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Situational Awareness: An Analysis And Preliminary Model Of The Cognitive Process

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Abstract

Little is understood about how people acquire many types of practical skilled behavior, e.g., situational awareness. An initial examination of the cognitive literature and application experience indicated that situational awareness is a complex cognitive process with pattern recognition as a key element. A baseline cognitive analysis and literature review verified this. Based on this analysis, a model of situational awareness was developed. Based on this model, studies were designed to validate the model and new training strategies for situational awareness. The validation studies demonstrated that superior pattern recognition performance results when training is conducted in conditions appropriate to the perceptual and cognitive systems' neural encoding processes.

[1] This report is based on work conducted while all authors were associated with the University of Central Florida Institute for Simulation and Training Awareness; the first author was a full time employee, the second author was a consultant, and the third and fourth authors were graduate students. The work was funded by the Florida High Technology and Industry Council under a grant entitled "Training Technology for Situational Awareness, FHTIC-UCF-64-02-706.

1.0 INTRODUCTION

Advanced technology systems are limited primarily by the human component. To achieve improved effectiveness it becomes imperative to gain an understanding of the cognitive processes involved in situational awareness, and to develop methods or tools to augment the human's ability to acquire necessary skills.

It is interesting to note that current training in situational awareness is effectively knowledge-based. For example, the tank commmander is taught the performance levels of his tank, capabilities of various threats, etc. This is delivered as raw knowledge-based data. Yet to be successful, the commander must operate within a skill-based domain. Observations show that as a tank commander gains operational experience, he learns how to transform information from the knowledge-based domain to the rule-based domain to the skill-based domain, if he survives long enough. The obvious question is how can we utilize this knowledge to help the tank commander acquire the situational awareness skills during training?

A preliminary examination of the literature reveals several major psychological theories that provide insight on the problem of skilled behaviors, see Figure 1. The most important aspect is the synergism of these diverse behavioral theories when linked with situational awareness. We have looked at four major theories which related to how people learn or acquire complex behavior. These theories all converge on the notion that situational awareness involves complex dynamic pattern recognition. Therefore, research on skill-based pattern recognition processes is warranted and appears to be a unique and extremely promising approach.

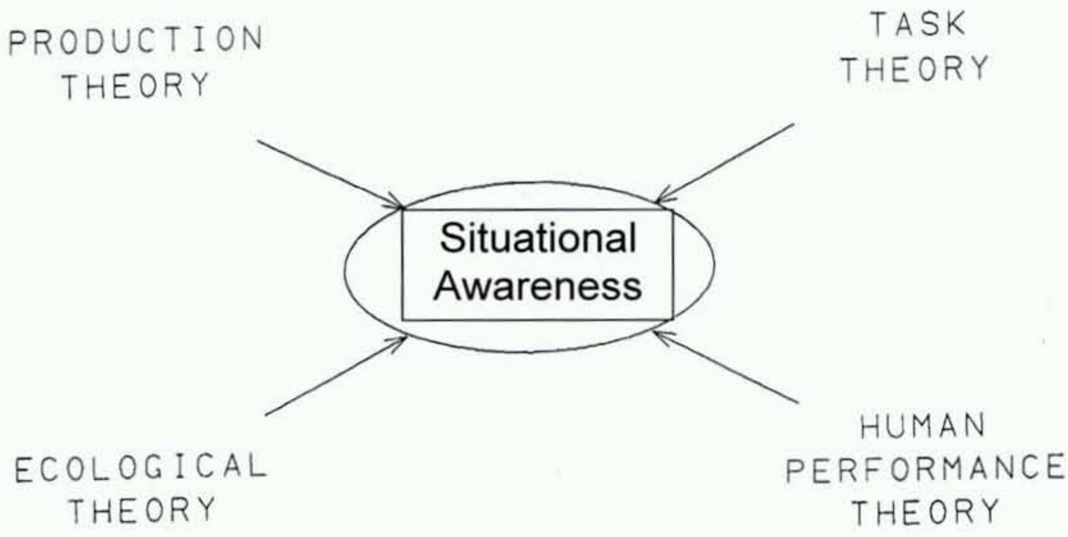

Figure 1. Primary Cognitive Theories Relevant to Situational awareness.

1.1 THEORETICAL BACKGROUND

The following paragraphs briefly describe the theoretical ideas and constructs which emerged from preliminary examinations of the cognitive basis of situational awareness. While the theoretical constructs appear promising, an in depth analysis and synthesis is required to fully develop and validate these concepts. They are the foundation for the theoretical model which will provide a structure upon which to systematically and logically develop useful tools to enhance the acquisition of situational awareness.

1.1.1 Categories of Behavior

Rasmussen (1986) has suggested that performance is based on the way that information is organized. Within this approach three basic hierarchical levels of behavior termed knowledge-based behavior, rule-based behavior and skill-based behavior are proposed (see Figure 2). Knowledge-based behavior is the most basic form and consists of a store of factual information regarding the system. The information contained in this store is not integrated and has to be processed individually. As a result, any performance resulting from the organization of information at this level is generally slow and error prone. Moreover, each decision is thought to be conscious and planned. While knowledge-based behavior is a necessary step, it is not sufficient to acquire complex skills.

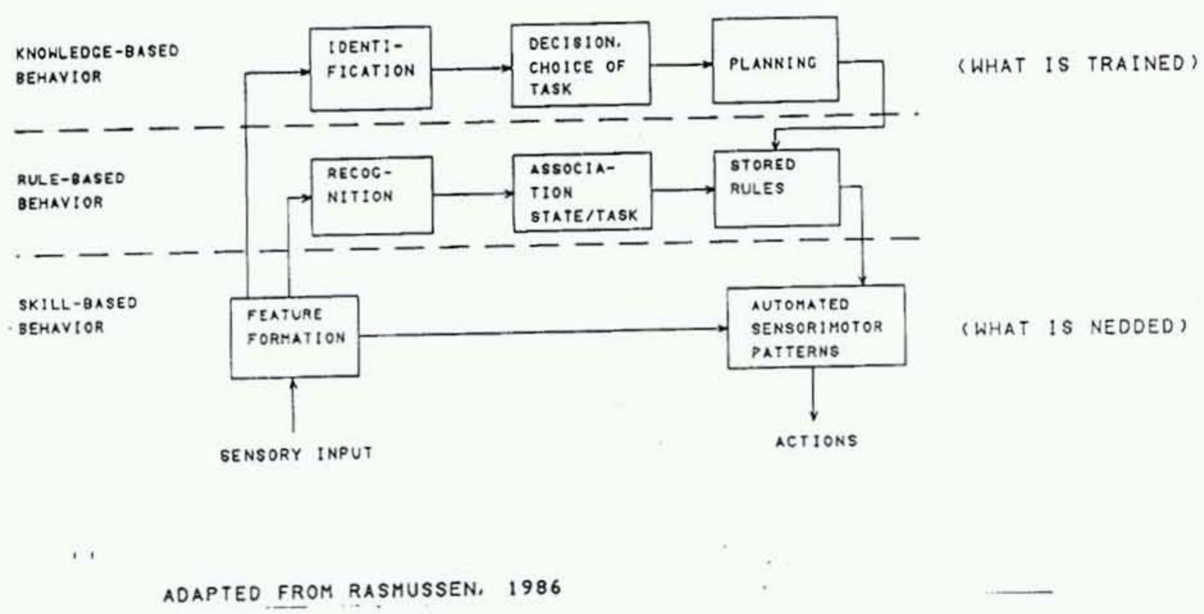

Figure 2. Classes of Cognitive Behavior (adapted from Rasmussen, 1986).

The second level is rule-based behavior. Rule-based behavior reflects the human's attempt to simplify the environment by integrating information. At this level, behavior is guided by the integration of information obtained at the first level. When operating at the rule-based level, the human is able to recognize critical variables and generate a response based on the integration of the variables, it is at this level that the pattern recognition process has begun to guide behavior. While this level of behavior also appears to be necessary, it also is not sufficient.

The third level is skill-based behavior. Skill-based behavior is the most complex, yet fastest, category of behavior. In skill-based behavior, the individual appears to be responding to complex patterns of stimuli or features within the environment which elicit automated patterns of response. That is, the response is linked directly to the sensory inputs. Performance is quick and generally error free. It is to this level that the training of skills should be directed.

These classes of behavior are not independent. They represent progressive stages of cognitive processing which reflect the individual's degrees of learning or experience. Each level of processing results from an increasing degree of knowledge compilation and integration. This theory suggests that the individual stimuli and responses presented during the knowledge-based phase are being integrated into patterns of stimuli that are associated with particular responses at the rule-based level. As behavior progresses to the skill-based level the link between the pattern of stimuli and the associated response is itself a complex pattern so that the initiation of a set of stimuli will automatically trigger the appropriate response. Theoretically, the end result is the elimination of the integration and assessment processes.

Throughout the training process and later in actual situations, practice and experience continue to aid in the extraction, compilation and integration of knowledge and rules. Just as rule-based behavior derives from the integration of information and responses, i.e., knowledge. skill-based behavior derives from the proceduralization of rules. The automaticity of skills indicative of skill-based behavior, such as situational awareness, is an outgrowth of the process of knowledge compilation which is founded in knowledge-based and rule-based behaviors. The pattern recognition which underlies the skill- based behavior comes from some level of processing that relates or compiles information to form a pattern. The resulting pattern/response combination is simply a highly complex or "ultimate" rule. This systematic progression of knowledge compilation from rule-based to skill-based behavior indicates that it should be possible to develop training strategies to positively influence the acquisition of situational awareness skills.

To be most effective, training programs should target the skill-based level of behavior. That is, the training program should not stop at rule-based behavior as many programs appear to be doing. While rule-based behavior is an important step in the development of proficiency, it should not be viewed as the end point. Skill-based

behavior is the logical endpoint. It is at this level where performance is best. It is at this level where performance is automatic and most natural. It is also at this level where performance will eventually be based if the operator is given the appropriate experience. While the operator can obtain this experience in the actual situation, the cost may be very high.

The four psychological theories described in the following paragraphs each provide part of the information necessary to understand and model the processes involved in the transition between the three classes of behavior.

1.1.2 Human Performance Theory

Human performance theory provides the scientific basis of engineering psychology. It is concerned with how human beings perform tasks. More importantly it strives to synthesize theories and models which can explain and predict human performance. The explanatory nature of these theories and models requires that they be feasible on a physical, biological, or behavioral basis. Figure 3 illustrates a basic model of human performance which depicts the relation between various information processing activities. These relations and their associated processes, established on empirical data, provide a structure which permits performance to be predicted. This framework also provides a framework upon which to incorporate the effects of moderating variables, such as workload, stress, motivation, etc. As such, human performance theory can be used to systematically evaluate or develop design alternatives which consider sensory, perceptual, cognitive, motor and environmental variables. Human performance theory parallels a spectrum of variables fundamental to skilled behavior, and will provide a central focal point for this project.

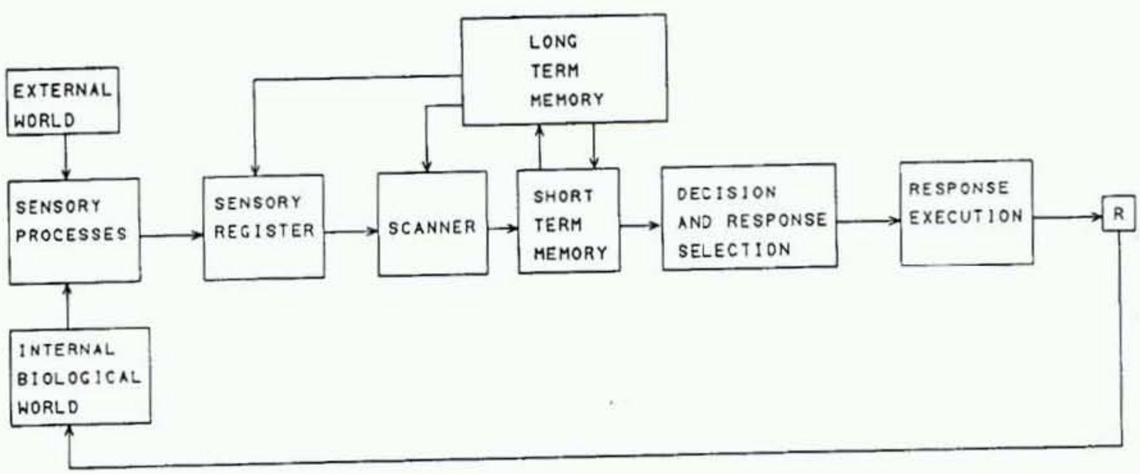

Figure 3. Basic Model of Human Performance.

1.1.3 Task Theory

Task theory (Teichner, 1974) was developed as a supplement to human performance theory to provide a detailed explanation of the subtasks underlying the decision making processes. It accounts for changes in performance due to variables such as experience and training. The basic tenet of task theory is that the cognitive processes underlying decision making are comprised of a number of translations of information, i.e., a stimulus is recoded in a number of discrete steps until it is in the form capable of eliciting a response.

Teichner postulated two types of translations. In one type of translation the stimulus code could be transformed into another stimulus code, or what was called a stimulus-stimulus translation. Theoretically, the number of stimulus-stimulus translations was unlimited, although some limit would appear to be probable. The second type of translation was between the final stimulus code and the response code. Task theory also provides for three different types of tasks: conservation, creation and classification. A conservation task occurs when the number of stimulus codes equals the number of response codes. A creation task occurs when the number of stimulus codes is less than the number of response codes. A classification task occurs when the number of stimulus codes exceeds the number of response codes. Within each of these tasks compression or a reduction in the number of symbols that make up the stimulus could also occur.

Task theory postulates that as a person learns, these discrete subtasks or translations become combined so that fewer and fewer steps are required. Behaviors become more complex as steps become integrated. This reduction stems from a more direct translation between codes. Fewer steps are then required to elicit a response. Since each translation takes time, response time decreases. Teichner proposed that only one S-R translation could occur for each response. As a result, early in practice a number of S-S translations preceded one S-R translation. As practice continues, the number of S-S translations would decrease until only the S-R translation remained. Teichner further argued that even this translation could drop out so that the onset of a stimulus could trigger a specific response. The primary example of this type of behavior, where all translations are eliminated is the identification of numbers or letters. Both are highly overlearned.

The suggestion from task theory is that the ultimate goal of any training program is to eliminate all S-S and S-R translations. In so doing, the onset of the stimulus would result in an immediate response. The nature of the response would be fast and accurate. By viewing the final stimulus resulting from a number of independent S-S translations as a pattern the effect of practice would be to eliminate the intervening translation steps.

Task theory appears closely related to the heirarchy of behavior proposed by

Rassmussen, as illustrated in Figure 4. It predicts that when a person initially learns a task, their behavior is comprised of a large number of discrete stimulus-response relationships, i.e., response to each variable is a separate task. As learning or training progresses, the individual perceives relations between variables and begins to develop rules which combine stimuli into a single response pattern. As learning progresses to its ultimate level, the complex pattern of stimuli become fused into a single stimulus which elicits a response. This predicted change in processing behavior is perfectly correlated with the three basic classes of behavior described earlier and accounts for and explains the transition between these types of behavior.

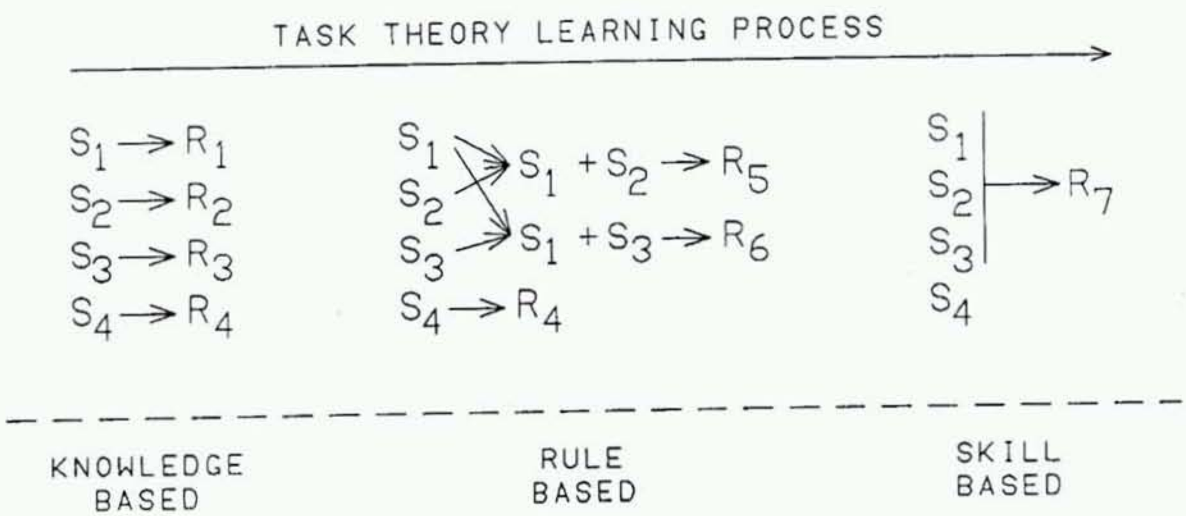

Figure 4. The Learning Process Within Task Theory.

