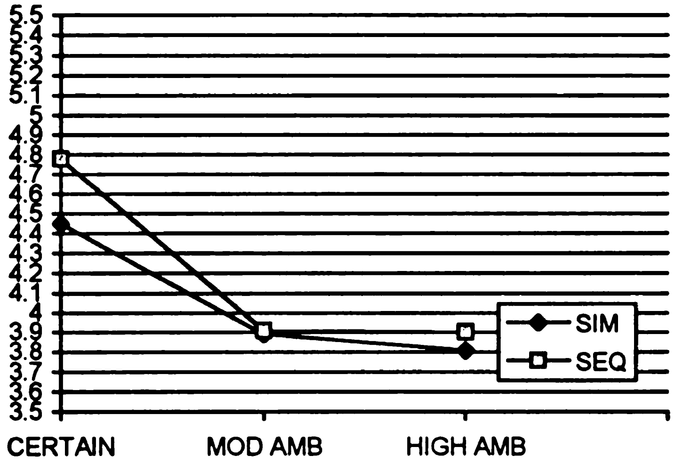


Table 27, cont.

27B: <u>Deceptive Targets</u>: Impact Of Ambiguity On Decision Accuracy



3. <u>Order effect: Anchoring-and-adjustment versus belief-updating</u>. Information conflict had a negative impact only on research participants in the sequential display condition.

While greater error is demonstrated for research participants in the sequential condition, it is not apparent if there is a consistent order bias in terms of primacy or recency. The conflicting targets were examined as to whether decision responses consistently overweighted the first few cues. The next table plots the mean score for conflicting targets which had (a) safe cues first, versus conflicting cues which had (b) threatening cues first.

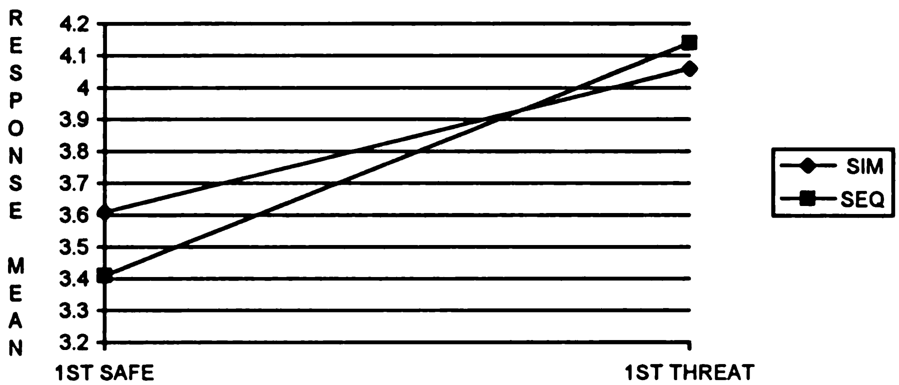
Table 28

<u>Impact of Order and Display on Decision Accuracy</u>

Source	DF	SS	MS	F	Pr	Eta2
Display	1	1.09	1.09	1.97	0.16	0.01
Order	1	88.87	88.87	160.45	0.00	0.39
Order x Display	1	4.29	4.29	7.76	0.00	0.03
Error	535	136.58				

Table 28, cont.

Response Means For Targets With First 4 Cues Safe Vs Threatening, By Display



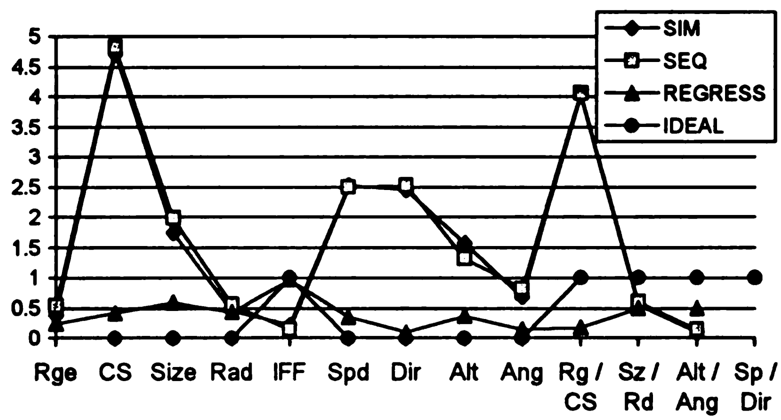
It can be seen that research participants in the sequential condition had a lower mean threat assessment for targets where the first three cues were safe, and higher mean threat assessment for targets where the first three cues were threatening. The mean correct response was the same regardless of order. This supports the expectation of primacy error as a consequence of sequential presentation of data. The interaction between display and safe vs threat (1st three cues) was significant for the prediction of response mean.

At the same time results demonstrates what appears to be a primacy effect for decisionmakers in the simultaneous condition, though not as strongly as for decisionmakers in the sequential condtion. Regression analyses were performed to ascertain the relative importance of each cue in predicting (a) the correct response, (b) decision responses of those in the sequential condition, and (c) decision responses of those in the simultaneous condition. Results are plotted in the following table. Also included are the actual weights that were used in the algorithm to assess the correct answer. Regression weights for the prediction of the correct answer will be somewhat different, depending on factors such as the degree of intercorrelation among predictor cues. In the algorithm, the correct answer is determined by equal weighting of the four interactions and the single IFF cue.