1.1.4 Production Theory

A production system model consists of three interacting modules. These modules consist of a data base of information, a set or sets of rules and a control strategy. The control strategy determines what rule(s) to select. The rule(s) are applied to the data base to add or delete new information until the desired goal is achieved. This structure has been implemented by Anderson (Anderson, 1983) into a model comprised of a Declarative Memory which stores propositions, a Working Memory or temporary store for new data and a Production Memory which is a set of rules that operate on the other components. A major control process is called knowledge compilation; a process by which individuals translate declarative facts into productions which, in turn, trigger actions. There are two subprocesses of compilation; proceduralization and composition. Proceduralization can be thought of as taking an abstract rule and refining it to respond to a specific set of circumstances. It forms refined procedures which can be stored in temporary and Production memories and later retrieved. When a specific situation arises, this new procedure can be quickly retrieved from the temporary store and triggered for action without a search through

long term memory. Once the production is formed, it becomes almost automatic since no interpretation of the situation is needed to form the appropriate production. The basic idea of the second subprocess, called composition, is that of combining productions which occur in sequence to form a single, although larger, production. The effect is a reduction in the number of productions for a task which speeds up response time to a task situation. Taken together proceduralization and compilation account for the incremental build up of skilled behavior and response speedup on complex cognitive tasks in a way analogous to task theory. The suggestion from production theory is that information is integrated and once integrated responses occur in an automatic fashion. The key is that sufficient and appropriate practice must be given.

1.1.5 Ecological Theory

The Ecological approach to Psychology (Gibson, 1979; Shaw, Turvey & Mace, 1982) emphasizes the higher order system of mutual and reciprocal constraints that couples an individual to his environment. An ecological analysis focuses on the information specifying perception and action goals, the energy interactions that drive the perception/action cycle, and the nature of the relation between the two. Information specifying the changing layout of the environment and adjustments to the action system required for goal directed behavior are mutually constraining form of information. The Gibsonian view of information focuses on the role of information in the perceptual guidance of skilled actions. The acquisition and development of skills depend upon the effective detection and use of information in the guidance of decision making and action. The assumption is that the fundamental processes are the detection of relations and patterns of relations that remain invariant over transformations and the detection of invariant types of transformation over time; behavior essential to situational awareness. Hence perceptual learning, according to Ecological Theory, involves pattern differentiation and sensitivity to new information parameters that emerge in the environment and require new modes of action. As with both task theory and production theory, Ecological Theory suggests that pattern recognition is an important behavioral factor.

1.1.6 Discussion

The cognitively oriented theories briefly summarized above provide insight into the processes that are involved in the acquisition of situational awareness. They provide a framework for integrating a vast amount of empirical and anecdotal information, and provide both predictions and explanations. More importantly, these theories appear synergistic when applied to the concept of situational awareness and tend to provide similar explanations of the underlying cognitive processes, including the learning process involved in transitioning from knowledge-based to skill-based behavior. These factors provide a clear indication that it is possible to develop an understanding and a model of the cognitive processes. A structured and predictive model can systematically guide research and developments in this area. Furthermore, the ability to

build upon existing, well-established theories as a foundation for this effort provides a wealth of information and empirical data which can be readily applied to the problem.

For each of these major theories, the role of patterns, pattern development and pattern use is of critical importance. All theories stress the role of patterns and suggest ways that patterns are developed and how they are used in the development of situational awareness. Once again, it is also obvious that once the patterns have been developed, the resulting behavior stemming from the pattern is automatic. While the manner in which the patterns are developed and the manner in which the behavior is triggered are different for each of the theories, the idea of patterns and the automatic response which results from the pattern appear to be similar. Each of these theories suggest that as practice continues, the processes of information extraction, integration and assessment are eliminated. The link between the external stimulus and the ultimate response becomes direct. Consequently, the response is quick and accurate.

The underlying premise which appears consistent both in theory and experience is that pattern recognition is the essence of the skilled behavior. The individual learns to respond to patterns of variables in the environment.

Figure 5 illustrates the concept of the skill-based behavior called situational awareness as a dynamic pattern recognition process. It can be viewed as a response space with the three dimensions; the relevant variables, time and criticality. The criticality of a variable is learned and changes as function of time based on the situation. These factors effectively describe a response surface. However, evidence suggests that tank commanders do not respond to every changing pattern of events. People tend to initiate responses when a pattern of variables exceeds some criterion. The use of a response criterion is the human's innate way of managing workload, and works on the principle that "if it isn't broke, don't fix it." The response criterion is not a fixed entity. It may change as a function of learning, physiological state, motivation, stress, etc.

If the response criterion is viewed as a plane cutting through the situational response surface, then, as shown in the insert, it can be illustrated as a two dimensional plane overlaid by the pattern of variables which exceed the response criterion. This is a constantly changing pattern due to the dynamic nature of the phenomenon. It is conjectured that these patterns elicit plans of action. Unlike rule-based models of cognitive behavior which may have hundreds of active plans at any moment in time, our concept suggests that only one plan is active at any one time, but that it changes dynamically. This later concept is both parsimonious and correlated to observed behavior.

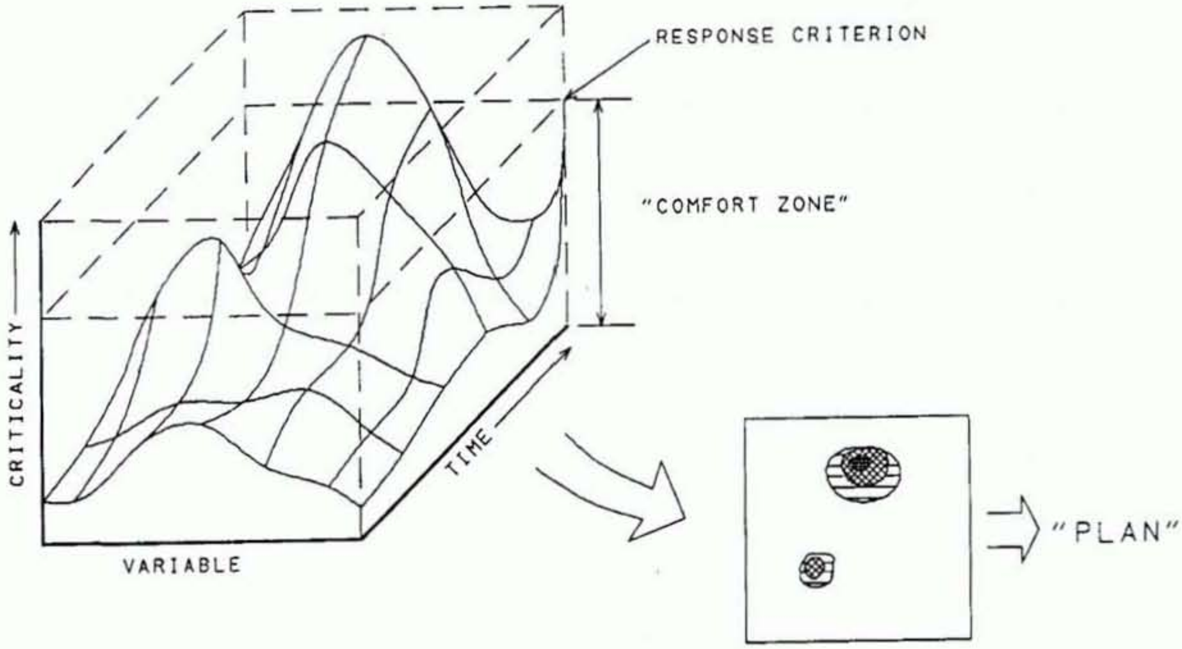

Figure 5. Situational awareness as a Dynamic Pattern Recognition Process.

It is interesting to note the similarity of this interpretation to neural network based models of cognitive processes, which relate responses to patterns of active nodes. Neural networks are an innovative method of modeling by which interactive patterns of inputs can be related to responses. Indeed, neural network approaches appear extremely appropriate as a means of implementing models of situational awareness under our interpretation. This method will be examined closely as part of this project.

1.2 ADDITIONAL LITERATURE ON SKILLED BEHAVIOR

Recent theories of postulating a neural activation basis for behavior and cognitive functioning (e.g., Rosenfield, 1988) suggest that situational awareness may in fact result from the energy transformations that occur through the interactions of networks of perceptual, cognitive, and motor neurons. Consistent with the behavioral model proposed by Rasmussen (1986), the neural network concept may account for the highly stereotyped patterns of behavior typical of skill-based performance.

A cognitive analysis of situational awareness was conducted. In addition to the detailed examination of the four initially identified cognitive theories (Human Performance, Task, Production, and Ecological theories), the literature in the areas of attention, arousal, expectation, motor skill acquisition, language processing, and other related areas was examined for data applicable to situational awareness. A larger than expected amount of corroborative data was uncovered supporting the concept that pattern recognition is a central component of situational awareness. The literature

reviewed contained a large body of data which indicated that situational awareness processes are fundamental to a large class of human behavior; these data were used to develop an information processing model of situational awareness.

Extensive literature was reviewed for the cognitive analysis and several areas provided significant supporting data for the concept of situational awareness presented earlier. The first of these areas focused on a new theory of memory by Rosenfield (1988) whose work is based on both behavioral and recent neurophysiological data. Rosenfield's research and analysis indicates that memory is a complex process that responds to patterns within the context of the external and internal stimulus environment. Thus, Rosenfield's suggestion that memory can be most effectively simulated by neural network models supports the ideas presented in this report.

The visual-spatial acquisition skills literature provided another major source of support. This literature includes an extensive amount of research which has been conducted to determine the basis of skilled behavior. Research in this area has examined many tasks including chess, gomoku, bridge, music, computer programming, circuit diagram analysis and a number of others. The data clearly indicate that pattern recognition is the fundamental process. Furthermore, the research has demonstrated that the differences between skilled experts and novices are accounted for by differences in their pattern recognition abilities. This research has led to detailed theories by Chase and Simon (1976), and Newell and Rosenbloom (1980) that are similar in some respects to the proposed theory of situational awareness.

The literature on motor skill learning also provides significant corroborative data, supporting not only the pattern recognition process, but also confirming the learning processes/effects formulated based on production theory and task theory. In a major review of motor learning, Keele (1988) expressed: "The recognition that pattern acquisition is a major component of skill learning may suggest strategies of training. In particular, less emphasis might be placed on actual motor activity and more on description and exposure of patterns that the learner must acquire. Training simulators would be ideal for such a strategy...The simulator can frequently present patterned situations that occur infrequently during the real task but whose acquisition is important for expert-level performance."

Figure 6 summarizes the breadth of supporting data found during the analysis. An annotated bibliography of the literature reviewed as part of the cognitive analysis is provided in Appendix A.

- Completed a relatively extensive examination of existing literature
  - Articles
  - Books/Handbooks
  - Reviews
- Started with the four baseline theoretical approaches

Human Performance Theory	Task Theory
Production Theory	Ecological Theory

- Found between 100 and 120 supporting references in approximately 20 different topic areas

Adaptive Learning	Problem Solving
Intelligent Systems	Auditory Perception
Language Processing	Visual Language
Context Effects	Skill Learning
Production Systems	Motor Skills
Perceptual Organization	Human Performance
Arousal and Stress	Memory Org. & Percept.
Neurophysiology	Visual-Spatial Skills
Decision Making	Ecological Theory

Figure 6. Summary of the Cognitive Analysis Review

In reviewing this literature it became clear that fundamental to each area was the notion of patterns and behaviors that involved the use of a pattern recognition process. A pattern is defined as the spatial and/or temporal organization of physical characteristics. It is variations in the spatial and temporal organization of patterns to which humans respond. When patterns do not change the human adapts to them and no longer recognizes or responds to them. Thus, the air conditioner humming in the background is not noticed until a change in the physical characteristics occurs. Sensory deprivation studies, investigations concerned with vigilance, assembly line work and research in many other areas all demonstrate that variation is important for human performance. Furthermore, developmental studies have shown that if the environment does not generate changes in patterns during specific time periods in the growth of the organism the nervous system or parts of the nervous system will not develop normally. Since it appears that the development of patterns and the subsequent recognition of patterns is a fundamental aspect of human performance, theories dealing with situational awareness must address this issue.

Skilled behavior is the ultimate goal of training. Skilled behavior refers to behavior that is fast and correct, and requires little "conscious" effort, that is behavior

which is automatic (Schiffrin and Schneider, 1977; Schneider and Schiffrin, 1977). It is not sufficient to simply provide training in pattern recognition. What is needed is training in pattern recognition so that the onset of a very few external stimuli will trigger a correct response.

2.0 BEHAVIORAL AND NEUROPHYSIOLGICAL CORRELATES OF SITUATIONAL AWARENESS

In meeting the objectives of this project a review of the basic psychological literature was undertaken with one of the goals being the identification of one particular model that could:

1. be used to identify situational awareness;
2. be related to other current cognitive models;
3. be related to the brain and nervous system;
4. be simulated using a neural network; and,
5. serve as the basis for developing training strategies for situational awareness.

Since one particular model that would satisfy these five criteria could not be identified, the approach taken was to identify a conceptual model of the neuron and then to adapt that model into a larger neural network based theory. The variable criterion model, first proposed by Grice (1968), was selected as the starting point. This model has survived the test of experimentation for the past 20 years. While Grice does not see the variable criterion model as a model of the neuron, its behavior and the physiological models of neural activity are remarkably similar. Further, the variable criterion model can be viewed as a model for the behavior of the whole nervous system. The resultant model is quite complex. It describes mechanisms of pattern registration, spreading activation that triggers additional patterns or subsets of patterns, transformations which trigger the correct response pattern or set of response patterns and which execute an appropriate response pattern.

2.1 BASIC MODEL OF IMMEDIATE BEHAVIOR

The basic process underlying the variable criterion model (Figure 7) is that energy is accumulated until a sufficient amount has been accumulated to trigger a response. The amount required to trigger a response can be viewed as a criterion, or a threshold. The rate of accumulation is a function of stimulus intensity. The more intense the stimulus the faster the accumulation and the quicker the response. Given that the variable criterion model can be viewed as a conceptual model of the neuron, linking of many variable criterion models can be viewed as a system for modeling the nervous system. The output from one variable criterion model can serve as the input to other variable criterion models or as a feedback to itself.

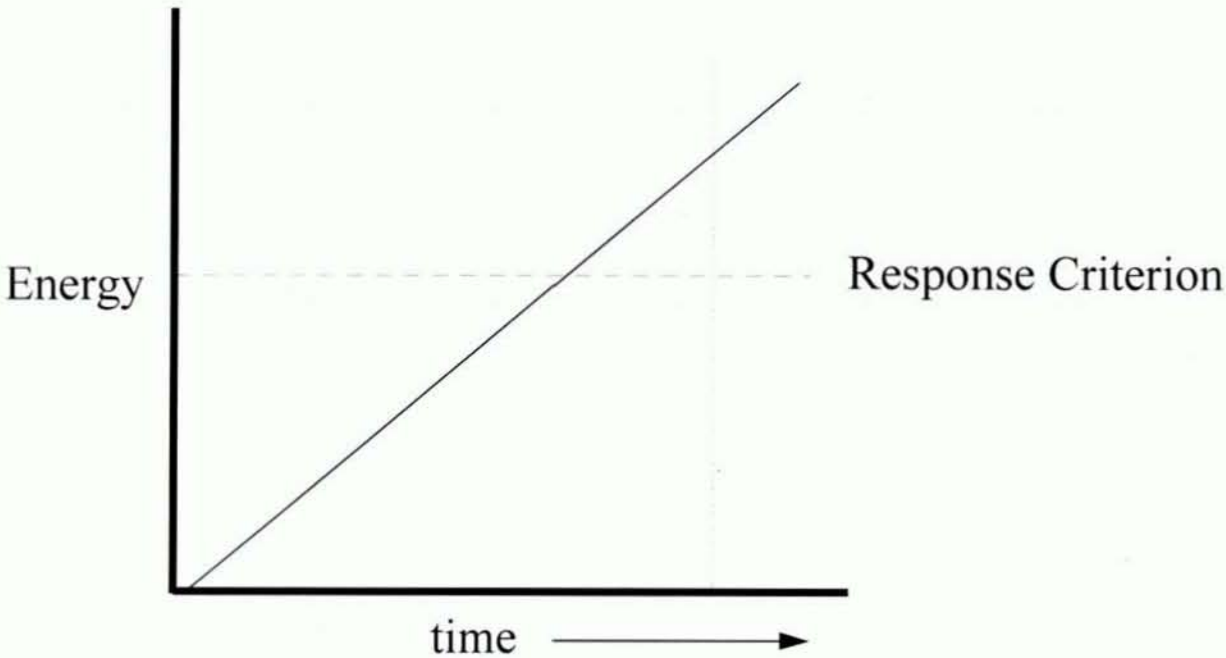

Figure 7. Variable Criterion Model.

Prior to the complete acceptance of the variable criterion model as a conceptual model of the neuron, some modifications are required. First, the amount of energy accumulated prior to the triggering of a response must be acquired before a fixed amount of time. That is there is a restriction on the slowest rate of energy accumulation. If the accumulation does not reach the criterion amount within this interval the accumulation returns to zero and the process starts over. Second, after the criterion amount of energy has been accumulated, a decay process occurs.

The accumulation of energy mimics the events occurring at the dendrites of the neuron which do not fire the neuron until the post-synaptic threshold has been reached. Once that threshold is reached, the neuron fires. That is, an impulse travels down the axon to the synaptic junction where the whole process reoccurs.

Using this model as the basic element, different arrangements of variable criterion models can be used to mimic different kinds of neural circuits. Three basic circuits have been isolated in the human nervous system: convergent, divergent and serial. In convergent circuits the output of one neuron can trigger many other neurons. This type of a circuit provides a means by which the activation of one element can activate other elements in parallel. In divergent circuits, the output of many neurons summate to trigger one neuron. Finally, one neuron can activate another neuron in a strictly serial fashion. In addition to these basic circuits, it also appears that there is a type of circuit that has the function of feeding back on the inputs. The arrangement of these basic elements into circuits provides a way by which the activation of one neuron can direct the activity of other neurons.