Results indicate that decisionmakers differed from ideal regression weights and from the algorithm weights. Also, research participants in both conditions had very similar patterns of cue regression weights, indicating greater weight for cues presented earlier, such as range, corridor status, the interaction of range and corridor status, size, speed, and direction.

Table 29

Regression Weights for Decision Responses by Display: Comparison to Ideal Regression Weights and Algorithm Weights



Cue weights are consistent with the prediction of anchoring-and-adjustment for the sequential condition, along with the previous result that subjects in the sequential condition were more influenced in the direction of their mean decision response. However, order effects cannot explain the similar finding for decisionmakers in the simultaneous condition. This may be due to use of a heuristic based on these characteristics on the assumption they are more important or more predictive or a visual salience effect (Jarvenpaa, 1990). The ideal regression weights are more unit-weighted compared to actual weights or to algorithm weights.

Performance over time

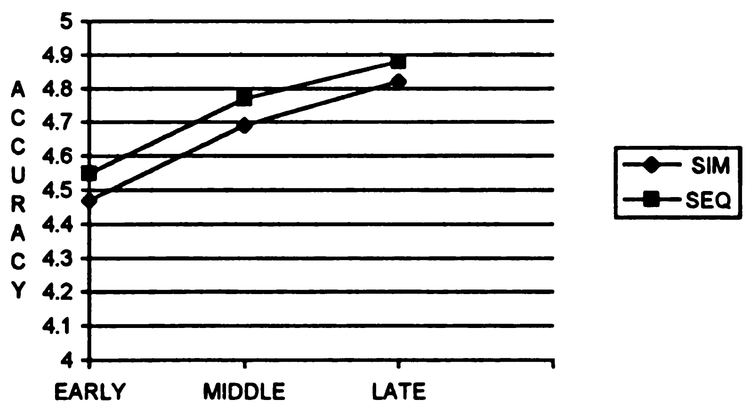
The display manipulation can be critiqued as being a weak manipulation for the elicitation of recognition, because the research participants are not so experienced that they immediately recognize each target. One reason for the manipulation as it was performed is that this study focused on performance error. If research participants were trained to the point where they recognized targets with ease, there would be very little error to compare. Research on implicit recognition found effects after one stimulus presentation, and so it was expected that any advantage due to recognition of the entire target pattern would appear during the course of the 185 targets that the research participants responded to. In addition, the 185 targets were repetitions (10 sets) of the same 18 targets. Thus, it was expected that any advantage due to holistic recognition would be demonstrated over the performance of the entire target set. However, it may be that hypotheses may be more fully supported if we look at performance on the last few repetitions of the targets.

Table 30

Later Performance: Main effect of display

Source	DF	SS	MS	F	Pr	Eta2
Display	1	8.83	8.83	2.28	0.13	0.01
Error	535	2074.14	3.87			

Accuracy by Time Period, Display



Results indicate the display manipulation had no significant effect on performance on the last two sets of targets. Mean performance is provided in the next table, broken out by early (first three sets of targets), middle (sets 4-7), and last three sets of targets. It can be seen that research participants in the simultaneous display condition were less accurate at first, but became as accurate as research participants in the sequential display condition after several repetitions of the targets. Next, analyses were run with time pressure and ambiguity included as variables.

Highly favorable versus highly unfavorable targets: Last few repetitions. An ANOVA was performed using highly favorable (low time pressure, certain information, no conflict) and highly unfavorable (high time pressure, ambiguous information, conflict) targets.

Table 31

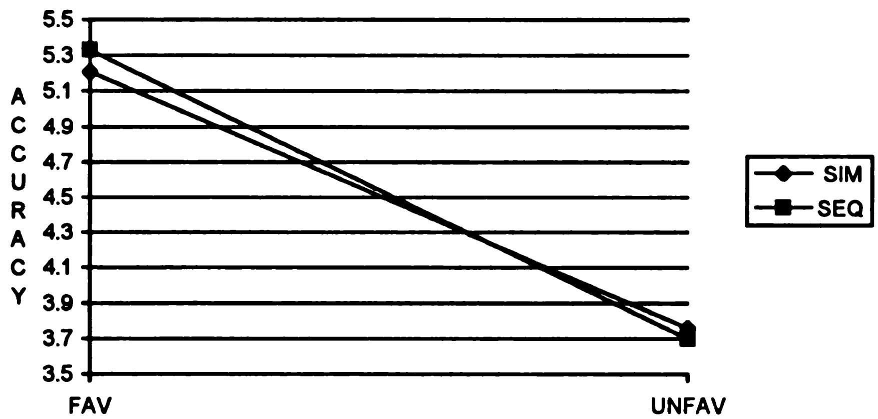
Impact of Favorability and Display on Decision Accuracy: Last 36 decision events

Source	DF	SS	MS	F	Pr	Eta2
Display	1	0.00	0.00	0.00	0.98	0.02
Favorable	1	1328.75	1328.75	714.99	0.00*	0.65
Favorable x Display	1	9.86	9.86	5.31	0.02*	0.01
Error (Favorable)	377	700.62	1.85			

	Simultaneous	Sequential	Total
Early (1st 3 reps)	4.47 (1.31) 15444	4.55 (1.28) 13554	4.51 (1.29) 28998
Middle (4-7 reps)	4.69 (1.23) 20592	4.77 (1.20) 18072	4.72 (1.22) 38664
Last (8-10 reps)	4.82 (1.20) 15158	4.88 (1.18) 13303	4.84 (1.19) 28461
Total	4.66 (1.25) 51194	4.73 (1.23) 44929	4.69 (1.24) 96123

Table 31, cont.

	Favorable	Unfavorable
Simultaneous	5.21 0.84	3.76 1.26
Sequential	5.33 0.72	3.70 1.26



As demonstrated above, ANOVA results indicate a significant interaction between favorability and display, in support of the overall proposition, and consistent with overall results. Research participants in the sequential condition performed more accurately when conditions were favorable than did research participants in the simultaneous condition.

Chapter 6

DISCUSSION

This study drew from three avenues of research (i.e. decisionmakng; automatic versus effortful cognitive processes; visual cue characteristics) to predict patterns of decision error when complex information is visually displayed. Research in decisionmaking and decision processes have established systematic patterns of error occur as a consequence of several factors, such as limitations of information processing capability (Massaro & Cowan, 1993), expectations and cognitive set, susceptibility to framing effects, and reactions to uncertainty or emotional distress (Parkinson & Manstead, 1992).

Cognitive limitations in information processing capability results in simplifying strategies, such as the use of heuristics or rules-of-thumb (Stevenson, et al.). A different simplifying strategy is demonstrated when decisionmakers underutilize relevant prior-probability information and overweighting similarity when attempting to categorize an array of cues, demonstrating the error described as representativeness by Kahneman and Tversky (1972; Kahneman, Slovic & Tversky, 1982). In addition, decisionmakers demonstrate systematic error in processing cues that are presented over time, by either failing to adjust assessments sufficiently as more recent cues are presented (i.e. anchoring and adjustment error; Kahneman & Tversky, 1982) or by placing too much weight on the most recent information (i.e. belief updating error; Hogarth & Einhorn, 1992). Research in cognitive abilities have established primacy and recency effects in basic tasks such as working memory and retrieval from longterm memory.

A different type of decision error is demonstrated when ecisionmakers systematically respond in favor of decision alternatives depending on how the problem is represented. For example, individuals favor alternatives that are described as a gain rather than a loss, when alternatives do not differ in any real sense. This would not be a function of limitations in cognitive processing, as the decision task does not differ in cognitive demand as a function of these alternatives. Instead, it indicates a systematic bias in favor of alternatives that are positive in phrasing. Biases can also occur when expectations influence perception and/or assessment of information. This occurs regularly as demonstrated by prejudicial attitudes and resistance to information contradictory to well-established beliefs and opinions. Errors in military tactical decisionmaking have demonstrated this, when expectations of peaceful versus hostile intent influenced errors of passivity (U.S.S Stark), errors of aggression (U.S.S. Vincennes), and errors of friendly fire (shootdown of friendly blackhawk helicopters in Iraq).

Decision errors have been assumed to arise from alternative decision processes which are less effortful and less systematic, compared to an ideal rational decision process based on complete analysis of all cues and decision rules. Alternative decision processes are often referred to as intuitive, and assumed when decisionmakers demonstrate increased error. (Kahneman & Tversky, 1982; Kleinmuntz, 1990). At the same time, there are increasing arguments that intuitive decision processes are more descriptive of actual decisionmaking in complex, dynamic, and naturalistic settings, and that this intuitive process is adaptive and functional in circumstances where careful and systematic analysis is not always possible (Zey, 1993).

In this study, the decision task was based on analysis of primarily visually displayed cues (eight visual cues and one audio cue), requiring assessment of each cue and application of decision rules to integrate cue information. A review of research on decision processes, decision error, and visual display characteristics resulted in contradictions for the prediction of decision error.

Previous investigations have related intuitive processes to presentation of visual cues as opposed to quantitative cues. Intuitive decision processes have characteristically been assumed to result in increased error. Others, such as Hammond (1987) suggested that an intuitive process is appropriate for decision tasks that have a subjective or aesthetic component. However, in his study Hammond found that the intuition-inducing condition resulted in high accuracy, even when the task was analytic in nature.

At the same time, researchers in visual display characteristics appear to be striving to elicit more intuitive responses, by creating displays that will capitalize on human capabilities for pattern recognition. They report high performance in information integration when visual cues are presented as a pattern, as opposed to more separable cues. However, if visual patterns elicit a more intuitive response, decision accuracy should be lower than when decisionmakers deliberate information in a more systematic and effortful manner. Thus, there are competing hypotheses for the prediction of efficacy when less effortful, more intuitive decision processes are elicited and utilized by the decisionmaker.

This study sought to clarify apparent contradictions regarding the pattern of decision error associated with display of visual cues. First, conceptualizations of intuitive processes were reviewed to distinguish what is meant by intuition and intuitive error in relation to visual displays. The notion of intuitive decisionmaking is widely referred to; however, the concept is loosely defined and alternative conceptualizations differ widely as to the implicit or explicit nature of the process. The intuitive response elicited by visual displays is best described as resulting from recognitition of information that has been presented before to decisionmakers, that is, based on explicit rather than implicit information. When recognition is certain, it is automatic, rapid, and effortless. While certain recognition is explicit and automatic, increased error will arise when the recognition response is uncertain and thus more intuitive. It is this error which is of interest in this study, and which will be compared to decision error expected to arise from more effortful analysis of information.