2.2 GENERAL MODEL OF SITUATIONAL AWARENESS

While the variable criterion model was identified as the elementary building block for a model of situational awareness, the next step in meeting the objectives of this project is to develop a model that could be used to address situational awareness within traditional cognitive terminology, while retaining all of the advantages of the variable criterion model. This would provide a way to link traditional models developed from cognitive psychology to the newer neural network models.

2.2.1 Traditional view

Historically, the models of cognitive psychology refer to different structures within which certain functions occur. The structures generally include three different types of memory (sensory memory, short term memory/working memory, long term memory) and a scanner. The functions that are assumed to occur within these structures are: stimulus registration, stimulus selection and either stimulus-stimulus translations or decision making or hypothesis testing, and either stimulus-response translations or response selection and response execution. The chain of events is that a stimulus is encoded into sensory memory where it is selected by the scanner and transferred to short term memory which contains additional information from long term memory. The information from long term memory is used to interpret and analyze the representation of the stimulus and some decision is made. The outcome of that decision is then used to select an appropriate response which is then executed.

While this approach may describe the manner in which information is processed, it does not appear to be responsive to current neural network simulation techniques, nor does it appear to represent the way in which the nervous system works or is structured. The traditional view suggests that there are regions in the brain which store information, other regions in the brain which make decisions, and other regions which perform different functions. With such an approach comes the idea of codes and the idea that codes are visual or auditory or tied to one of the other sensory modalities. All of these implications appear to be false.

These false implications are the result of a general philosophy of parsimony subscribed to by most Psychologists, i.e. find the simplest explanation. This has led to a number of classic behavioral stereotypes which are not empirically supported. One example of an unsupported stereotype is hemispheric dominance of the brain, and its supposed consequences. Reading any good Psychology text would leave you with the impression that all right handed people are left brain dominant and all left-handed people are right brain dominant. This conclusion is totally false. While dominance is relatively strong for right-handed people, their is little strong evidence for hemispheric dominance in left handed people. Furthermore the data for right-handed people is far from uniform. While the percentage is low, their are right handed people who show no

dominance of even left hemisphere dominance. Much of the evidence supporting functional localization of the brain is based on the direct brain stimulation studies by Penfield (1969). These studies have led to the belief that memories and other functions are mediated by localized sections of the brain. What is not generally reported is that, at least for memories, the triggering of latent memories was only observed in a small percentage of his patients and, in addition, it was often impossible to replicate these memories within patients. The subfield of Psychology called human factors has utilized the concept of population stereotypes to guide design decisions. Smith (1978) has clearly demonstrated that most of these stereotypes are anything but stereotypical behavior. Population stereotypes simply represent the most frequent behavior, not a uniform behavior. If you have two possible behaviors, the population stereotype is the behavior exhibited by at least 50.1% of the population, but that means that as much as 49.9% may not exhibit that behavior. If there are four possible behaviors, you could be faced with situation where 74% of the people do not exhibit the "stereotypical behavior," and this is not uncommon in the empirical data. This is certainly not a very convincing generalization about human behavior. About the only certain conclusion that can be drawn about "population stereotypes" is that it is not typical behavior.

The human brain is the most complex entity ever created. There is little logical basis upon which to conclude that its behavior can be described by some simple set of discrete processes. Humans, for all their creativity and technological marvel have create nothing which can rival the human brain. For example, 1 square millimeter of the human retina makes more decisions in 1 second than the most sophisticated supercomputer create by humans can make in about 300 years (Scientific American). In this example we are talking about a fairly straight forward sensory process, the complexity of a higher level cognitive process involving multiple levels of interacting neurological processes pales in comparison. While pattern-based interpretations of behavior and neural network models may or may not be the ultimate representation of cognitive processes, they more closely reflect the complexity of cognitive processes and behaviors than traditional models, and provide better predictive capability.

2.2.2 Alternative View

The view of human performance proposed within this report may be seen as somewhat controversial and as somewhat speculative, however, this view appears to be compatible with contemporary theories of Psychology.

The discussion will begin with what the nervous system does not do and how it is not structured and will then discuss what it does do. It does not "process information" or patterns or codes. It also does not contain distinct sections called long-term and short-term memory. It is not comprised of modules where one template is matched against a current representation. The information contained in a photo or a scene or a set of numbers is not decomposed by the nervous system and then recomposed to form a mental image, representation or template. Furthermore, information is not

transformed into a larger subset of additional information. Networks of neurons are not structured so that each neuron is associated with a particular letter. A five letter word is not comprised of the activation of five out of 26 neurons or that the onset of two numbers with a multiplication sign will result in the "activation of arithmetic facts" (LeFevre, Bisanz, Mrkonjic, 1988). If the computer or electrical analogy of the nervous system is to be used then let it be used correctly.

Neurons and the nervous system do transmit impulses from one location to another. Neurons are always firing, usually in non-random fashion. Non-random, because the environment that is triggering the firing is non-random. If a neuron fires, this does not suggest that it has, by its activation, sent a +1 code to the following neuron. Furthermore, a set of eight neurons, going from a resting state to an active state, does not mean that an eight bit word has been transmitted to a subsequent neuron as colleagues in the area of computer modeling are apt to suggest.

The process in the nervous system starts with a sensory transformation of changes in activity at the level of the receptor. Receptors are differentially responsive to different physical properties of the stimulus. Some receptors are more sensitive to environmental changes in space, while others are more sensitive to environmental changes in time. Receptors transform the physical characteristics of the physical stimulus into neural events. This initial transformation initiates a chain of events within the nervous system. The pattern of the changes is propagated within the nervous system and results in a patterned change in the activity at the arm, hand, fingers or other body part that is structurally capable of moving.

Outside the nervous system is the environment. Activity in the nervous system is the result of activity in the environment. Sometimes, as with vision, the activity is caused by the organism (eye movements). Other times the activity is caused by other organisms or by changes in the physical properties of the environment. It is not invariants which trigger nervous system activity but the variants. One sees because the eye moves and the items in the environment move. One hears because of changes in the pattern of sound waves reaching the tympanic membrane. That is, the pattern of environmental events in time and space trigger a corresponding pattern of activity in the nervous system. Without these changes in the environment, normal nervous system activity would not occur.

Changes in the environment which then become constant result in adaptation. Sometimes the process of adaptation requires millions of years, while at other times it takes seconds. Adaptability provides for survival. However, when we begin to study human behavior it is as if we forget that humans adapt. Consider the following scenario:

A subject is brought into the experimental situation. The first thing done (after reading the "Rights of a Human Subject") is to read a set of instructions. The

instructions usually spell out in detail the following:

A. The responses to be performed:
   1. push the button,
   2. move the stylus,
   3. turn the knob

B. The specific stimuli that will be shown:
   1. the letters A, F, G,
   2. the digits 3, 5, 6,
   3. the colors red, blue and white,

C. The task to be performed:
   1. find, or
   2. identify, or
   3. compare, or
   4. match,

D. Contingencies:
   1. If you find the red digit then press the right button,
   2. If the first letter matches the second letter then turn the knob to the left.

With these instructions the occurrence all of other events have been eliminated. Data, usually latency, accuracy or both are collected. The data are then used to infer information regarding the a) type of process, b) structure of the process, c) organization of processes, d) events that occur within a process, or e) some other characteristic of the mental process or processes that has resulted in the averaged and shaped data. Sometimes the experiment provides "evidence" for one type of process over another such as exhaustive versus self-terminating memory search or parallel versus serial processing. What was in vogue one year has been "disproven" or not supported the next year (although recently the years have started to turn into months). In all cases mathematical support can be found for all approaches (Luce, 1986).

Because the data can support any implied viewpoint, it might not be the case that one viewpoint is true while all others are false. It is probable that all modes of processing can and do occur. Given the rigidness inherent in the experimental situation and given the adaptability of the human, it should come as no surprise that the nature of processing changes. In fact there is even current empirical support that it does change. The change is from "controlled processing" to "automatic processing" which explicitly states that processing changes as a function of the mapping consistency between stimuli and response (Schiffrin & Schneider, 1977; Schneider & Schiffrin, 1977). If the nature of processing has been shown to change in an experiment there is

no reason to doubt that processing will change when the subject is introduced to the experiment, or that slight modifications of the experimental procedure result in changes in the ways that information is processed. In addition, there is no reason to doubt that other processes change throughout the experiment which could have an impact on the processes currently being inferred so that the experimenter thinks one specific process is begin influenced when in fact a different process is being influenced.

In the past 10 years psychology has witnessed the rise and fall of serial models, the beginning of the end to multiple resource models, and the rise and fall of stage models. It appears that psychology has, at last, approached parallel processing models, where it is assumed that processes are independent of one another. This approach then leads to other problems. If all processes operate in parallel is there anyway to determine which process is being influenced by our manipulations? If all processes operate in parallel is there anyway to determine how many processes there are? Or does each one of our independent variables lead to a new process? Furthermore, there is ample evidence to suggest that the processes are not independent. It does appear at least that the response performed on trial N will have an influence on the response performed on trial N + 1. Moreover, the presentation of auditory stimuli appear to have an influence on the perception of visual information. We also know that if color names are written in colors that do not correspond to their names then interference will occur. This then leads one to another idea, that while the processes are parallel they are not independent.

If there are any processes, these processes must stem from the structure of the nervous system and the process of firing a neuron. Taken as whole, events in the environment trigger a chain reaction of events within the nervous system. The onset of the visual environmental pattern triggers the activation of a set of neurons that are differentially sensitive to certain spatial characteristics contained within the stimulus and certain temporal characteristics that occur between stimuli. At each location within the nervous system, each neuron triggers the onset of additional neurons. While at the same time the triggering set of neurons terminates its patterned response. It is also proposed that the onsets and offsets of these specific sets of neurons are asychronous, such that the onset and offset of each neuron within the set of neurons do not correspond to an all or none situation. Instead, the onsets and offsets of the set of neurons associated with the onset of the physical stimulus have distributional properties.

With the onset of the physical stimulus a set of neurons are activated. The activation is temporally displaced and appears to be a function of stimulus intensity. The activation of these neurons trigger other neurons which are spatially and temporally distant from the earlier activated set of neurons. Eventually this sensory activation process terminates in different sensory and motor regions of the cortex. As a result, the onset of a visual stimulus triggers a spatially and temporally distributed set of neurons.

For example, when you are instructed to look for the number one, a specific set of auditory neurons are activated. This activation results in the priming of specific neurons located in the visual cortex and results in a decrease in the criteria associated with these neurons. Neurons associated with the response are also primed. The onset of the visual stimulus triggers or activates specific neurons which where originally primed by the activation of the auditory neurons. Since the neurons associated with the response were also primed by the instructions, the onset of the number one results in a response. Prior experience with the responses, the stimuli, and the task result in which specific sets of neurons to prime. Children do not come into the world knowing how to "look." They have been taught this behavior. Likewise, new born children do not know what the number one is. Specific auditory neurons are activated by the verbal instruction (assuming they "understand" language), but no visual neurons are primed. As an example, if you are instructed to rumplut when the Frizpit occurs, you do not know how to pumplut and you do not know what a Frizpit is. You can not do the task. If you are instructed to look for the Frizpit, you know what to do, but you can not tell me what a Frizpit is. Specific sets of neurons associated with the response are primed, but specific set of neurons in the visual cortex that should be primed by the auditory command are not primed. You do not know what a Frizpit is.

This approach suggests that task specific behavior is the result of the priming and activation of specific sets of neurons which correspond to environmental events. Events trigger or activate other events. Transformations do not occur instead triggering occurs. One "stimulus code" is not transformed into another "stimulus code." Instead, the onset of a visual stimulus triggers or activates a specific set of neurons associated with vision, audition and other sensory modalities. The interaction of these specific sets of neurons has been shown in a number of investigations. The specific sets of neurons which are primed and/or activated is a function of learning, practice, the stimulus, and the response. The result in the nervous system is a pattern of activity that is propagated throughout the nervous system.

Memory is not a thing, or even a process. Short-term memory is simply the activation of a set of neurons. Long-term memory is the structural arrangement of sets of neurons. Activation of a particular set of neurons results in "memory recall." One way to maintain "information in short term memory" is to keep specific sets of neurons active, whether this is accomplished by subvocal speech or not is not important. What is important is that the process of maintaining information in short-term memory is really accomplished by continued activation of specific sets of neurons. This process may result from feedback from some subsequently triggered set of neurons. Awareness of the items in memory occurs because sets of neurons are active.

2.3 DESCRIPTION OF THE THEORY

Usually cognitive theories are descriptive in nature. That is, they specify processes occurring between the onset of a stimulus and the initiation of a response.

In keeping with that tradition three specific processes and one general process are described. The specific processes, for the lack of a better set of descriptors, will be called input processes, central processes, and output processes. Each of these processes should be viewed as sets of neurons which interact with other sets of neurons. It is speculated, and there is some evidence to suggest, that the activity of the neurons associated with input and central processes temporally overlap the activity associated with the sets of neurons associated with the output processes. It is also speculated, and once again there is some evidence to suggest, that the sets of neurons associated with the central processes are activated after the activation of the sets of neurons associated with the input processes. It must be noted that the previous and following discussions of "activity" should not imply that all other neurons are "not active" only that they have a higher threshold or criterion and may not be involved in the specific task at hand. Activity or being active refers to the firing of sets of neurons. Priming refers to a general process in which the criterion is lowered.

2.3.1 Input processes

The onset of a visual stimulus triggers a sensory process by which the stimulus is registered, that is the physical characteristics alter the output of the receptors. Following this process is the process of decomposition-recomposition. That is, each spatial characteristic of the stimulus activates sets of neurons which correspond to the separate spatial characteristics of the stimulus but their outputs when taken as a whole at different points along the spatial continuum of the nervous system are correlated with the total stimulus.

The effect of practice is to increase the number of times specific sets of neurons are activated within a fixed period of time. That is, at any one point in time, the same number of sets of neurons will be active; however, with practice, within a constant interval of time, the same sets of neurons will have been activated a greater number of times. To put it another way, the amount of time a set of neurons continues to be active would decrease. This would allow for an increase in the number of displays for the presentation of information as one becomes more experienced with the system. This would also suggest that as one becomes more experienced with the system, the operator is "more aware" of events that are occurring.

2.3.2 Central processes

After the input processes are activated, the central processes are activated. Central processes are the result of the activation of sets of neurons that have been established through exposure to, and experience with, prior stimuli. That is the process of learning establishes a link between stimulus characteristics and specific sets of central process neurons. What is represented by these sets is of great importance but as of yet the representation is unknown. The central processes include the identification and recognition of characteristics of the stimulus or of the whole stimulus

and linking these characteristics or the whole stimulus to other characteristics such as verbal labels. These processes also include Teichner's S-S translations and the tasks of conservation, creation or classification as proposed by Teichner. Early in practice, the initial number of activated sets of neurons is very small. With practice, the onset of the stimulus initially activates a larger number of sets of central process neurons. Within a specific trial, as time progresses, a greater number of sets of neurons are activated.

If it were possible to measure the activity of all of the initially activated sets of central process neurons immediately following their onset at one point in time and space, and after extensive practice, it could be represented as in Figure 2. The x-axis of this figure presents a finite number of the possible sets of neurons that are initially capable of being activated. The y-axis represents the level of activity. The horizontal line represents the criterion required for the activation of subsequent sets of neurons. Note that the activity of some sets of neurons have reached that criterion while others have not. The view at the level of the criterion would represent the specific pattern of activity which corresponds to the stimulus input.

2.3.3 Output processes

At the same time as the input processes and central processes are occurring, the response processes are also occurring. These processes include linking the stimulus or characteristics of the stimulus to the different responses. Early in practice the number of sets of neurons that are active is very large. With practice, the onset of the stimulus initially activates a smaller number of sets of output neurons.

Within a trial, as time progresses, fewer sets of neurons associated with the response become active until there are no further sets to activate, at which point the response occurs. With the onset of the stimulus, the maximum number of sets are active. It is proposed that there is an inverse relation between the number of central process neurons activated and the number of output process neurons that are active. This inverse relation stems from the finite set of neurons contained within the brain, and the idea that as time progresses more and more central process neurons are activated.

2.3.4 Priming

Priming is the general process by which specific sets of neurons associated with any of the three specific processes are "made ready" for activation. For those neurons involved in the task (including input, central and output process neurons), a reduction in their criterion occurs. The onset of a stimulus then activates those primed neurons. Research by Grice (presented later) has shown that the occurrence of a stimulus can serve as a prime for the next stimulus. It is also assumed that instructions can prime sets of neurons. Moreover, any response that provides feedback to the organism can result in priming sets of neurons for the next stimulus.

2.3.5 Discussion, Supporting Data and Further Conjecture

While Teichner assumed that the variable criterion model reflected only the early stage of information processing, which has invariably been called, Stage 1, encoding, preattentive processes, visual information store, or iconic memory, the proposal contained in this report suggests that the elementary process which is occurring within each of the proposed specific processes is the same. The advantage of this approach is in regard to the model's compatibility with the neurological evidence. The processes which occur within a neuron are the same regardless of the location of that neuron. Moreover, the process which occurs between neurons are the same, whether one is referring to neurons in the occipital lobe, neurons in the temporal lobe or neurons in any other part of the brain. If the neurological processes are the same, then a conceptual model of the elementary process must also be the same regardless of which general process is being discussed. This is a radically different viewpoint from most current cognitive theories. In most of the current cognitive theories, there are still differences between, for example, short term memory processes and long term memory processes. However, at the neurological or neuron level these differences disappear.

2.3.5.1 Evidence for priming

In a study using physically identical stimuli Posner and Boies (1971) found a U-shaped function relating SOA to the latency for the response of same. The optimal interval between the stimuli was about 500 msec. Likewise Grice, Nullmeyer and Spiker (1977) found a similar function.

The argument is that the presentation of the first stimulus was responsible for priming the output neurons and priming the input and central process neurons. Priming the response for one stimulus seemed to inhibit responses associated with other stimuli, this could be viewed as reducing the number of sets of neurons associated with the response through a reduction in the criterion levels of the output process neurons. That is, priming appears to lower the criteria associated with specific sets of output process neurons and in so doing reduces the initial number of sets of neurons associated with the output processes. The effect associated with priming the input and central processes, is to reduce the criterion levels of those sets of neurons associated with these processes and in so doing it also has identified the specific sets of neurons that could be activated and involved in these processes. Additional non-physiological evidence for the priming effect is also provided by Henderson, Pollatsek and Rayner (1987) and Miller (1983; 1987). Physiological evidence which supports the priming effect is provided by Evarts (1984).

The notion of priming suggests a number of other experiments. For example, temporally successive stimuli that are similar to each other should result in faster responses than stimuli that are dissimilar, which they do (Grice & Gwynne, 1985).

Further, with increases in similarity, given the same response for each stimulus, latency should decrease. This would hold to the extent that the stimuli require the same response. However, since the stimuli prime the same sets of neurons, similar stimuli that require different responses should result in longer latencies with a higher probability of errors than if those stimuli require the same response. Most of these relations have been uncovered earlier and can be found in the literature dealing with positive and negative transfer, and proactive and retroactive interference. The results of these studies should be reinterpreted in light of the response priming notion.

Instead of presenting the exact digit which matches the digit on a search slide, the to be searched for digit is presented visually as a word. The first slide, or prime, would contain the word FOUR. The search slide contains the digit 4 in addition to other digits. The response latency to the first stimulus observed, if it could be measured, would be long and the response would probably be incorrect. The reason being that the wrong set of input neurons and central process neurons were primed. The criteria associated with the correct set of neurons will be reset for the next stimulus observed by the activation of the current set of neurons. This also suggests that the effect of context is to lower the criterion associated with specific sets of neurons and raise the criterion for other sets of neurons.

2.3.5.2 Evidence for specific processes

A set of experiments performed by Loftus, and his students (1988) sheds some light on the proposed model. Using a backward masking procedure, Loftus was able to identify two separate processes, which he termed perceptual processing and conceptual processing. The two processes occurred in series, with conceptual processing occurring about 300 msec after the perceptual processing. While the terms are different, the idea is the same. Conceptual processing is analogous to the central process and perceptual processing is analogous to the input process.

Further support for the arrangement of the processes as proposed is provided by Grice and his colleagues. Grice has demonstrated two functions being associated with correct response time in a choice response time and in a disjunctive response time situation. These are what he terms sensory strength and associative strength. Sensory strength refers to the growth of the function involving the initial accumulation of energy or as it is termed in this proposal the input processes. The associative strength represents the degree of association between the stimulus and the correct response (Grice, Nullmeyer, & Spiker, 1977; Grice, Spiker, & Nullmeyer, 1979; Grice, Canham, & Schafer, 1982; Grice, Nullmeyer & Spiker, 1982). The associative strength function starts at about 280 msec for both choice reaction time and disjunctive reaction time (Grice, Hunt, Kushner, Nullmeyer, 1974).

The results from the Grice and Loftus investigations suggest that what is being termed the central process starts somewhere between 280 and 300 msec after the

onset of the stimulus. The interval from stimulus onset to the onset of the central process appears to be involved in the input processes, and as is assumed in this report, the output processes.

2.3.5.3 Implications for Simulation

The use of a common basic process for the neuron provides support for using simulated neural networks to mimic real neural networks. There are two major differences between the theory set forth in this report and simulated neural networks. First, the theory suggests that stimuli can prime the neurons associated with subsequent neurons. This would involve altering the weights between the connections of simulated neural networks. Second, the proposed approach to situational awareness suggests sets of neurons that are differentially sensitive to physical characteristics. Most neural networks suggest that all stimuli either inhibit or excite specific neurons within a common set of input "neurons." The activation pattern of the input layer triggers a pattern within the hidden layer which then triggers a pattern in the output layer. The speculation contained within the current approach is that specific physical characteristics, such as the wavelength of light, differentially activate a specific set of neurons.

2.3.5.4 Implications for Situational awareness

The proposed theory suggests that situational awareness occurs sooner because a larger number of central process neurons are activated with the onset of one particular stimulus. It also implies that skilled performance results from a decrease in the number of sets of output neurons that are activated with the onset of that same stimulus. Ideally, the theory suggests that the onset of one stimulus or a part of one stimulus could trigger the activation of a response.

There are two different approaches to generating this automatic behavior. First, the training program developer could provide the stimulus or those stimuli and the responses that are specifically associated with one and only one situation. Training with one particular stimulus or set of stimuli and the desired response which is consistently and only associated with a given situation should result in a response that is automatic. This would require that the training program developer specify such a stimulus or set of stimuli and responses for each situation as well as being able to specify in advance each situation.

The second approach would be to provide the stimuli and available responses for all situations and let the individual being trained determine the critical variables and appropriate responses for each situation. This approach would appear to require a long training phase. Like the first approach, this approach would require knowing each situation in advance. The trade-off in time would favor the first approach.

The general process of priming could be used to shorten the training phase. For each situation that has been identified, the prime could be an auditory cue, such as the word "stall" followed by visual stimuli. With practice, the prime would serve to reduce the criteria for specific sets of neurons that would be activated with the onset of the visual stimuli. Once again, the particular stimuli that are associated with this situation and only this situation have to be identified in advance.

3.0 TRAINING PROCEDURES

Procedures for training will be directed at priming, the input processes, central processes and output processes as presented in Section 2.0. For each process specific procedures will be outlined and the impact of this procedure on the process will be hypothesized. The objective of any training procedure are four- fold. First, any training procedure should provide information and experience with stimuli and responses that will prime specific sets of neurons. Second, any training procedure should result in a reduction in the amount of time required to activate the input process neurons. Third, any training procedure should result in an increase in the number of initial sets of central process neurons that are initially activated. Third, any training procedure should result in a decrease in the total number of output process sets of neurons that are initially activated. The realization of these objectives will result in behavior that is quick and accurate.

3.1 Priming

The objective of training for improved priming is to reduce the number of other sets of neurons that could be activated when specific stimuli and responses occur. The specific training procedure would involve the presentation of a priming stimulus followed by specific stimuli that require a specific response or set of responses. The priming stimulus could then eventually be eliminated; however the internal pattern of activation resulting from the original prime and the subsequent stimuli and responses should be maintained.

3.2 Input processes

The objective of training for improved input processes is to decrease the time to activate specific sets of input neurons. There are two ways in which to improve input processes. One way, which is beyond the scope of this project, is to reduce the number of existing displays through integration. The other way is to establish connections between the existing displays that are needed to activate central process activities. For example, if three out of 10 displays are required for a correct response to some situation, then these three displays could be coded the same way, or situated in the same location, or have specific characteristics in common.

With regard to specific training procedures, the displays that are used could be

presented within a tachistoscopic presentation, where the duration of those displays is reduced as a function of the identification accuracy. In this adaptive training procedure, the task is to identify the specific value of the parameter and the parameter presented on the display. If the accuracy level is 100 percent, then the duration of the display would be reduced. The result of the reduction in duration would be to increase error rate. Practice at this level would continue until the accuracy rate returned to 100 percent at which time the exposure duration would be reduced again. Such a procedure should result in a reduction in the time required to activate the input process neurons and should carry over to the actual situation.

3.3 Central processes

The objective of training for improved central processes is to increase the number of sets of central process neurons that are active. Because a situation is defined by a number of different parameters the situation can be considered to be a pattern which results from these different parameters. The generation of this pattern within the nervous system requires a large number of active sets of neurons. Early in practice, the number of sets of active neurons is very small, that is the central process is involved with only one parameter. Later in practice, the number of sets of active neurons is greater; that is, the central process is involved with many parameters. The same linking of displays that improve the input processes should also improve central processes.

Another approach for the improvement of central process activities would be to identify the parameters associated with specific situations and then to present the situation and parameters together. For example, when an aircraft stalls in flight a loss of altitude, an initial decrease in speed followed by an increase in speed, and change in attitude all occur. This is could be considered as the definition of a stall. By defining the situation by the parameters, the operator of the system will become "aware" of the situation. The theory is suggesting that a larger number of sets of neurons is being activated with this procedure. Repeated exposure to this situation should improve recognition performance because the number of active sets of neurons is greater.

Training could simply involve tachistoscopic presentation of all the visual displays with each display presenting a specific value of a parameter. The response would be a number of possible situations. The task of the subject would be to respond to the ensemble of displays by pressing a button that is associated with the defined situation. Recall, however, that the occurrence of the actual environmental situation is not discrete, but continuous, so that changes in the parameters are also continuous. Nevertheless, the tachistoscopic presentation procedure should provide improvement in recognition of the situation.

Between different situations, the within display change should be large. For example, if the difference between a stall condition and a dive condition is

characterized by a small difference in the speed indicator, the difference should be magnified. The reason for using magnification is due to the idea that the input process neurons are activating the same sets of central process neurons. In order for a difference to be identified, there must be a large difference between the activated sets of central process neurons.

One way to accomplish this situation definition process without training would be to provide status information pertaining to situations. If the total number of possible situations is known, then the occurrence of each particular situation could be signaled. This would require the system designer to know the defining parameters of each situation and then to provide a status display that would signal the presence of that situation.

3.4 Output processes

The objective of training for improved output processes is to reduce the number of sets of output process neurons that are active. Naturally, training should consist of the appropriate responses to perform given the occurrence of a specific situation. Early in practice, information is provided which specifies what the controls do and how they are activated.

Training in later phases should emphasize, repeatedly, the exact response to perform given the occurrence of a specific situation.

3.5 Discussion

While the proposed training procedures are directed to each of the theoretical processes proposed within this report, sufficient practice should be directed towards the total set of proposed theoretical processes. This procedure would allow for the integration and coordinated activities between processes. Moreover, it would serve to strengthen the connections between the individual stimuli, the resulting patterns and subsequent responses.

Some mention should be made of part-whole training. Usually, part training consists of subdividing the task into component parts. Each part is characterized by specific input and output processes. Eventually, the separate parts of the task are combined to form the "whole" task. Within the theory presented in this report, part task training should consist of training in each of the separate processes and then combining the processes. For example, training on input processes would use all of the displays. Simple repeated exposure to the displays would begin to increase the total number of displays incorporated into one view. Training on central processes would involve repeated exposure to the parameters of the critical displays and identifying the defined situation. Training on output processes would involve the use of controls and the specifics of which controls to be used and their activation given the onset of

different situations. Further, the temporal organization of input process, central process and output process activities should be maintained.

In essence, this analysis suggests that skill-based training should be founded upon exposing the learner to the inherent patterns of relevant information in the learning environment. Rather than force the learner to figure out what is noise and learn to ignore the irrelevant information, the training paradigm should guide the learner through the process. This could be accomplished in tow ways. In the first approach, the training paradigm could present only the relevant patterns and then gradually add the real-world noise to the environment. In the second approach, the relevant information pattern could be highlighted. Then as training progresses, the highlighting could be gradually reduced thereby blending the patterns into the normal stimulus environment. The support studies described in the next session explore the first of these potential training paradigms. It should be noted that these approaches are somewhat controversial since they are exactly opposite in philosophy to the popular mission training approach being pursued in the military.

4.0 SUPPORT STUDIES

Three support studies were conducted to verify the role of pattern recognition in situational awareness. These empirical studies were conducted to obtain answers to research questions raised during the cognitive analysis and subsequent development of an information processing model. These studies helped to direct and refine the model development effort. Several ideas for support studies were generated to test the underlying concepts of the model.

First, a study was conducted to confirm that experimental manipulation of information displayed in an in-flight environment would affect pattern recognition performance. Pilots identified and recovered from unusual attitudes in a general aviation trainer (GAT-1); their performances varied consistently over the range of experimental manipulations which were derived from the situational awareness concept. The data trends obtained from this initial study supported the hypothesis that situational awareness is determined largely by pattern recognition skills.

A second, similar, study was conducted using a PC-based flight simulation task to investigate a training strategy for situational awareness based on the theoretical analysis and findings of the first support study. The study evaluated the effectiveness of a training strategy which was used to teach the identification of aircraft attitudes based on patterns of information in the primary instrument cluster.

The third study was conducted to validate the training strategy supported by the second study in a different environment. This study assessed the ability to train pattern recognition processes in an M1 tank simulator. The specific application was the detection of patterns in muzzle flashes to determine direction of shell flight when being

fired upon.

4.1 STUDY #1

After an assessment of needs and available equipment, an experimental paradigm based on the recovery from unusual attitudes in simulated flight was selected for the first support study. A paradigm different from that intended for the final validation study was deliberately selected to test the generalizability of the concepts. The simulated flight task has clearly identifiable patterns of information and responses that pilots are trained to use. A General Aviation Trainer (GAT) was used for this study because the capabilities of this simulator include realistic instrument indications, it is perfectly suited for the implementation of the unusual attitude recovery paradigm.

The objective of this support study was to assess whether the unusual attitude recovery paradigm was sensitive to experimental manipulations suggested by the situational awareness model. Four unusual attitudes (combinations of nose high/low and bank right/left) were employed in the study. Recovery was accomplished with all instruments working or with the airspeed, rate of climb or altitude indicators failed. The loss of information through instrument failure disrupted the pattern of information that tells the pilot the appropriate recovery response. To assess the impact of these manipulations on performance, recovery times were measured. All conditions were carried out without external visual reference so that the total information pattern was conveyed through the instrumentation.

Preliminary data were collected using pilots on the staff of the University of Central Florida Institute for Simulation and Training. The data clearly indicated that performance varied with experimental manipulation. Therefore, this support study provided a valid paradigm testing the basic constructs that were later developed into a model. The statistically derived trends in the preliminary data, as shown in Figure 8, are in accordance with the predictions formulated from the pattern recognition concept. Despite the limited sample size, the results corresponded to the hypothesis that the selective removal of information through instrument failure would produce performance decrements. Thus, there was strong agreement between the predictions of pattern recognition concepts and the data obtained from the unusual attitude recovery study.

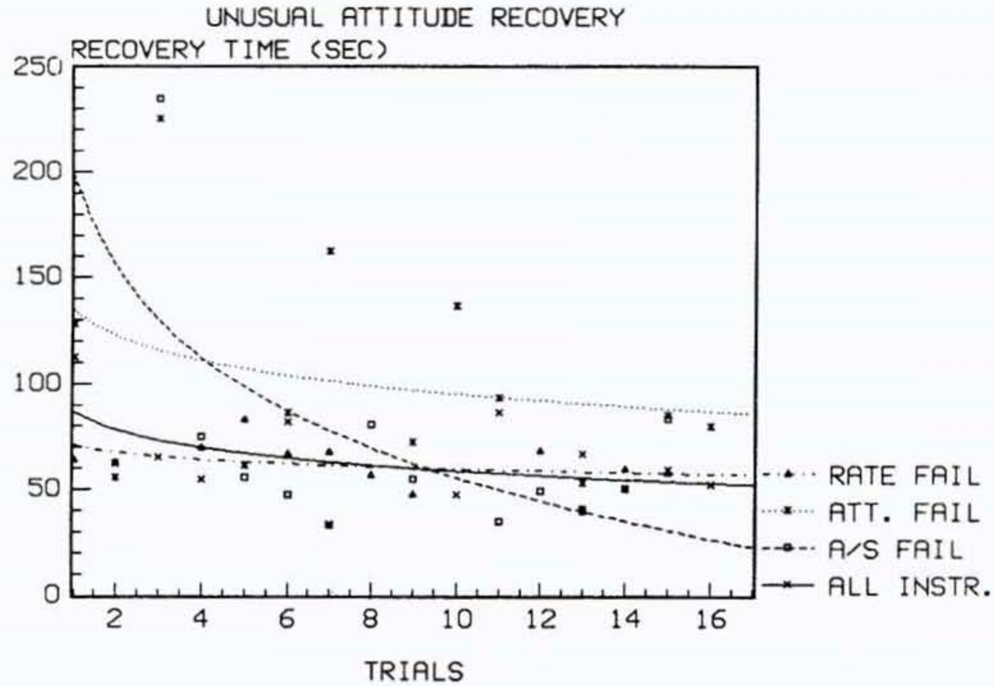

Figure 8. Effect of Instrument Failure on Unusual Attitude Recovery Task.

4.2 STUDY #2

The second support study examined the ability to specifically train people to extract the patterns associated with the unusual attitude recovery paradigm. The objective was to demonstrate that training strategies relevant to situational awareness can be deduced from theoretical analysis and applied in training. The cognitive analysis indicated that people should better learn to identify relevant patterns and their correct responses if they are exposed to those patterns in isolation. This was the basic training strategy that resulted from the analysis.

The study was conducted using MicroSoft Flight Simulator 3.0 (Microsoft, 1988) on an IBM PS/2 Model 30 which enabled the training conditions to be implemented without significant software modifications. The experimental group was trained to identify unusual attitudes in isolation. Only those instruments that provided information relevant to the identification and recovery from each orientation were displayed. After subjects learned to correctly recognize and respond to each attitude, irrelevant instruments were added into the cockpit environment. The control group was trained in the recovery task using the full instrument panel as found in standard training environments. In the control condition the subject was required to extract the relevant information out of the total environment. Learning rates and performance data were examined. Figure 9 summarizes the findings of the study. The results supported the predictions of the model. During the training trials those subjects trained with the reduced instrument panel showed significantly better performance. This would be expected in part because reduced clutter in the cockpit environment simplifies the

learning task. The key result was the transfer of learning to the test conditions in which all instruments were present. The recovery time for the test was averaged over eight trials. The group trained with the full instrument cluster continued to show improvement due to practice during the test condition. However, the significant finding is that although the experimental group showed a slight negative performance effect due to the addition of the instrument clutter, their performance still averaged almost ten percent better than that of the control group. The negative performance effect was accentuated because the transition from reduced instrumentation to full instrumentation was a step function. The optimal strategy would have been to gradually introduce the irrelevant instruments which would minimize the negative performance effect. The findings clearly support the prediction that training the pattern recognition skill in isolation would lead to better performance. The study demonstrated that this training strategy is a valid concept for improving situational awareness.