It is not unreasonable to expect an intuitive process to be less accurate when contrasted with more rational analysis of information. If particular types of visual displays elicit more intuitive assessments, it would appear that decision accuracy would suffer. However, it has been pointed out that effortful and systematic analysis is not always possible in dynamic and naturalistic decision contexts. Intuitive responses are characterized as faster and less effortful, which can be an advantage when conditions do not allow a careful analysis of information.

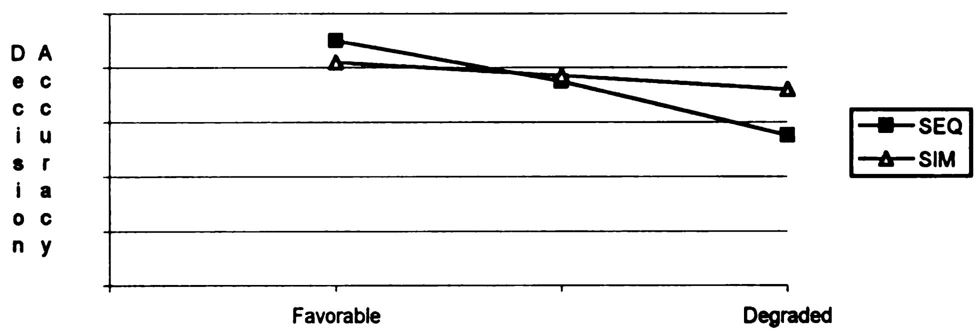
Based upon previous findings (Hammond, 1987; Bennett, 1989) the simultaneous display of a meaningful array of visual cues was expected to influence decision makers to respond more quickly and intuitvely. This intuitive response was predicted to result in increased error when the decision task requires integration of complex decision rules, particularly when averaging cue values is not appropriate. In contrast, sequential and cumulative display of visual cues was expected to facilitate more effortful consideration of cue values and the decision rules which determine the correct assessment. In this study, the sequencing of cues further facilitates consideration of decision rules, as the pairs of cues which interact are presented back-to-back. Thus, the decisionmaker is guided to systematically consider cues and cue interactions.

The expectation that simultaneous presentation of a visual pattern would result in less accurate integration of information is at least partially counter to reviews in the visual display literature that report that configural (pattern-based) displays are better for integration of information. Separable cues have been reported as less effective for the integration of information, yet in this study, the sequential display of cues would be perceived as more separable, and is expected to result in higher accuracy.

While investigation of main effects of simultaneous versus sequential display of visual cues may help clarify conditions where configural versus separable cues are more appropriate, the primary interest in this study are interactions predicted to occur between visual display characteristics and variables expected to facilitate or inhibit rule-based deliberation. These variables determine the favorability of the decision context for effortful analysis of information, and includes both task characteristics (e.g. time pressure, uncertainty, conflict, and decision frame) and individual characteristics (cognitive ability and decision style). Sequential display of information is expected to elicit more accurate decision performance than the simultaneous display when conditions are favorable, because the decision task demands careful rule-based deliberation of cues. However, the sequential display condition is expected to result in less accurate decision performance when the decision context is degraded by factors such as time pressure, ambiguity, conflict, frame, and capability of the decisionmaker. In contrast, simultaneous display of information was expected to elicit a more recognition-based response which, while not as accurate as effortful deliberation under favorable conditions, would be more robust when the decision context is degraded.

Inherent in these predictions are assumptions that the variables chosen in this study as manipulations of favorability are in fact degrading to effortful cognitive processing. The task characteristics chosen for study include time pressure, ambiguity, conflicting information, and irrelevant background (frame) information. In addition, individual difference variables were also included with the expectation that individual with low cognitive ability and/or an incongruent cognitive style would also have a detrimental effect on performance. Thus the most favorable decision making condition would be where there is no time pressure, certain information, nonconflicting information, no irrelevant frame, with decisionmakers who are high in cognitive ability, with an analytical cognitive style. Figure 12 captures the essential expectations of this study.

Figure 13. Interaction expected between visual display condition and favorability of decision context.



Performance was expected to be less accurate when any of the variables affecting favorability are degraded.

Main effects.

In general, research participants in the sequential condition performed more accurately than research participants in the simultaneous condition. This finding is consistent with predictions. The congruence between sequential presentation and the underlying cognitive demand to consider cue interactions would account for higher performance in the sequential display.

Results related to decision context variables generally supported expectations, with lower mean accuracy resulting from several variables associated with favorability of decision context. Accuracy was significantly lower when decisions were made under morderate or high time pressure. Accuracy was also significantly lower when cues were highly ambiguous. Preliminary analysis indicated no effect of conflict on accuracy, but subsequent analysis revealed that conflict significantly affected response means. Decision frame also had a significant effect on accuracy, such that the frame eliciting a more passive response (assessing targets as less threatening) resulted in higher accuracy. Error in general tended to be characterized by assessing targets as more threatening than the correct assessment. Cognitive ability had a strong effect on decision accuracy, as expected. Cognitive style did not significantly affect accuracy. Preliminary analyses for main effects of time pressure, ambiguity, and conflict led to misleading results, which were clarified by subsequent results.

Time pressure, ambiguiity, and deceptiveness. While initial results indicated that time pressure and ambiguity had curvilinear effects on decision accuracy, subsequent analyses explained these curvilinear effects as due to interaction with target deceptiveness. As described in the section on exploratory analyses, deceptive targets were defined as targets which appear more threatening than they actually are, due to presence of several threatening cues combined with a few safe cues which render cue interactions with the threatening cues as safe. They were generated randomly as a result of creating decision events representing an equal distribution of the range of assessment choices.