- **Subjects trained with tailored(reduced) instrument cluster perform better during training**
- **Subjects trained with reduced instrument cluster do better with full instrument cluster during test than those trained in that environment**

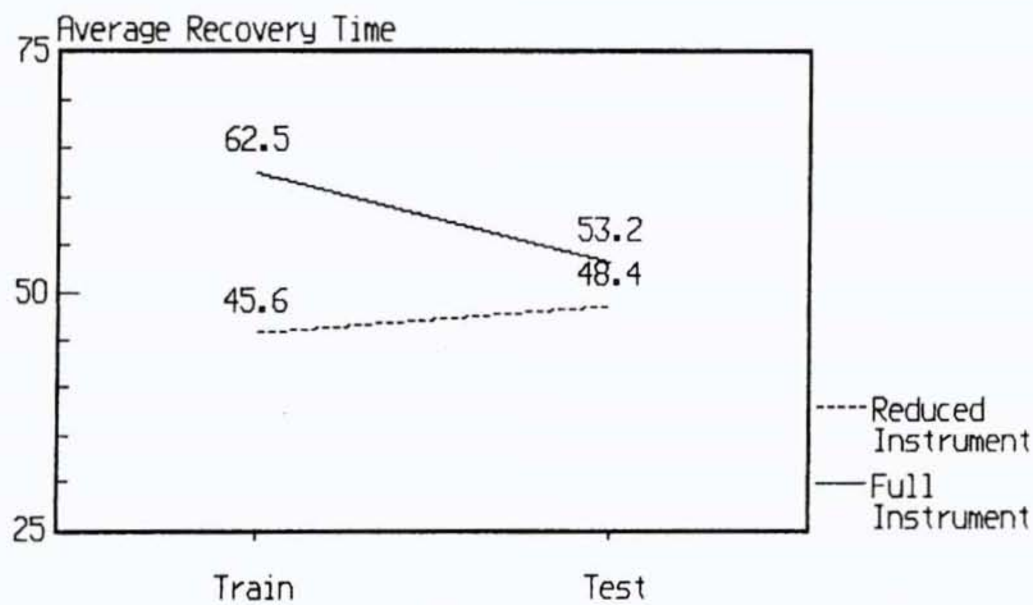

Figure 9. Situational Awareness Training for Unusual Attitude Recovery

4.3 STUDY #3

The main objective of the third support study was to validate the use of pattern recognition, within the concept of the skill-based behavior called situational awareness, as an effective training strategy in an M1 tank simulator. The ability to effectively search for, detect, locate, identify, classify, and confirm correct targets are crucial survivability skills for tank personnel. These skills may be dependent on the ability to recognize and discern patterns such as the shape of muzzle flare. The study tested the hypothesis that learning to first identify these patterns in isolation, rather than within the context of a complicated battlefield setting, would improve the effectiveness of training and transfer of pattern recognition skill.

Two SIMNET M1A1 tank simulators and a laptop computer were employed in this study. SIMNET is a network of medium fidelity, fixed-base tank simulators which allows two or more tanks to work together or in opposition. SIMNET was chosen because its computer-managed capabilities permit consistency among experimental presentations. SIMNET displays, such as the laser range finder and the turret azimuth indicator, enable experimenters to maintain precise control over stimulus presentation in a variety of battlefield conditions.

4.3.1 Method

Twenty civilian volunteers from the University of Central Florida participated in the validation study of pattern identification training. Participants were first briefed on the nature of the experiment. They were then told that the study involved training of pattern recognition skills and were assigned alternately to either of two training groups.

In the control group, the visual display consisted of a battlefield scenario with the opposing tank positioned in the center of the screen partially camouflaged by a treeline backdrop. Howitzers, trucks, and other tanks on both sides of the target tank were added for clutter, and the simulated sounds of weapon fire, ordnance explosions, and tank engines added to the "blooming, buzzing confusion (James, 1890)." Subjects were instructed as to which relevant cues to attend to (i.e., muzzle flash pattern) as the opposing tank fired rounds at the subject's tank.

Subjects in the experimental condition were trained with a minimum of extraneous cues; only the opposing tank and the horizon were presented in the visual scene and the sound was turned off. Subjects in both conditions were tested in the cluttered battlefield condition, identical to that presented to the control group during training. Subjects' reaction times were automatically recorded when they pressed a response key.

4.3.2 Results

Subjects from both training conditions were able to reliably identify patterns in all target locations, indicating that pattern identification training was successful. Performance measures were computed for each subject for each of the eight directions of fire. The measures included mean percent correct responses, mean reaction time in seconds, and mean number of elevation (vertical) and azimuth (horizontal) errors. The mean sum of the elevation and azimuth errors was also calculated. The experimental group had a 60.1% accuracy rate in identifying the direction of fire using the muzzle blast pattern, while the control group was only accurate in 45.5% of the trials. Analysis of variance showed that this performance difference between groups was significant and also that the effects were significantly related to direction of fire. Also, gender differences were related significantly to reaction time, but did not affect accuracy (see Table 1).

Table 1. Analysis of Variance Results

Source	SS	df	MS	F	p
		Mean Percent Correct			
Training Group	.97	1	.97	7.51	=.007
Direct. of Fire	3.63	7	.52	4.03	=.001
Gender	.03	1	.03	.26	n.s.
Total	25.63	159	.16		
		Mean Reaction Time			
Training Group	.02	1	.02	.01	n.s.
Direct. of Fire	11.39	7	1.63	.79	n.s.
Gender	73.97	1	73.97	36.00	<.001
Total	356.13	159	2.24		

Since the effect of training condition was confounded by the direction of fire (i.e., there was a significant interaction), an ANCOVA was conducted to examine training effects and gender differences with direction of fire held constant. This analysis revealed advantages for the control training strategy as indicated by significant main effects of strategy on mean percent correct, mean vertical error, and composite error. In addition, the relationship between gender and reaction time was significant (see Table 2). Mean reaction latencies of male responses were faster than female responses for every direction of fire.

The results indicated that subjects performed better in simulated battlefield conditions following training in an environment which contained only the cues necessary for pattern identification skill acquisition. Not only did this training lead to

greater accuracy, but the magnitude of errors that were made were smaller on average than for the control training condition. As predicted by the neural activation theory of situational awareness (Companion & Gilson, 1988), subjects trained in the uncluttered environment performed significantly more accurately overall than those who were trained in the complex battlefield condition (Figure 10).

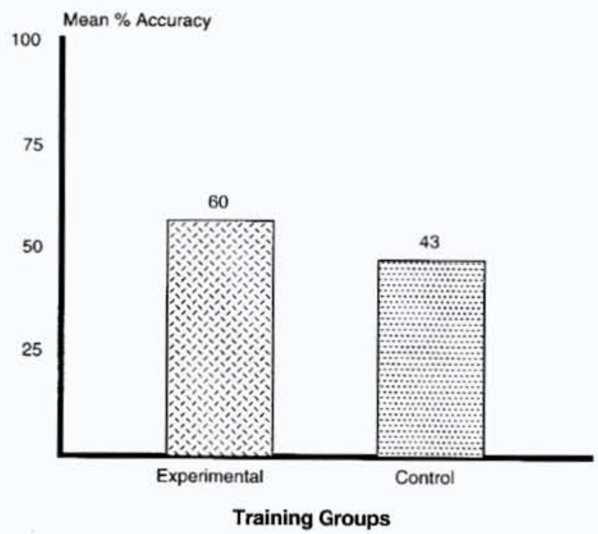

Figure 10. Mean Accuracy by Condition.

Table 2. Analysis of Covariance Results (Direction of Fire as Covariate)

Dep. Variables	SS	df	MS	F	p
Main Effects of Training Condition					
Mean Pct. Correct	1.04	1,159	25.63	6.78	=.010
Mean Elev. Error	1.33	1,159	39.72	5.48	=.020
Mean Azim. Error	.13	1,159	24.44	1.05	n.s.
Mean Comp. Error	2.29	1,159	73.53	5.19	=.024
Mean React. Time	.01	1,159	356.1	.00	n.s.
Main Effects of Gender					
Mean Pct. Correct	.03	1,159	25.63	.20	n.s.
Mean Elev. Error	.01	1,159	39.72	.05	n.s.
Mean Azim. Error	.22	1,159	24.44	1.74	n.s.
Mean Comp. Error	.34	1,159	73.53	.76	n.s.
Mean React. Time	74.16	1,159	356.13	41.76	<.001

The results of this study demonstrate the significance of pattern identification skill training which was derived from the neural activation theory of situational awareness. These specific findings, obtained in a SIMNET M1A1 Tank simulator, indicate that situational awareness training in a sparse stimulus environment that contains only the cues necessary for pattern recognition learning is superior to similar training conducted in a realistic, cue-cluttered condition. This training advantage may lead to the development and exercise of the situational awareness pattern identification skills that are believed to be the key to survival and success in a battlefield environment. The results effectively validated the cognitive model of situational awareness developed earlier in the project. Field studies should be conducted to validate and extend our findings to improve situational awareness training of Army personnel.

5.0 NEURAL NETWORK MODEL DEMONSTRATION

The cognitive analysis revealed a plethora of data supporting the importance of pattern recognition in cognitive processes such as situational awareness. This concept is being proposed with increasing frequency to account for human cognitive processes at every level. Neural network modeling approaches are appropriate for modeling pattern recognition processes, and have been utilized in a number of advanced cognitive modeling applications. This approach appears promising for developing computer models of situational awareness. As a consequence, several neural network based models of situational awareness were developed to explore their applicability and validity to this class of cognitive behavior.

5.1 UNUSUAL ATTITUDE RECOVERY MODEL

Simple neural network models were developed for the pattern recognition portion of the unusual attitude recovery task. The pattern recognition in the unusual attitude recovery paradigm is essentially a diagnostic process, so a back-propogation model was selected for the simulation. The models were based on a back propagation paradigm, utilizing supervised learning techniques, and modeled as a multilayered, fully connected, feed-forward network. Both two-layer and three- layer models were developed. Because two-layer models cannot learn different responses to very similar patterns, they are not appropriate for most applications. However, by utilizing a two-layer model, a feasibility demonstration and research on the learning characteristics of the networks provided a baseline for comparison.

The models were designed to use information from the six primary aircraft instruments as inputs. These six instruments provided the following information: pitch, roll, altitude, airspeed, vertical velocity, heading and turn and bank. Different combinations of information on these seven parameters indicate aircraft orientation. For example, when the airplane nose is up, the instruments indicate that pitch is positive, altitude is increasing, airspeed is decreasing and vertical velocity is decreasing (Figure 11). The two neural network models were trained on the maximum values for

each parameter for each of the nine possible orientations. The training of the models showed that the three- layer model took approximately three times longer to achieve the same level of recognition accuracy as the two layer model (Figure 12). After training was completed, the neural networks were tested using approximately fifty new patterns. The new patterns represented orientations with instrument parameters initialized at less than their maximum values. For example, the model was trained at a value of 20 degrees of positive pitch for the nose up condition. When the new pattern contained a value representing only 5 degrees of positive pitch, the model could still recognize that the nose was up. The ability of neural networks to extrapolate to patterns of information that were not previously trained (as humans also do) underscores their utility in modeling behavior. This research clearly demonstrated that neural networks are useful for modeling behavior related to situational awareness and that simple models can be developed for real world tasks.

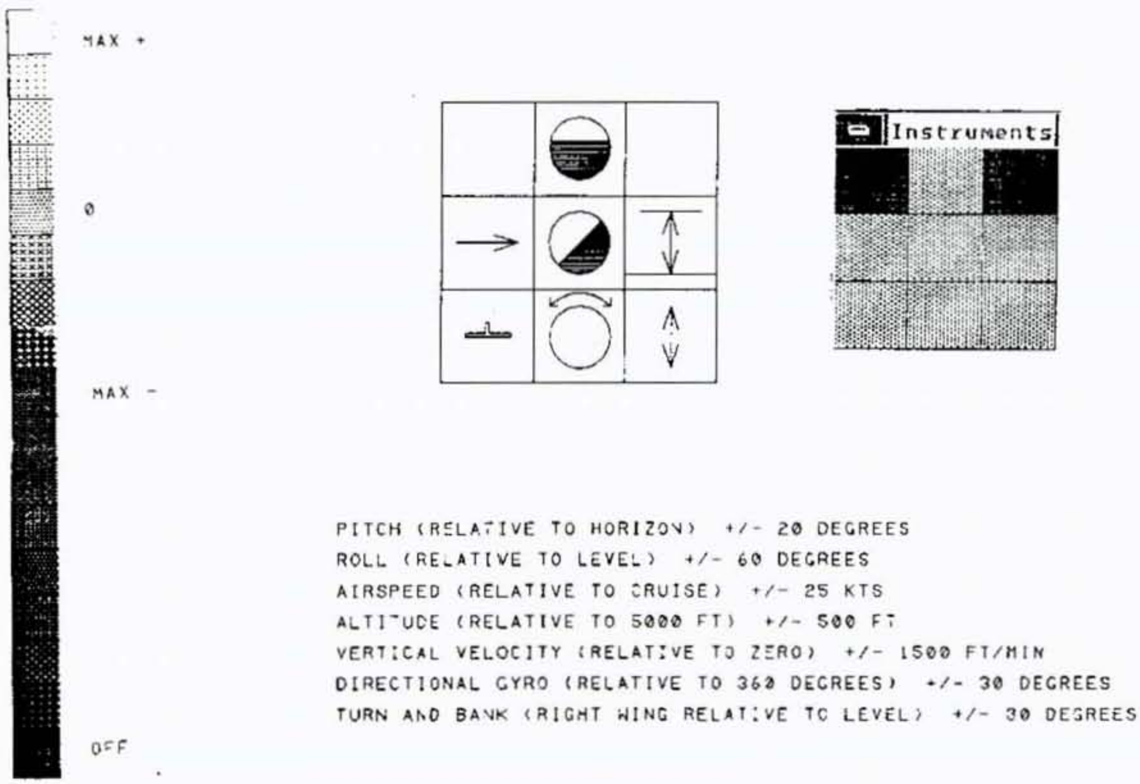

Figure 11. Illustration of Attitude Representations.

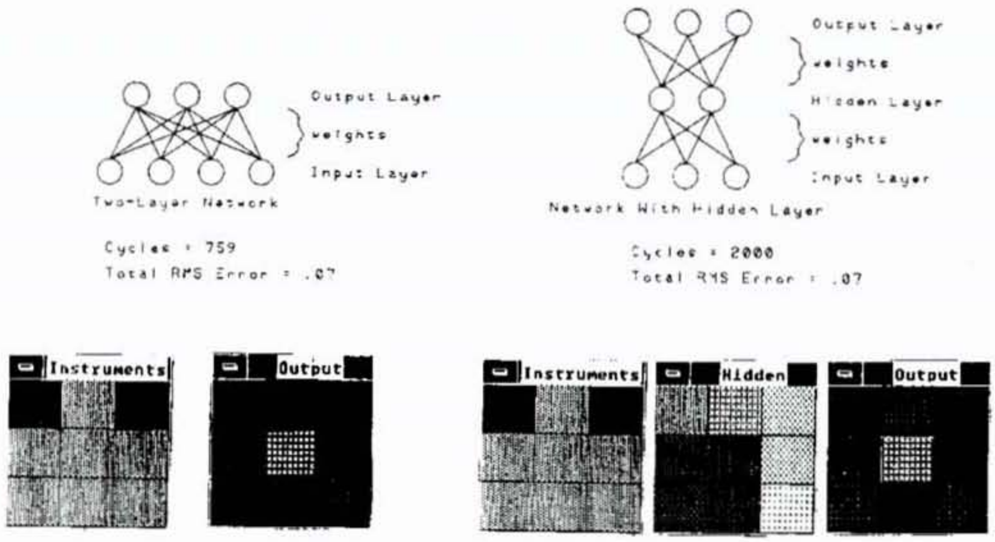

Figure 12. Training of two- and three- layer neural; networks.

5.2 DIRECTED EXPERT SYSTEM

A "proof of concept" expert system which modeled the operator's skill-based decision making was developed. The primary focus was on modeling the decision making processes of a battlefield tank commander. The development of the expert system utilized structured, incremental prototyping techniques to manage risk.

The model development involved two distinct phases; knowledge engineering and the actual model implementation. The knowledge engineering phase involved interactions with subject matter experts to determine the specific variables and values that would be incorporated in the model. The implementation of the model involved the programming of the neural networks, rule-based modules and their integration. Of the six functional blocks of the generic model identified as relevant route planning and aspects of the threat assessment models were implemented using algorithmic and rule-based approaches, tactics planning was implemented as a user defined input, and the mission planning, status assessment and situation assessment functions were implemented primarily using neural networks. Table 3 summarizes the characteristics of the overall decision making model.

TABLE 3
SUMMARY OF EXPERT SYSTEM CHARACTERISTICS

- Designed as a Proof-of-Concept, i.e., narrow slice model

- Hybrid Decision Making Model
  Includes algorithmic, rule and neural network components
  Employs nested neural networks with supervised learning

- Based on METT-T
  Mission
  Enemy
  Terrain
  Troops
  Time

- Free Play Environment
  User defined situation
  Model evaluates for Go/No Go decision
  Model provides explanation of decision
  If Go, then model selects optimal route

5.2.1 Knowledge Engineering

With the help of a subject matter expert the input data concerning the principles of METT-T for developing the expert system nets were determined. Some modifications were made to the data set to better represent real-life combat situations and guide decision making.

An information analysis of the behaviors performed by tank commanders and drivers in the M1 tank environment was conducted to build the knowledge base for the development of the situational awareness expert system. The military combat principles of METT-T (Mission, Enemy, Terrain, Tactics, and Troops) were examined to help provide and verify this information. The analysis examined doctrine, standard operating procedures (SOP), tactics, etc. Military decision making is a process requiring two different skills:

1. Ability to recognize and analyze the essence of a problem.

2. Creative ability to devise a practical solution to the problem.

The Commander uses the Estimate of the Situation as a logical problem solving approach. It is the process by which a commander considers all the circumstances

affecting the military situation and arrives at a decision as to a course of action to be taken to accomplish the mission. The Course of Action (CA) selected by the commander is reached after considering all the circumstances affecting the military situation and reaching a decision as to the CA to be taken to accomplish the mission.

The basic factors bearing on the Mission and CA are METT-T:

Mission
- intent of the higher commander
- essential tasks required
- constraints that limit possible actions

Enemy - the relative combat power of opposing forces
- strength
- composition
- training
- morale
- fatigue
- equipment
- logistically supportable

Terrain - the nature of the terrain and weather
- advantages and limitations of weather
- advantages and limitations of terrain amount of space available to execute the mission

Troops - troops available

Time - time available to plan, prepare, and execute a plan.

Specific levels of each variable were identified in concurrence with a subject matter expert to develop the knowledge data base that served as the basis for the expert system development. The degree of fidelity was tailored to be sufficient to demonstrate the objectives of the project within cost and time constraints

The range of options under MISSION from Defense through Offense were narrowed to encompass the following:

DEFENSE	OFFENSE

Defend
Delaying Operations
Spoiling Attack
Movement to Contact
Meeting Engagement
Demonstration (Supporting Attack - No Enemy Engagement)
Holding Attack (Supporting Attack - With Enemy Engagement)
Hasty Attack
Deliberate Attack

The strength, composition, equipment and logistics portions of the ENEMY and TROOPS (own troops) factors within METT-T were selected to provide a wide range of interactions, including interactions with weather. The options available for the enemy army includes the number of T-80 tanks, Troops, BMP-1 Troop Vehicles, Hind Helicopters, SU25 Jets, and Surface to Air Missiles (SAMs). Options available to the own/friendly troops include the number of M1A1 Tanks, Troops, Bradley M2A1 Troop Vehicles, Apache AH64 Helicopters, A-10 Jets, and SAMs. A simplified definition of the morale and fatigue effects under both enemy and own troops was also derived.

The TERRAIN variable was analyzed to define a set terrain features that could be used by the route planner module to exercise a variety of decision options. The set of parameters included fordable and unfordable rivers, bridges, swamps, and other features which could provide varied situation. Vertical terrain features were generally not included because of complexity. It was decided to include a feature to specify that own/friendly troops or the enemy troops were starting on a hill because of the interaction with mission, i.e., in a defensive mission it is an advantage to be on a hill. Only a limited weather impact was included in the TERRAIN variable, heavy rain is an option because it can impact the availability of air support.

The TIME variable was also defined in a simplified manner. The model requires that the mission to be specified as time critical or not time critical. This simple time factor affects both the mission assessment and status assessment functions.

In summary, the knowledge engineering focused on defining a narrow slice of variables that could be addressed within the project level of effort. However, the knowledge engineering was structured to include all of the parameters within METT-T and to ensure that a wide variety of decision tradeoffs were included.

5.2.2 Hybrid Model Development

A skill-based expert system model was developed for a commander position. As required, alternate model implementations were evaluated. The final model was a hybrid model based on both rule-based and neural network-based modeling techniques. A hybrid approach was chosen because some of the decisions involved in combat are simple enough to employ a rule- based system, whereas no clear cut rules exist for other decisions. In the latter case, rules must be extrapolated from the relevant information. Neural networks are proficient at this type of task.

While they are highly interrelated, there are essentially three modules in the overall model. The first module is the environmental module which permits the user to set up the scenario conditions. This involves specifying terrain, locations of troops, composition of troops and other factors. The second module is the hybrid decision making module. This module is comprised of the neural network and rule based decision modules which represent the core of the commander's decision making tasks. The third module is the route planner module. This module selects a route through the terrain and threat data base. These three modules encompass the six functions identified in the generic model as relevant to situational awareness decision making. These functions are distributed across the three modules, though in some cases the function may involve more than one module. Figure 13 illustrates the relation between the three modules.

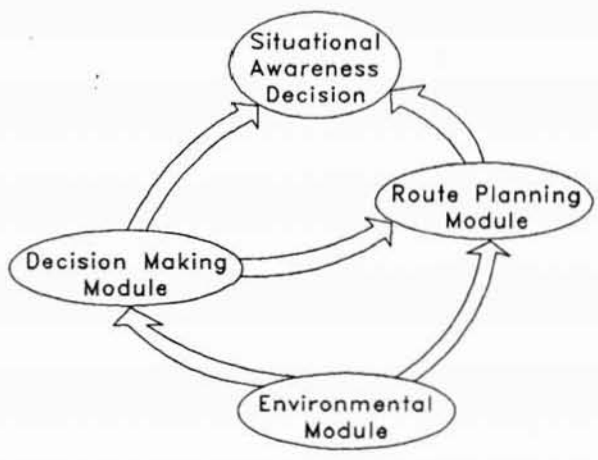

Figure 13 Overview of Expert System Architecture.

It was originally believed that a neural network approach would be best for the route planning module of the project. The neural network approach has the advantages of operating at a faster rate and the ability to generalize to any situation. However, the

network must be trained on a representative sample of all possibilities in order to learn the proper path finding rules. Research on this issue indicated the extreme difficulty in developing an unbiased set of training instances for the neural network. After developing and testing both a neural network and a state space search model it was determined that the latter would be the more efficient of the two. The preliminary model was a rule-based state space search program written in PC Scheme (a Texas Instruments LISP program). Since PC Scheme is an interpreted language, it is somewhat slow and was therefore converted to C to increase its operating speed.

5.2.2.1 Environmental Module.

The tactical environment model, within which the situational awareness expert system model operates, permits the user to build the tactical situation for each exercise in a free plan manner. The user is provided a 6k by 6k gaming area broken into 300 meter square blocks. The user builds the terrain for the exercise by locating rivers, swamps, roads and ditches on the playing area. No positive vertical terrain features were incorporated in the "proof-of-concept" implementation other than being able to place the starting points for each force/target on a hill [this impacts the tactical decision making]. Additional details of the terrain include making portions of the river fordable or unfordable and the placement of bridges across the river.

Tactical aspects of the environment specified by the user are the location and composition of the two opposing forces/targets and the location of threats on the gaming area. The options for composition of the forces and targets were selected to provide a range of tactical situations which can exercise the situational awareness decision making model. A single type of pop-up threat was included to demonstrate dynamic, real time decision making by the model. All data inputs to the environmental model are input by use of the mouse and keyboard. Additional details of the environmental model are provided in the discussion of the optimum route planner module. Figure 14 illustrates part of the graphic scenario generated in the environmental module.

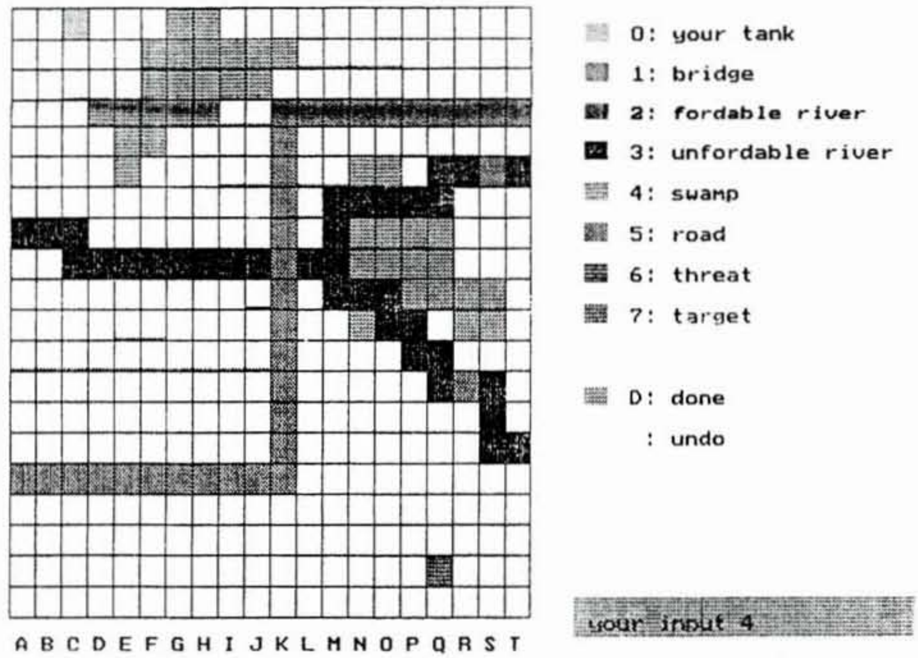

Figure 14 Example of Graphic Environmental Module Scenario.

5.2.2.2 Decision Making Module

Due to the complexity and variety of decision making tasks performed by the tank commander it was determined that a nested neural network approach would be best suited for the task for those portions of the model implemented using neural networks. The decision process of a tank commander was divided into submodules including, among others, composition (force ratio) assessment, personnel assessment, fuel assessment, threat assessment, route assessment, and a final situation assessment decision. Figure 15 illustrates the simplified overall structure of the decision making module. Consultation with a subject matter expert led to the determination of the range of values to be used for each variable within the nets. These values were used to train the neural network to implement appropriate decision making rules. The individual networks were then combined into a nested network. Each net or subnet was trained for not less than 5000 iterations over a full or partial data set. The error range achieved for the neural net portion of the demonstration is approximately + or - 5%. Figure 16 illustrates of the personnel rating decision making subnet with appropriate data values. This example is representative of other subnets within this module. While designed to be a narrow slice implementation of the expert system, the resulting nested neural network modules adequately exercise the richness of the METT-T decision making process.

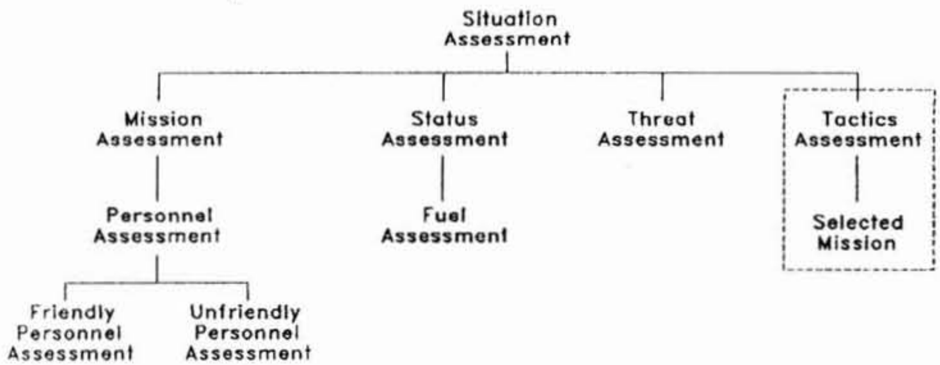

Figure 15 Decision Making Module Architecture.

To provide the inputs to the decision making module, user is are asked to respond to questions about the mission they are about to undertake. The user is given a choice of nine missions ranging from the extreme defensive (i.e., Defend) to the extreme offensive (i.e., Deliberate Attack). Users also provide information about the enemy composition and their own unit's composition, training level, fatigue factor, weather and time criticality. Finally, the user must also provide information on whether their unit is working with another friendly unit, because some missions require coordinated units. The expert system then responds either with either a go or no go decision and calculates the probability of successfully completing the chosen mission given the inputs made by the user. If a go decision is made, the decision making module triggers the route planning module. In the event that the situation changes during the exercise, e.g., a bridge is blown up, the decision making module is triggered to reevaluate the go/no go decision based on the changed situation. All decision making occurs in real time.

The decision making module is also designed to provide feedback to the user. When the decision is a no go or less than a good probability of success, the decision making module provides screen based feedback that identifies the METT-T principle(s) violated by the defined situation. This feedback provides an explanation of why the decision making module arrived at its decision, which can be useful in training exercises. This represents one of the potential training uses of this type of expert system. It permits "what if?" scenarios to be evaluated comparing student decisions against the expert system decision and feedback.

Sample Training Data

Personnel Net

Inputs: Training	Inputs: Morale	Inputs: Fatigue	Expected Output: Troop Efficiency
0 = Green .5 = Regular 1 = Expert	0 = Lost 1 = Won	0 = Fatigued (0 hrs.) .6 = Mild Fatigue (24 hrs.) 1 = Not Fatigued (48 hrs.)	Percent efficiency compared to expert troops (x100)
0	0	0	.2
.5	1	.6	.7
1	0	1	.9
0	0	1	.4
1	1	0	.7
0	0	.6	.3
.5	1	1	.8
0	1	.6	.5
.5	0	.6	.4
.5	1	0	.5
0	1	0	.4
.5	0	0	.3
1	0	.6	.8
1	1	.6	.9
.5	0	1	.6
0	1	1	.6
1	0	0	.6
1	1	1	1

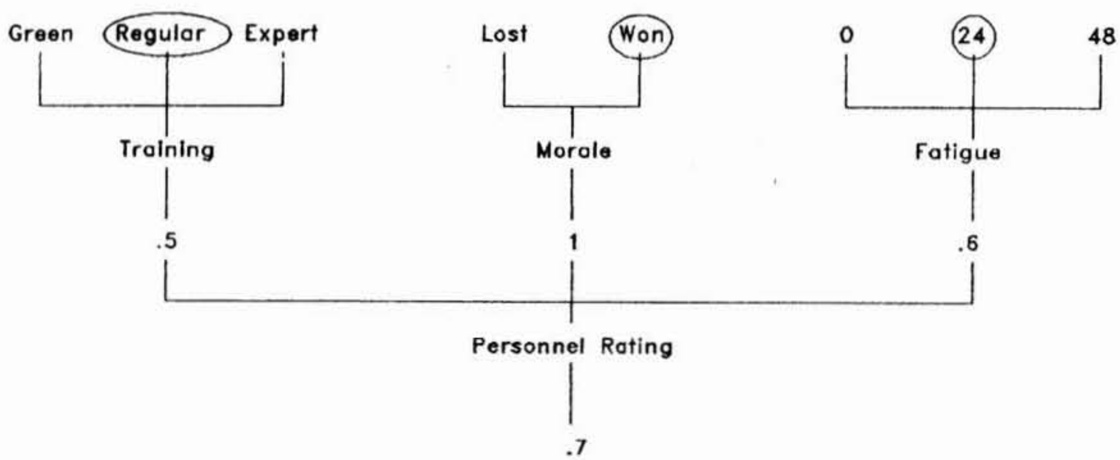

Figure 16 Example - Personnel Rating Subnet.

5.2.2.3 Optimum Route Planner Module

In developing the route planning portion of the project several existing

approaches were examined for applicability. Neural network, algorithmic, dynamic programming and rule- based approaches were all examined. Simple prototype models were developed using neural network and rule-based approaches. The intent of the project was to use neural networks for this model and that remained the long term goal, however, our research indicated that the initial implementation would be more achievable with a rule-based model. The shortcomings with our initial neural network approaches were due to software limitations which, in turn, added an unmanageable complexity to the development of the neural network training data. Our preliminary neural network modeled the route planning as a single large network. With the number of variables involved the total number of potential training cases is huge. Developing a balanced training data set is a complex process. Our initial training sets contained several biases. While the neural network could easily identify the trained situations, its ability to generalize to new situations was not acceptable.

After investigating the alternative approaches to route planning, a state space search program was selected. The operational optimum route planner employs a state space search using heuristic values. The route planner uses the terrain specified through the environmental module, which allows users to create any terrain pattern in a free plan manner for each exercise. The user selects from a list of terrain features using a mouse interface. Terrain features include rivers [fordable and unfordable], swamps, bridges, roads, and threats, and are represented by different colors. After locating terrain features within the 6k by 6k gaming area (broken into 300 meter square blocks), the route planner generates a 20 x 20 danger matrix that is uses to select the route. The module assigns a danger index based on a predetermined threat value table. Taking each danger- weighted cell into account, an optimum route to a given target is then drawn. This route planning algorithm minimizes the overall danger value through the situation. A new feature was added to the original route planner. After the optimum path is drawn the vehicle automatically follows the route. At this point alterations can be made to the terrain, such as the elimination of a bridge along the path or the addition of a pop-up threat. A new path is then instantly calculated and the vehicle changes direction accordingly. Figure 15 illustrates a situation/terrain map generated in the environmental module with the optimum route overlayed on the map.