Deceptiveness of cue information had a strong main negative effect on accuracy, probably due to increased cognitive demand for consideration of decision rules. Decisionmakers performed much more accurately when cues within an interaction were consistent, thus allowing an averaging strategy to be effective. Deceptiveness also accounted for the initial curvilinear nature of the main effects of time pressure and ambiguity. Time pressure and ambiguity had a strong negative effect on targets which were deceptive, but not on targets which were not deceptive. The unexpected findings regarding deceptiveness demonstrate that visual displays in general can result in rapid yet accurate response, when decision rules are simple, or when complex rules can be replaced by a simplifying strategy.

Cue conflict. Cue conflict was expected to degrade decision making performance. However, while conflict interacted with display condition as predicted, conflict had no main effect on performance. This may be due to the nature of targets created with conflicting cues. When targets have both safe and threatening cues, the resulting assessment will be somewhere in the moderate threat range. Also, because interacting cues were displayed sequentially, there was greater consistency of interacting cues. For example, the first four cues consist of two pairs of interacting cues. If the first four cues are safe, these interactions are easier to assess. These characteristics of the manipulation of cue conflict probably served to reduce the negative effect of conflict on performance in general.

In addition, when conflicting targets presented safe cues first, the mean threat assessment was less threatening than the correct assessment and when threatening cues were presented first, the mean threat assessment was more threatening than the correct assessment. In this way, the errors due to order of presentation cancelled each other out, resulting in a mean that was no less accurate than nonconflicting targets.

<u>Frame</u>. Frame had a significant main, however, the effect is quite small. Research participants encountered many (185) decision events. Frame effects may have been washed out after the first few decisions. In addition, decisionmakers were encouraged to provide ebjective accurate assessments. This was stated within the background information containing the frame manipulation, and likely weakened frame effects.

The use of written descriptions to manipulate frame, while consistent with previous manipulations, is likely too weak to make an impact over a series of decisions. Reading about a previous error made by another person is not likely to be as salient as feedback regarding one's own error. In this case feedback obtained on each decision probably had a much greater impact on decision performance over time and is likely to be the most salient influence on subsequent assessments. However, in realistic and operational settings, a disasterous error is not always made in the context of a steady stream of decisions. Instead, there may be long periods of inactivity and ambiguity followed by a single ambigous decision event, which may be more vulnerable to frame effects from background information and recent events. Further research is needed to investigate frame effects related to decision errors that occur in realistic settings.

This is not to say that frame effects found in the laboratory setting are not applicable to operational settings. Instead, the expectations held by a decisionmaker in realistic and threatening circumstances is perhaps more likely to affect the judgment process than any controlled frame manipulation in the laboratory. For example, in operational military settings, background information and recent events are additional bits of information relevant to determination of rules of engagement and tactical decisionmaking. At the same time, operational decisionmakers must be able to separate assessments that include this background information from assessments of threat based solely on indicators of threat. Further research is indicated regarding frame effects as they relate to single decision events within more operational settings, where background information can be regarded as relevant to the decision at hand.

In this study, all information cues were perceptual. It is not known whether perceptual cues are more or less resistant to frame effects. It may be that written descriptions of frame information has more effect when the decision event is also presented as a written problem. Further research is indicated to investigate the impact of frame effects on quantitative versus perceptual information cues. In addition, alternative manipulations of frame should be investigated. When information cues are perceptual, frame effects may also be more salient when presented perceptually. For example, in one manipulation the screen may present a number of unknown aircraft at a safe distance, with one aircraft flying at a more threatening range. The single aircraft would be the decision event. The alternative manipulation would exclude the other aircraft, or present alternative frame information, such as a nearby cluster of friendly aircraft.

This study demonstrated that frame effects can be associated with interpretation of visual/audio cues, even when the manipulation is relatively weak. Further research is needed to understand the dynamics of this effect, to identify situations where the frame effect would be most powerful, and to develop interventions to minimize the effect. A useful start would be the systematic investigation of frame effects (i.e. cognitive set) produced by different manipulations (e.g. written, verbal, visual, audio, previous error), for different types of decision tasks (e.g. rational deliberation, recognition, consensus, negotiation) under conditions varying in time pressure, ambiguity, and consequence of error.

Individual differences. Cognitive ability had a significant main effect on performance, as predicted. The relationship was somewhat curvilinear, such that the greater difference was between research participants low versus moderate in ability, as opposed to moderate versus high ability. This is probably due to a ceiling effect of the task demand. This main effect is consistent with the ubiquitous finding that cognitive ability predicts performance on cognitive tasks.

There was no significant effect of cognitive style on decision accuracy. Hypotheses regarding the congruence of cognitive style and task demand/constraints predicted that research participants with a preference for intuitive thinking would perform more accurately than research participants with a preference for logical fact-based thinking when in the simultaneous condition. However, there was no main effect, nor were interactions with display found. There was no main effect for cognitive style, neither was there an interaction with display.

One explanation for the lack of significant impact on decision accuracy is that the task demands between the simultaneous and sequential conditions were identical except for the cue presentation order. In both cases the cues were visual/perceptual, and correct assessment of threat was based on an algorithm. It may be that the tasks were too similar for any effect of preference to be demonstrated.