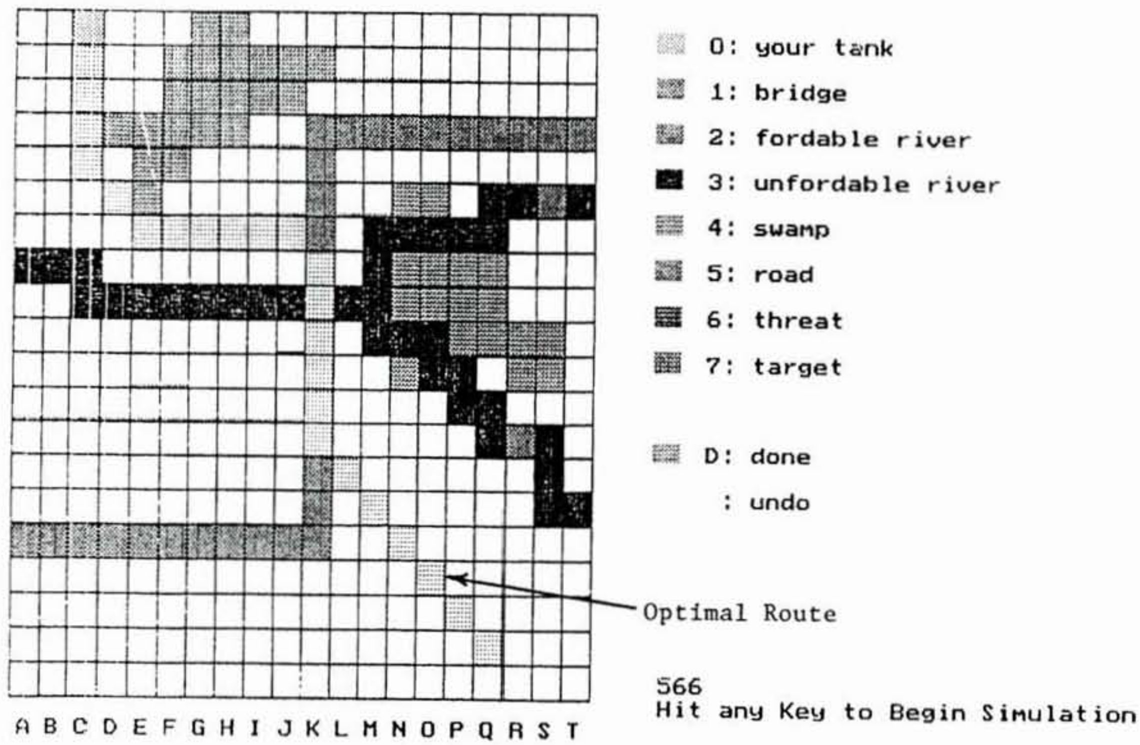

Figure 15. Example of Optimal Route Selection.

6.0 CONCLUSION

This report has presented a comprehensive review and analysis of situational awareness. It has examine the cognitive basis of this important class of behavior and concluded that it is a dynamic pattern recognition process. The practical application of this interpretation to learning and training have also been examined. AS a result, a new view of skill-based learning has been established and a positive approach to facilitating its acquisition and simulation has been proposed.

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APPENDIX A

ANNOTATED BIBLIOGRAPHY

Adaptive Learning

Billman, D., & Heit, E. (1988). Observational learning from internal feedback: A simulation of an adaptive learning method. Cognitive Science, 12, 587-625.
Focused sampling was found to benefit learning increasingly with the complexity of the learning task.

Estes, W. K. (1986). Memory storage and retrieval processes in category learning. Journal of Experimental Psychology: General, 115, 155-174.
The discovery of correlational rules is most difficult when the rule occurs in isolation among a large set of unsystematic cues.

Fisher, M. A., & Zeaman, D. (1973). An attention-retention theory of retardate discrimination learning. In N. R. Ellis (Ed.), International Review of Research in Mental Retardation, Vol. 6. New York: Academic.
The salience of a stimulus feature increases when that feature accurately predicts the feedback. also Zeaman & House (1963).

Holland, J. H. (1973). Adaptation in natural and artificial systems. Ann Arbor: The University of Michigan Press.
The author introduces the notion of adaptive plans which operate by generating and testing rules to use available knowledge to guide learning.

Mackintosh, N. J. (1975). A theory of attention: Variations in the associability of stimuli with reinforcement. Psychological Review, 82, 276-298.
Learning about a single feature is more difficult when that feature covaries with another predictor feature. also Rescorla (1972).

Maratsos, M. P., & Chalkley, M. A. (1980). The internal language of children's syntax: The ontogenesis and representation of syntactic categories. In K. E. Nelson (Ed.), Children's language. New York: Gardner Press.
The basis for learning syntactic categories may be formed by learning co-occurrence properties without external feedback.

Rasmussen, J. (1983). Skills, rules, and knowledge: Signals, signs, and symbols and other distinctions in human performance models. IEEE Transactions on Systems, Man and Cybernetics, SMC-13, 257-266.
Three general levels of behavioral abstraction are identified: Knowledge-based, Rule-based, and Skill-based behaviors.

Rescorla, R. A. (1972). Informational variables in Pavlovian conditiong. In G. H. Bower (Ed.), The psychology of learning and motivation. New York: Academic.

see Mackintosh (1975).

Trabasso, T., & Bower, G. H. (1968). Attention in learning. New York: Wiley.
Subjects in a simple learning task displayed attentional limits but did not learn how to allocate attention. Instead subjects sampled features independently from trial to trial.

Zeaman, D., Campione, J., & Allen, M. (1970). Opposing effects of redundancy in retention of a verbal discrimination task Journal of Verbal Learning and Verbal Behavior, 9, 607-613.
The learning benefits from redundant relevant cues depends on the relation to irrelevant cues.

Arousal and Stress

Duffy, E. (1962). Activation and behavior. New York: Wiley.
Different levels of alertness are associated with EEG differences. also Lindsley (1951).

Easterbrook, J. A. (1959). The effects of emotion on cue utilization and organization of behavior. Psychological Review, 66, 183-201.
Increased arousal restricts the range of environmental events that could be processed.

Frankenhauser, M. (1975). Sympathetic-adrenal medullar activity, behavior, and the psycho-social environment. In P. H. Venebles & M. J. Christie (Eds.), Research in psychophysiology. London: Wiley.
The adrenal hormonal system plays a functional role in regulating task performance.

Hockey, G. R. J. (1970). Changes in attention allocation in a multi-component task under loss of sleep. British Journal of Psychology, 61, 473-480.
Stress causes "tunneling of attention" when monitoring multi-element displays.

Lindsley, D. B. (1951). Attention consciousness, sleep and wakefulness. In J. Field, H. W. Magoun, & V. E. Hall (Eds.), Handbook of physiology (vol. 3). Baltimore: Williams & Wilkins. see Duffy (1962).

Posner, M. I. (1978). Chronometric explorations of mind. Hillsdale, N. J.: Erlbaum.
Stimuli that increases arousal lead to faster, less accurate responses.

Selye, H. (1956). The stress of life. New York: McGraw-Hill.
Physiological stress can occur without the individual being aware of it or feeling any unpleasantness or pain.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit formation. <u>Journal of Comparative Neurology of Psychology</u>, <u>18</u>, 459-482.
The Yerkes-Dodson law states that performance is associated with arousal in an inverted U-shaped relation, and the optimum level of arousal is inversely related to task difficulty.

<u>Auditory Perception</u>

Cutting, J. E. (1976). Auditory and linguistic processes in speech perception: Inferences from six fusions in dichotic listening. <u>Psychological Review</u>, <u>83</u>, 114-140.
Illusory conjunctions are formed when voicing switches its apparent location and recombines with features of another phoneme.

Eimas, P. D., & Corbit, J. D. (1973). Selective adaptation of linguistic feature detectors. <u>Cognitive Psychology</u>, <u>4</u>, 99-109.
Voicing (one of the basic features distinguishing phonemes) can be independently adapted.

Huttonlocher, J. (1968). Constructing spatial image: A strategy in reasoning. <u>Psychological Review</u>, <u>75</u>, 550-560.
In order to understand verbal premises, people sometimes transform them into visuospatial images.

Lisker, L., & Abramson, A. S. (1967). The voicing dimension: Some experiments in comparative phonetics. In Proceedings of the Sixth International Congress of Phonetic Sciences, Prague.
The particular instantiation of voicing delay depends both on the phoneme to which it belongs and on its context.

Savin, H., & Bever, T. (1970). The nonperceptual reality of the phoneme. <u>Journal of Verbal Learning and Verbal Behavior</u>, <u>9</u>, 295-305.
Whole syllables were detected faster than the initial phoneme of the same syllable.

<u>Context Effects</u>

Ashcraft, M. (1976). Priming and property dominance effects in semantic memory. <u>Memory and Cognition</u>, <u>4</u>, 490-500.
Context effects were found even when related words were separated by several trials.

Balota, D. A., & Rayner, K. (1983). Parafoveal visual information and semantic contextual constraints. <u>Journal of Experimental Psychology: Human Perception</u>

<u>and Performance</u>, <u>9</u>, 726-738.
The relationship between contextual constraints and parafoveal preview may vary with the amount of time the reader has to think about the context before the preview appears.

Fischler, I. (1977). Associative facilitation without expectancy in a lexical decision task. <u>Memory and Cognition</u>, <u>3</u>, 18-26.
Related word combinations presented simultaneously, occurring after a long sequence of unrelated trials, produced facilitated language processing.

Haber, L. R., & Haber, R. N. (1983). Perceptual processes in reading: An analysis-by-synthesis model. In F. I. Pirozzolo & M. C. Wittrock (Eds.), <u>Neuropsychological and cognitive processes in reading</u>. New York: Academic.
see Hochberg (1970).

Haber, R. N. (1976). Control of eye movements during reading. In R. A. Monty & J. W. Senders (Eds.), <u>Eye movements and psychological processes</u>. Hillsdale, N. J.: Erlbaum. see Hochberg (1970).

Hochberg, J. (1970). Components of literacy: Speculations and exploratory research. In H. Levin & J. P. Williams (Eds.), <u>Basic studies on reading</u>. New York: Basic Books.
The combination of parafoveal preview and information gained through sentence context provide a large amount of advance knowledge of upcoming text. also Hochberg (1976), Haber (1976), Haber & Haber (1983).

Hochberg, J. (1976). Toward a speech-plan eye-movement model of reading. In R. A. Monty & J. W. Senders (Eds.), <u>Eye movements and psychological processes</u>. Hillsdale, N. J.: Erlbaum. see Hochberg (1970).

McClelland, J. L., & O'Regan, J. K. (1981). The role of expectations in the use of parafoveal visual information in reading. <u>Journal of Experimental Psychology: Human Perception and Performance</u>, <u>7</u>, 634-644.
Contextual constraints and preview information combine to prepare processing of target words more effectively than would be expected by adding the individual contributions of the two processes. see also Paap & Newsome (1981).

Paap, K. R., & Newsome, S. L. (1981). Parafoveal information is not sufficient to produce semantic or visual priming. <u>Perception and Psychophysics</u>, <u>29</u>, 457-466. see McClelland & O'Regan (1981).

Schvaneveldt, R. W., & McDonald, J. E. (1981). Semantic context and the encoding of words: Evidence for two modes of stimulus analysis. <u>Journal of</u>

Experimental Psychology: Human Perception and Performance, 7, 673-687.
Codes at the phonological and/or semantic levels influence context effects with feedback going to letter identification.

Schvaneveldt, R. W., & Meyer, D. E. (1973). Retrieval and comparison processes in semantic memory. In S. Kornblum (Eds.), Attention and Performance, IV. New York: Academic Press.
The authors concluded that spreading activation is the mechanism underlying context effects. Activation of one logogen excited other logogens through spread of activation along associated links connecting the logogens.

Tulving, E., & Gold, C. (1963). Stimulus information and contextual information as determinants of tachistoscopic recognition of words. Journal of Experimental Psychology, 66, 319-327.
In addition to parafoveal preview as a means of processing text, sentence context provides clues and places constraints on what can come next.

Tulving, E., Mandler, G., & Baumal, R. (1964). Interaction of two sources of information in tachistoscopic word recognition. Canadian Journal of Psychology, 18, 62-71.
Target words (on a tachistoscope task) that complete a sentence inappropriately increase accuracy of whole report over a wide range of exposure durations.

Zola, D. (1981). Redundancy and word perception during reading. Perception and Psychophysics, 36, 280.
When reading text, individuals tend to fixate for shorter periods on words that were highly predictable in context.

Decision Making

Buch, G. (1984). An investigation of the effectiveness of pilot judgment training. Human Factors, 26(5), 557-564.
Pilots trained in air judgment were less likely to engage in unwise or unsafe flying procedures.

Fischoff, B. (1977). Perceived informativeness of facts. Journal of Experimental Psychology: Human Perception and Performance, 3, 349-358.
Because of an inherent dislike for uncertainty, individuals overestimate the likelihood of their predictions. Expertise does not necessarily reduce the magnitude of biases, or dependence on heuristics.

Gettys, C. F. (1983). Research and theory on predecision processes (Tech. Rep. TR 11-30-83). Norman: University of Oklahoma, Department of Psychology.
Individuals normally underestimate the number of possible hypotheses and generate

only a fraction of possible problem solving actions.

Hick, W. E. (1952). On the rate of gain of information. Quarterly Journal of Experimental Psychology, 4, 11-26.
The Hick-Hyman law [RT = (a + b) Hs] identifies the reaction time to stimuli in terms of a linear function. also Hyman (1953).

Hyman, R. (1953). Stimulus information as a determinant of reaction time. Journal of Experimental Psychology, 45, 188-196.
see Hick (1952).

Johnson, E. M., Cavanagh, R. C., Spooner, R. L., & Samet, M. G. (1973). Utilization of reliability measurements in Bayesian inference: Models and human performance. IEEE Transactions on Reliability, 22, 176-183.
When integrating a number of information sources, individuals tend to treat all sources as equally reliable and fail to devalue sources of poor reliability.

Kahneman, D., Slovic, P., & Tversky, A. (1982). Judgment under uncertainty heuristics and biases. Cambridge, Mass.: Harvard University Press.
Individuals do not accurately use probability data when evaluating alternative hypothesis.

Lester, L. F., & Bombaci, D. H. (1984). The relationship between personality and irrational judgment in civil pilots. Human Factors, 26(5), 565-572.
Personality variables influence the risk taking tendency in pilots.

Mynatt, C. R., Doherty, M. E., & Tweney, R. D. (1977). Confirmation bias in a simulated research environment: An experimental study of scientific inference. Quarterly Journal of Experimental Psychology, 29, 85-95.
Cue-seeking behavior may be guided by the hypothesis that was tentatively chosen, thus individuals find information that confirms what they already believe to be true (confirmation bias).

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. Science, 185, 1124-1131.
Simple or recently experienced hypotheses are more likely to be considered in making a decision because they are more easily remembered (Availability heuristic).

Tversky, A., & Kahneman, D. (1981). The framing of decisions and the psychology of choice. Science, 211, 453-458.
When individuals must make a choice between possible negatives, they tend to choose the riskier, more severe, loss than the certain loss.

Wason, P. C., & Johnson-Laird, P. N. (1972). Psychology of reasoning: Structure

and content. London: Batsford.
Given the possibility of confirmation bias, the best way to test a hypothesis is to seek information which disconfirms it.

Wickens, C. D. (1984). Engineering psychology and human performance. Columbus, Ohio: Charles F. Merrill.
Decision makers may not process all available information.

Wright, R. E. (1974). Aging, divided attention, and processing capacity. Journal of Gerontology, 36, 605-614.
When under time stress, individuals do not process all information.

Ecological Theory

Gibson, J.J. (1979). An ecological approach to visual perception. Boston: Houghton Mifflin.
Percpetual behavior involves the search for patterns of invariance in the environment.

Human Performance

Broadbent, D. E. (1957). Effects of noise on behaviour. In C. M. Harris (Ed.), Handbook of noise control. New York: McGraw-Hill.
In order to detect brief interruptions in information processing, tasks should present information either infrequently and unpredictably or at very high rates and the task should be continued over long periods of time.

Broadbent, D. E. (1958). Perception and communication. London: Pergamon.
Short-term changes in efficiency in task performance can be compensated for by an individual's ability to self-regulate behavior.

Broadbent, D. E. (1971). Decision and stress. London: Academic.
The pattern of errors found in a task requiring subjects to recall brief lists of items was used to infer the structure of the short-term/long-term memory relationship, the nature of coding used in storage, and the capacity of the system.

Fitts, P. M. (1966). Cognitive aspects of information processing, III: Set for speed versus accuracy. Journal of Experimental Psychology, 71, 849=957.
Situations that employ decision speed as the dependent variable are subject to the speed/accuracy trade off.

Mackworth, N. H. (1950). Researches on the measurement of human performance (Medical Research Council Spec. Rep. No. 268). London: HMSO.
In a signal detection vigilance task, the frequency of false alarms and misses

increases after a period of time.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. Psychological Review, 84, 1-66.
Target stimuli (letters) and distracting stimuli processed in parallel lead to a fast reaction time regardless of the number of distracting stimuli.

Intelligent Systems

Davis, B. R. (1985). An associative hierarchical self-organization system. IEEE Transactions on Systems, Man, and Cybernetics, SMC, 15(4), 570-579.
A learning program was developed which discovers conditional rules among a large set of relevant features. The system works on the premise that the presence of one feature is likely given the presence of another.

Schudy, R. (1987). A conceptual framework for intelligent real time information processing. In proceedings of SOAR conference.
The author presents a model of information processing.

Schudy, R., & Corker, K. (1987). A situation-response model for intelligent pilot aiding. In proceedings of SOAR conference.
The situation-response model involves a situation assessment step in which the current situation is recognized in terms of generic situation types. Behavior is driven by procedures previously associated with those situation types.

Simon, H. A. (1969). The sciences of the artificial. Cambridge, Mass.: Massachusetts Institute of Technology Press.
Response shortcuts such as reflexes, sensory-motor control, rule-based behavior, and satisfying increase the speed at which information is processed.

Language Processing

McConkie, G. W., Zola, D., Blanchard, H. E., & Wolverton, G. S. (1982). Perceiving words during reading: Lack of facilitation from prior peripheral exposure. Perception and Psychophysics, 32, 271-281.
It is possible that the effective visual field varies from a maximum of 15 or 16 letters to a minimum of six spaces as a function of variation in concurrent processing demands.

Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. Journal of Experimental Psychology, 90, 227-234.
Lexical decisions about two simultaneously presented words were made faster and

more accurately when the words were related.

Morton, J. (1969). Interaction of information in work recognition. <u>Psychological Review</u>, <u>76</u>, 165-178.
The author proposes a logogen system receiving inputs from a cognitive system, which accesses world and linguistic knowledge and computes and represents information conveyed by text. This allows the target word to become available to perception.

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), <u>Theories in cognitive psychology</u>. Hillsdale, N. J.: Erlbaum.
Priming consists of two components; an attended component which was used to predict and prepare for the target stimulus, and an unattended (automatic) component by which the prime activates pathways and stores codes. The attended component inhibits processing for incorrectly predicted targets, whereas the automatic component is only beneficial to processing.

Rayner, K., McConkie, G. W., & Erlich, S. (1978). Eye movements and integrating information across fixations. <u>Journal of Experimental Psychology: Human Perception and Performance</u>, <u>4</u>, 529-544.
Parafoveal previewing may depend on the processing load imposed by the reading material. When reading text, individuals must recognize and process the material being fixated, the processing of parafoveal material is of secondary concern. also Rayner, McConkie, & Zola (1980).

Rayner, K., McConkie, G. W., & Zola, D. (1980). Integrating information across fixations. <u>Cognitive Psychology</u>, <u>12</u>, 206-226.
see Rayner, McConkie, & Erlich (1978).

Shaffer, W. O., & LaBerge, D. (1979). Automatic semantic processing of unattended words. <u>Journal of Verbal Learning and Verbal Behavior</u>, <u>18</u>, 413-426.
Words that were presented incidentally and actively ignored by subjects still caused semantic priming effects.

Stanovich, K. E., & West, R. F. (1979). Mechanisms of sentence context effects in reading: Automatic activation and conscious attention. <u>Memory and Cognition</u>, <u>7</u>, 77-85.
Automatic spread of activation through the logogen system and active expectations based on predictions of upcoming text causes the cognitive system to exert its influence on language processing. also Stanovich & West (1981).

Stanovich, K. E., & West, R. F. (1981). The effect of sentence context on ongoing word recognition: Tests of a two-process theory. <u>Journal of Experimental Psychology: Human Perception and Performance</u>, <u>7</u>, 658-672.

see Stanovich & West (1979).

Memory Organization and Perception

Conrad, R. (1964). Acoustic confusion in immediate memory. British Journal of Psychology, 55, 75-84.

In short-term memory tasks, individuals tend to transform visual stimuli into verbal labels so that they can rehearse them.

Ebbeson, E. D., & Konecki, V. (1980). On external validity in decision-making research. In T. Wallsten (Ed.), Cognitive processes in choice and decision making, Hillsdale, N. J.: Erlbaum.

Because of differences in long-term memory storage, expert pilots can more automatically interpret patterns of environmental cues and reach a more rapid and accurate assessment than novices. also Phelps & Shanteau (1978).

Phelps, R. H., & Shanteau, J. (1978). Livestock judges: How much information can an expert use. Organizational Behavior in Human Performance, 21, 209-219.

see Ebbeson & Konecki (1980).

Pitz, G. F. (1965). Response variability in the examination of relative frequency. Perceptual and Motor Skills, 21, 867-873.

Individuals tend to overestimate the frequency of very rare positive events.

Slovic, P. (1984). Facts vs. fears: Understanding perceived risk. Paper presented at a Science and Public Policy seminar.

Highly salient and well publicized events are overestimated whereas less salient events are underestimated.

Motor Skills

Archer, E. J. (1958). Effect of distribution of practice on a component skill of rotary pursuit tracking. Journal of Experimental Psychology, 56, 427-436.

Some motor skills are performed less well under massed than under distributed practice.

Danaher, J. W. (1980). Human error in ATC system operations. Human Factors, 22, 535-546.

Reaction times are faster when the individual is prepared for a possible stimulus.

Koonce, J. M., Chambliss, D. J., & Irion, A. L. (1964). Long term reminiscence in the pursuit rotor habit. Journal of Experimental Psychology, 67 498-500.

Performance on motor skills tasks two years following five minutes of concentrated practice was better than at the end of the initial five minutes.

Pachella, R. G. (1974). The interpretation of reaction time in information processing research. In B. H. Kantowitz (Ed.), Human information processing: Tutorials in performance and cognition. Hillsdale, N. J.: Erlbaum.
The chance of making errors increases as one becomes more pressured by time (speed-accuracy trade-off). also Wickelgren (1977).

Wickelgren, W. A. (1977). Speed-accuracy tradeoff and information processing dynamics. Acta Psychologica, 41, 67-85.
see Pachella (1974).

Perceptual Organization

Attneave, F. (1955). Symmetry, information and memory for patterns. American Journal of Psychology, 68, 209-222.
Subjects identified symmetrical stimuli (patterns) more accurately than asymmetrical ones.

Bell, H. H., & Handel, S. (1976). The role of pattern goodness in the reproduction of backward masked patterns. Journal of Experimental Psychology: Human Perception and Performance, 2, 139-150.
'Good' patterns are perceived more quickly and therefore are more likely to be encoded even when under conditions of poststimulus masking.

Bregman, A. (1977). Perception and behavior as composition of ideals. Cognitive Psychology, 9, 250-292.
To perceive constancies of physical properties, two or more physical dimensions combine to specify psychological attributes of real-world objects.

Bricker, P. D. (1955). The identification of redundant stimulus patterns. Journal of Experimental Psychology, 49, 73-81.
Redundancy of stimuli was detrimental to learning performance.

Checkosky, S. F., & Whitlock, D. (1973). Effects of pattern goodness on recognition time in a memory search task. Journal of Experimental Psychology, 100, 341-348.
The slope of the function between reaction time and memory set size was greater for poor patterns indicating that good patterns are remembered better.

Clement, D. E., & Varnadoe, K. W. (1967). Pattern uncertainty and the discrimination of visual patterns. Perception and Psychophysics, 2, 427-431.
Subjects were significantly faster at discriminating between two 'good' patterns than between two 'poor' patterns.

Deese, J. (1956). Complexity of contour in the recognition of visual form. (WADC Tech. Rep. 56-60). United States Air Force.
Redundancy led to greater discriminability in complex patterns but did so at the expense of increased processing time.

Garner, W. R. (1962). Uncertainty and structure as psychological concepts. New York: Wiley.
Simple, regular, and symmetrical patterns are said to be redundant because the perceiver infers what constraints were used in creating the patterns. also Garner & Clement (1963), Royer & Garner (1966).

Garner, W. R. (1974). The processing of information and structure. Potomac, Md.: Erlbaum.
The author suggests that the quicker response times for good patterns found in the Checkosky and Whitlock (1973) study were perhaps due to the encoding stage of processing.

Garner, W. R., & Clement, D. E. (1963). Goodness of pattern and pattern uncertainty. Journal of Verbal Learning and Verbal Behavior, 2, 446-452.
see Garner (1962).

Garner, W. R., & Sutliff, D. (1974). The effects of goodness on encoding time. Perception and Psychophysics, 16, 426-430.
Replicated the findings of Clement and Varnadoe (1967). In addition it was found that 'good' patterns were perceived and encoded faster than 'poor' ones.

Gilchrist, A. L. (1979). The perception of surface blacks and whites. Scientific American, 240, 112-124.
Discontinuities in light intensity can signal either the real edge of an object or an illumination edge created by a cast shadow.

Gilchrist, A. L. (1980). When does perceived lightness depend on perceived spatial arrangement? Perception and Psychophysics, 28, 527-538.
Different physical dimensions of lightness perception are registered in parallel and are mapped into a combination of psychological values determined by the physical values and by the cognitive rules for pairing them.

Hinton, G. E. (1981). Shape representation in parallel systems. Proceedings of the Seventh International Joint Conference on Artificial Intelligence, 2, 1088-1096.
There exists three sets of interconnected units (retinal features, objects features, and retinal unit mapping into object units) which create the perceptual constancies of physical properties.

McClelland, J. L., & Miller, J. (1979). Structural features in figure perception. Perception and Psychophysics, 26, 221-229.
Facilitation of a recognition task depends on the structural relevance of the target part to the whole. The target was better discriminated in an object context only where it plays a role in defining the object.

Oyama, T. (1974). Perceived size and perceived distance in stereoscopic vision and an analysis of their causal relations. Perception and Psychophysics, 16, 175-181.
The perceived dimensions of size and distance are directly determined by both physical variables and are independent of each other.

Pomerantz, J. R. (1977). Pattern goodness and speed of encoding. Memory and Cognition, 5, 235-241.
'Good' patterns are not perceived quicker than poor ones, but rather are processed better due to the memory component of processing.

Pomerantz, J. R. (1981). Perceptual organization in information processing. In M. Kubovy & J. R. Pomerantz (Eds.), Perceptual Organization. Hillsdale, N. J.: Erlbaum.
Subjects labeled 'good' dot patterns those that yield fewest alternative organizations.

Pomerantz, J. R., Sager, L. C., & Stoever, R. G. (1977). Perception of wholes and their component parts: Some configural superiority effects. Journal of Experimental Psychology: Human Perception and Performance, 3, 422-435.
Whole figures create new emergent features which are easier to discriminate than the original target features. Emergent features may be directly registered by specialized feature detectors in the early stages of processing.

Royer, F. L., & Garner, W. R. (1966). Response uncertainty and perceptual difficulty of auditor temporal pattern. Perception and Psychophysics, 1, 41-47.
see Garner (1962).

Wallsten, T. S., & Barton, C. (1982). Processing probabilistic multidimensional information for decisions. Journal of Experimental Psychology: Learning, Memory, and Cognition, 8(5), 361-383.
Individuals tend to focus attention on physically salient cues instead of ones that are most reliable.

Weisstein, N., & Harris, C. S. (1974). Visual detection of line segments: An object-superiority effect. Science, 186, 752-755.
Subjects were better able to recognize lines of particular orientation when they were

embedded in meaningful three-dimensional drawings than when presented with haphazard lines. Thus perception of the whole affected the perception of the parts.

Problem Solving

Kahneman, D., Slovic, P., & Tversky, A. (1982). Judgment under uncertainty: Heuristics and biases. Cambridge, England: Cambridge University Press.

Problem solvers use heuristics to help them reach a diagnosis with little mental effort. also Rasmussen (1981).

Rasmussen, J. (1981). Models of mental strategies in process plant diagnosis. In J. Rasmussen & W. B. Rouse (Eds.), Human detection and diagnosis of system failures. New York: Plenum.

see Kahneman, Slovic, & Tversky (1982).

Production Systems

Anderson, J. R. (1980). Cognitive Psychology and its implications. San Francisco: Freeman.

With practice more and more complex situations come to be recognized as a unique pattern.

Skill Learning

Allard,F., Graham, S., & Paarsalu, M. E. (1980). Perception in sport: Basketball. Journal of Sport Psychology, 2, 14-21.

Skilled basketball players were better than others at recalling player positions in structured settings, but not in unstructured settings. Apparently, chunking of elementary components into larger patterns is one important aspect of skill learning.

Card, S. K., Moran, T. P., & Newell, A. (1980). Computer text-editing: An information processing analysis of a routine cognitive skill. Cognitive Psychology, 12, 32-74.

By breaking an editing task into its constituent parts and assigning values to each part, the authors were able to predict the efficiency of different methods, thus enabling them to select the best system.

Chase, W. G., & Simon, H. A. (1973). The mind's eye in chess. In W. G. Chase (Ed.), Visual information processing. New York and London: Academic.

In a task requiring the memorization of chess piece placement, master chess players remembered significantly more positions than the class A or novice players when the pieces were placed in a real game setting, but not when placed at random. This was apparently due to the master's extensive practice in acquiring configural chess patterns and ability to store larger chunks in short-term memory.

Crossman, E. R. F. W. (1959). A theory of the acquisition of speed-skill. Ergonomics, 2, 153-166.
In the learning process, time-saving methods are more likely to be selected, therefore learning is the gradual increase in the probability of methods that minimize total time.

Hunter, I. M. L. (1968). Mental calculation. In P. C. Wason & P. N. Johnson-Laird (Eds.), Thinking and reasoning. Baltimore, Md.: Penguin.
One subject's ability to recall long strings of digits may be due to a storage of number facts and unitization of digits based on these facts.

Newell, A., & Rosenbloom, P. S. (1981). Mechanisms of skill acquisition and the law of practice. In J. R. Anderson (Eds.), Cognitive skills and their acquisition. Hillsdale, N. J.: Erlbaum.
As the basis of their chunking model of skill acquisition, the authors propose that with practice one can recognize briefly exposed chunks (words) better than the individual components (single letters). Higher-level chunks cannot be learned until lower-level ones are learned. The authors power law of learning states that the logarithm of reaction time decreases linearly with the logarithm of the number of practice trials.

Reicher, G. M. (1969). Perceptual recognition as a function of meaningfulness of stimulus material. Journal of Experimental Psychology, 81, 275-280.
Words are more quickly recognized than letters because the word as a whole is represented by a higher level code which when triggered by the constituent parts activates the output.

Woodworth, R. S., & Schlosberg, H. (1954). Experimental psychology (Rev. ed.). New York: Holt, Rinehart, & Wilson.
Depending on the size of the task to be learned, the individual may or may not have been able to save time and energy by learning the task as a whole as opposed to learning and integrating the parts.

Visual Language

Carpenter, P. A., & Just, M. A. (1975). Sentence comprehension: A psycholinguistic model of sentence verification. Psychological Review, 82, 45-73.
Subjects in sentence-picture verification tasks translate both verbal description and visual pictures into abstract representations for comparison. also Carr & Bacharach (1977), Clark & Chase (1972).

Carr, T. H., & Bacharach, V. R. (1977). Encoding and performance in sentence verification under varying memory load. Memory and Cognition, 5, 590-596.

see Carpenter & Just (1975).

Clark, H. H., & Chase, W. G. (1972). On the process of comparing sentences against pictures. Cognitive Psychology, 3, 472- 517.
see Carpenter & Just (1975).

Warren, R. E. (1972). Stimulus encoding and memory. Journal of Experimental Psychology, 94, 90-100.
Stroop color naming took longer when the target word followed an associated prime. Irrelevant semantic relationships interfered with the color naming task.

Visual-Spatial Skills

Akin, O. (1982). The psychology of architectural design. London: Pion.
Architects recalled building plans pattern by pattern and in hierarchical order.

Anderson, J. R. (1982). Acquisition of cognitive skill. Psychological Review, 89, 369-406.
Acquisition of complex cognitive tasks involves learning procedures by acquiring facts and converting them into production rules. The number of production rules and time needed to apply each of them decreases with practice approximating the power law.

Charness, N. (1979). Components of skill in bridge. Canadian Journal of Psychology, 33, 1-50.
Expertise (e.g. bridge, chess) depends partly on the ability to quickly recognize patterns because patterns are associated with procedural knowledge about strategies for good performance. also Engle & Bukstel (1978).

Chase, W. G., & Ericsson, K. A. (1982). Skill and working memory. In G. Bower (Ed.), The psychology of learning and motivation (vol. 16). New York: Academic.
Experts can retain information related to their respective field far in excess of the normal limits of short-term memory.

Chase, W. G., & Simon, H. A. (1973). Perception in chess. Cognitive Psychology, 4, 55-81.
Master chess players outperformed weaker players at a position recall task because the more skilled players are able to recognize patterns from experiences which are not available to the less experienced players.

de Groot, A. D. (1966). Perception and memory versus thought: Some old ideas and recent findings. In B. Kleinmuntz (Ed.), Problem solving: Research, method, and theory. New York: Wiley.
Master chess players were far better at recalling the position of chess pieces than

weaker players due to their superior skill at visual memory.

Egan, D. E., & Schwartz, B. J. (1979). Chunking in recall of symbolic drawings. Memory and Cognition, 7, 149-158.
After just a brief period of exposure, electronics technicians were superior at recalling circuit diagrams.

Eisenstadt, M., & Kareev, Y. (1975). Aspects of human problem solving: The use of internal representations. In D. A. Norman & D. E. Rumelhart (Eds.), Exploration in cognition. San Francisco: Freeman.
Subjects were better able to recall patterns (stones on a game board) typical of the game 'Go' rather than 'Gomoku' when they believed a 'Go' pattern was presented.

Engel, R. W., & Bukstel, L. (1978). Memory processes among bridge players of differing expertise. American Journal of Psychology, 91, 673-690.
see Charness (1979).

Newell, A., & Rosenbloom, P. S. (1981). Mechanisms of skill acquisition and the law of practice. In J. R. Anderson (Eds.), Cognitive skills and their acquisition. Hillsdale, N. J.: Erlbaum.
The power law of practice [log (T) = log (B) - a log (N)] is true for a wide variety of skilled tasks. Since the rate of learning decreases as practice increases, the authors suggest that the power law of learning is generated by a learning process that includes a mechanism that continually slows down the rate of learning. In addition, the chunking theory of learning was developed and states that individuals gradually learn patterns and their associated responses.

Rayner, E. H. (1958). A study of evaluative problem solving. Part 1: Observations on adults. Quarterly Journal of Experimental Psychology, 10, 155-165.
This study examined the learning process which leads to master-level proficiency as a result of practice.

Reitman, J. (1976). Skilled perception in Go: Deducing memory structures from inter-response times. Cognitive Psychology, 8, 336-356.
Master 'Go' players exhibited superior recall for meaningful stone positions and much poorer recall on random positions. This finding was similar to that of Chase and Simon (1973).

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