In addition, according to Jung (1923), the preference for sensing versus intuition interacts with three other dimensions, resulting in 16 personality types. These other dimensions may influence the impact of cognitive style on decisionmaking. For example, the preference for extraversion versus introversion describes individual focus of attention, where extraverted orientation is focused on the outer world, and introverted orientation is more inwardly focused and reflective. The combination of extraversion and sensing preference should enhance the preference for concrete facts, whereas a combination of introversion and intuitive preference should result in a more reflective and intuitive orientation. Another preference described by Jung is that of "thinking" versus "feeling", where individuals with a thinking orientation prefer to base judgements on facts and logic, and individuals with a feeling orientation rely more on subjective values, interpersonal sensitivity, and emotional content. This preference may also influence cognitive style, such that the combination of sensing, extroversion, and thinking would be most rational and fact-based in style, and the combination of intuition, introversion, and feeling would be most intuitive in style.

Interactions with display condition

Findings regarding main effect expectations were not fully supported; however, it was not the main purpose of this study to investigate these main effects. The focus of this study was to investigate whether these degrading variables differentially impact performance depending on the manner in which information was presented to the research participants. The underlying basis for these predictions rests on the proposition that information display characteristics can elicit differing degrees of effortful deliberation versus a more intuitive recognition-based response. Sequential display of information was expected to elicit more effortful processing of cue information, and thus be more likely to result in accurate assessments when the decision task demands careful consideration of complex interacting cues. This advantage for the effortful decision process is expected to break down when the decision context is degraded. Thus, while main effects are predicted in this study, the proposition regarding interactions of display condition with these degrading variables is the primary focus and contribution of this study. Several of the interactions with display condition were significant and provided partial support for predictions. Significant interaction effects were demonstrated between display and time pressure, ambiguity, and conflict.

Display and time pressure. Preliminary analyses indicated that the interaction between display and time pressure was not as predicted. While subjects in the sequential condition were expected to perform less accurately under time pressure, they instead performed more accurately under moderate time pressure. Under high time pressure, there was no difference in accuracy between display conditions. Subsequent analyses demonstrated that the interaction differed depending on whether the cues were deceptive. When cues were not deceptive decisionmakers performed equally well regardless of time pressure or display. Consistent with expectations, subjects in the sequential condition did have higher mean accuracy under low time pressure, and lower mean accuracy under high time pressure, but the difference was not statistically significant.

When cues were deceptive, subjects in both conditions demonstrated much lower accuracy, in both moderate and high time pressure conditions. Subjects in the sequential condition performed more accurately than subjects in the simultaneous condition when performing under time pressure. However, these subjects also performed better than subjects in the simultaneous condition when targets are deceptive, thus the difference in accuracy between display conditions and time pressure is due to target deceptiveness. There was however a trend which is consistent with original expectations, in that decisionmakers in the sequential condition had lower accuracy under high time pressure compared to moderate, while mean accuracy increased slightly from moderate to high time pressure in the simultaneous condition. It may be that further manipulation of time pressure would demonstrate expected interactions. It is also likely that further time pressure would preclude any attempt at systematic effortful processing.

Display and ambiguity. Preliminary analyses also indicated that the interaction between display and time ambiguity was not as predicted. While subjects in the sequential condition were expected to perform less accurately under high ambiguity, they instead performed more accurately. As found with analyses of time pressure, subsequent analyses of the effect of display and ambiguity demonstrated that the interaction differed depending on whether the cues were deceptive. When cues were not deceptive decisionmakers performed equally well regardless of ambiguity or display, and tended to perform more accurately under moderately ambiguous conditions. When ambiguity is moderate, therre are fewer cues to attend to, and cues are consistent, thus the moderate ambiguity condition in effect lowered the cognitive processing required for assessment. When cues were deceptive there was a significant interaction that is partially consistent with expectations. Decisionmakers in the sequential condition performed more accurately when cue information was certain, but there was no difference in accuracy between display conditions which were ambiguous. This is partially supportive, in that participants in the simultaneous condition performed much less accurately on deceptive targets in general, but this difference is not reflected in the ambiguous conditions. Subjects in the sequential condition were more negatively affected by ambiguity in deceptive targets.

The interactions of time pressure and ambiguity with display condition were not as predicted. Subsequent analysis demonstrated that the impact of any one variable appears insufficient to manipulate favorability. Uncertainty may not be sufficient to make a decision context unfavorable, when the other task and individual difference variables are favorable. Data were then reanalyzed using a combination of time pressure and ambiguity as indicators of favorability.

The use of both variables to indicate favorability yielded results consistent with predictions. Research participants in the sequential display cond ition performed more accurately than research participants in the simultaneous condition when the decision context was very favorable. In contrast, research participants in the sequential condition performed less accurately than research participants in the simultaneous display condition for decisions made under very suboptimal conditions.

While the expected interactions between favorability of time pressure and ambiguity with display were found to be significant, the effect size is quite small. Thus it would appear that no practical significance is associated with this interaction. However, another reason for amelioration of expected interaction effects may be the experience level of the research participants. For example, Coury and Boulette (1992) found significant interactions between time pressure, ambiguity, and digital versus polygon display. Their subjects were more extensively trained (384 trials) and only those who reached a 90% accuracy level in the last 100 trials were allowed to continue. By that time decisionmakers in the polygon condition were performing with equal accuracy and more quickly. In their study, participants in the digital display condition were more negatively by time pressure, and by the combination of time pressure and ambiguity, than participants in the polygon condition. If this study were replicated with more extensive training to criterion performance in a self-paced context, expected interactions may be more strongly indicated.

Display and cue conflict. The prediction that conflicting cues would have a more negative effect on research participants in the sequential display condition was supported by results. While research participants in the sequential condition were more accurate than research participants in the simultaneous condition for both conflicting and nonconflicting cues, cue conflict had a negative effect within the sequential condition. In contrast, cue conflict enhanced the performance of research participants in the simultaneous condition.

This finding is interesting given that the main effect for conflict was quite small. Conflict was detrimental, but only to research participants in the sequential display condition. The insignificant main effect was attributed to the fact that conflicting targets were by definition, moderate in threat. Thus the research participants could eliminate the decision responses of very safe or very threatening.

The decision error predicted by order effect biases explains the detrimental effect of conflict on research participants in the sequential condition. When target cues do not conflict, the first few cues presented indicate the general threat of the target. This gives the subject a general impression which is then confirmed by subsequent cue information. However when the targets conflict, the subject encounters disconfirming information and must weight the contradictory cues. Research participants in both the simultaneous and sequential conditions had a tendency to error toward moderate assessments of threat. However, the sequential display resulted in errors in the direction of the first few cues, as predicted.

Display and frame. The frame manipulation was expected to influence the direction of decision error of research participants faced with sequential presentation of information. When the frame manipulation described the previous error as one of passivity (a hostile aircraft was not defended against when it should have been), research participants were expected to make somewhat more aggressive assessments. When the frame manipulation described the previous error as one of over-aggression, subject were expected to assess aircraft as less threatening than research participants in the overly passive frame condition. This effect was expected to be higher for research participants in the sequential display condition.

The difference in mean judgment between research participants in the two frame conditions was not significant. While effects of decision frame have been significant for single decision events, it is likely that this manipulation is not powerful enough when research participants are exposed to many decision events where they get feedback on their own error. The manipulation of frame through background information is likely to have been washed out by the more proximal effects of feedback on decisions actually made by each subject.

Display and cognitive ability. It was predicted that subjects with high cognitive ability would perform more accurately than subjects with low cognitive ability when cues were presented sequentially, but would not make much difference, if at all, in the simultaneous condition. This hypothesis was not supported. There was a significant main effect of cognitive ability on decision accuracy regardless of display manipulation. This may be due to the lack of expertise of the research participants. Research participants were in a learning mode for the first 2/3 of the targets presented. It is not unreasonable to expect cognitive ability to have a significant impact on this process of acquiring expertise.

It was predicted that a recognition-based response would be more robust with regard to individual differences in cognitive ability, as effortful deliberation is reduced. In this study, the manipulation of recognition as a response was not a strong one, in that research participants were not trained to a threshold level of recognition before data was collected. This was for several reasons. A primary reason is the focus of this study on patterns of decision error. If research participants were experienced to the point that recognition was immediate and certain, very little error would result, and the impact of display condition would be greatly minimized-- research participants would have the recognition response in both conditions. Instead, the focus was on ascertaining the impact of these display conditions, and the type of decision errors that can arise as a function of these conditions. Thus, training to the point of minimizing error would obviate any effects from the display conditions.

Display and cognitive style. There was no main effect for cognitive style, neither was there an interaction with display. As discussed previously, it may be that any effect of preference would not be demonstrated unless decision tasks are widely different in terms of being based on facts versus being reliant on intuition. For example, one variable which has been reported to influence decision process include quantitative versus perceptual information. In this study, both display conditions were exactly alike except for the manipulation of simultaneous versus sequential display of information. It may be that this manipulation was not strong enough for preferences in cognitive style to be demonstrated.

Summary

Results supported most of the relationships predicted in the overall model. In addition, subsequent analyses using a more pronounced manipulation of favorability provided further support, through statistical significance and consistency with predicted outcomes. Research participants in the sequential display condition performed more accurately when performing under highly favorable conditions (i.e. certain information with low time pressure). They also performed less accurately than research participants in the simultaneous condition under conditions that were highly unfavorable. In addition, results demonstrated the ordering effect predicted for research participants in the sequential display condition

Results indicated relative advantages of the sequential versus simultaneous display of information, depending on the degree of time pressure and uncertainty inherent in the decision task. Research participants in the sequential display condition performed more accurately overall, but were particularly vulnerable to primacy error when the first few cues presented conflicted with subsequent cues.

The advantages also appear to relate to the congruence of the display condition with the underlying cognitive demand of the task, which was greater for targets with deceptive cue interactions. When cue information was consistent such that an averaging strategy can be used, performance was as good under high time pressure as it was under low time pressure, regardless of the display condition. When cue interactions were deceptive and required greater deliberation, the sequential display of information was associated with higher performance.

These results are consistent with the proposition that simultaneous display of information elicits pattern recognition capabilities which is more robust than effortful cognition under degraded circumstances. This is not to say that demonstration of intuitive versus effortful cognition was conclusive; the contribution of this study simply adds to the growing body of research that describes decision making processes which are alternatives to an objective, rational ideal.

Results were also consistent with a more recent perspective on human decision processes that is appreciative of the capabilities and advantages of human decision making as opposed to focusing strictly on the limitations, biases, and errors associated with comparison of actual decision making to that of a rational ideal. Certainly, it has been demonstrated that human decision making is associated with consistent tendencies and sources of error. Yet the same tendencies, as sources of error, may be perceived as advantages if we investigate decision making in more realistic settings, (i.e. settings which are more ambiguous, complex, and dynamic). While computers and decision aids can greatly ease the cognitive demands of adherence to a rational ideal, there are many tasks for which the human is better suited. In this study, using a complex rule-based decision exercise, a more intuitive decision process was expected to be (a) less optimal than an effortful striving for rational processing, but (b) more robust in degraded circumstances, such that the more automatic, recognition-based process can in fact be an advantage and not simply a source of error. This is consistent with research regarding the use of heuristics and other cognitive strategies that reduce the cognitive demand of a particular decision scenario (Stevenson & Busemeyer, 1992).

Implications from this research also relate to applied research in information display. While it has been stated that presentation of graphic configurative information (i.e. patterns) can facilitate integration of information, there are limitations to this proposal, as demonstrated in this study. First, research participants as a whole performed more accurately, demonstrating superior integration of cue information, when information was presented sequentially as opposed to the simultaneous display of a perceptual holistic display. The cue information was more accurately integrated when cues were presented singly and additionally, as opposed to a simultaneous display more easily perceived as a whole configural pattern.

The finding that cue integration was more accurate in the sequential display condition rather than the more holistic simultaneous display condition may be due to the underlying cognitive demand of the decision task used in this study. This task demanded consideration of interactions among cues such that when one cue is safe, the other interacting cue should also be considered safe. This can be easily processed with a cue interaction such as speed and direction (fast speed is not a threat if the aircraft is headed away, as represented by the length and direction of an arrow), but other interactions were not as familiar, such as range and corridor status. In this situation, the averaging strategy associated with intuitive decision making can lead to significant error in this decision task. If the targets had been constructed such that an averaging strategy would be appropriate, the simultaneous condition would not be as handicapping to performance.

Another contribution of this study to applied information display research is the demonstration of order effects with sequential display of information. While sequential display of information led to more accurate integration of cue information under favorable conditions, there was higher error when the conditions degraded. This error was expected to be due to errors of primacy, where the first few cues presented to research participants would have greater impact on overall assessment than the subsequent cues. Targets were created to investigate this prediction, where the first few cues were very inconsistent with subsequent cues; for example, when the first three cues are very safe and the last few cues are very threatening. Subject performance was consistent with this prediction, with research participants in the sequential condition providing overall assessments which were safer than research participants in the simultaneous condition when the first few cues were safe, and which were more threatening when the first few cues were threatening. Thus, this study revealed the advantages (more precise assessment of complex information) and disadvantage (a greater tendency for primacy effects when cue information is inconsistent over time) of sequential display of information.

Subsequent research should investigate this boundary condition of underlying cognitive task demand. If, as suggested in this study, different decision processes are elicited by a combination of task demand, information display, and decision context, the implication is that decision making performance can be enhanced through establishing congruence among these factors. For example, decision performance under soboptimal conditions may be enhanced by change the task demand, by (a) reducing effortful cognitive load and (b) capitalizing on pattern recognition capabilities. In addition, research participants can be trained through repetition and training of expertise in order to achieve a higher degree of recognition-based response. For example, in this study, recognition-based responses could have been enhanced through repetitive training on safe versus threatening interactions, followed by repetitive training on overall assessments.

Other researchers also have predicted different decision processes and patterns of error associated with different display configurations of information. As the evidence mounts for the existence and characteristics of these decision processes, information display can become more sophisticated in enhancing decision performance. For example, researchers have proposed that more automatic recognition based responses are desirable, particularly when conditions become complex or stressful (Mahan, 1992, 1994; Hammond, 1988). At this time, display researchers are exploring the idea of adaptable display of information, where the manner in which information is displayed will change, according to factors such as decision context (complexity, ambiguity , workload) and individual characteristics (cognitive ability, expertise, fatigue). Before this human-centered approach to display technology can be realized, we must identify and delineate more specifically the characteristics associated with performance under different display conditions, and identify the explanatory mechanisms for these differences.

Differences in performance between sequential and simultaneous display condition, while significant, were not large. This is probably due to the graphic nature of the cue information in both display conditions. Larger differences in performance have been found when display conditions were manipulations of more fundamental differences, such as the comparison of display of numerical data versus the more intuitive, color differentiated graphics used in this study. In this study, for both conditions, display was based on perceptual cue information. Sequential cue information was added to result in a picture that was "built" sequentially. Sequential cues were presented in fairly fast sequence, particularly under the high time pressure condition. Therefore, even the research participants in the sequential condition were ultimately presented with a perceptual pattern. The manipulation, in seeking to focus on one aspect of the display type (simultaneous versus sequential display), was not as extreme a manipulation for the elicitation of a deliberative versus a recognitional response. The findings in this study was based on a conservative manipulation, indicating the potential for greater effect when the display manipulations are more differentiated.

This study, while not conclusive, indicates the need to study more fully the characteristics of deliberative versus recognition-based decision processes. Issues which call for further investigation include the identification of display and contextual variables which may elicit one process over another. In addition, it was assumed in this study that the congruence of the cognitive demand of the task with deliberation and sequential display would result in higher performance, which it did. Further research is indicated to verify the extent to which the task demand should be congruent with display characteristics in order to establish principles for maximization of decision performance.

Chapter 7

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