COMPARING THE COGNITIVE DECISION-MAKING STRATEGIES OF US AND UK NAVAL SONAR OPERATORS

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ABSTRACT

Sonar operators in the US and UK navies chase the same kinds of target and have the same kinds of sonar detection task. However, they use slightly different systems, sometimes with different degrees of success. This joint study, funded by the US Office of Naval Research, is using a Cognitive Task Analysis of decision strategies to help identify what are the performance differences between US navy and UK navy novices and experts.

Using Applied Cognitive Task Analysis (ACTA) as a common tool, researchers in the US & UK are conducting interviews, observations and measurements of individual trainees and experts and of experts operating in teams. The study includes several other levels of analysis, including organizational issues (from tactics to career patterns), technical issues (e.g. levels of automation and interface design), physiological measures (heart rate) and performance measures (process and outcome).

The methods used, progress, and results to date will be presented and discussed.

Introduction/Background

Technological advances have increased the capacity for collecting and fusing raw data into complex displays. The interaction between perceptual and cognitive processes plays a critical role in operator performance (Hanisch, Kramer & Hulin, 1991). There is evidence that suggests that pre-attentive processes and attention control guides, and may enhance, visual search strategies (Treisman, Vieira & Hayes; Bellenkes, Wickens & Kramer, 1997). For example, studies have shown the effects of perceptually salient features, i.e. features that "pop out" of a display. (Treisman & Gormican, 1988; Treisman, Vieira & Hayes, 1992; Wang & Cavanagh, 1994) However, performance is the result of the integration of bottom-up and top-down processes. We predict that the level of performance reflects both the user's mental model (based on knowledge, training and experience) and the perceptual saliency of the features presented in the display. Experience plays a pivotal role in the development of the user's mental model and in the ways in which they use perceptual cues more effectively. In order to achieve an understanding of task performance, one must evaluate both the cognitive and perceptual processing strategies employed by the user (Treisman et al., 1992; Hanisch, Kramer & Hulin, 1991).

Addressing Training and Performance Differences

Sonar operators in the US and UK navies share a similar task. Namely, their task is to chase the same kinds of target and have the same kinds of sonar detection task. However, they use slightly different systems and different ways of working – and sometimes achieve different degrees of success. This joint study, funded by the US Office of Naval Research, is using a Cognitive Task Analysis of decision strategies to help identify what are the performance differences between US navy and UK navy operators – experts and novices.

The differences in performance could be due to any of a wide range of factors - the sonar equipment used, the tactics, the way that tasks and teams are organized or the way that the individual operators perform their task. We are using a range of techniques to identify the factors that determine how complex detection and classification decisions are made in demanding military environments – moreover, we aim to identify the factors that differentiate best practice between different navies. The aim of the study is to identify best practice and to make recommendations for the development of training methodologies and display designs that will enhance non-expert performance and training time. The aim of the presentation is to outline the questions we are trying to answer; to identify the methods that we have selected to do this and to report on our progress to date. This study is in its second year and we have plenty of work still to do; and so present results are somewhat sketchy. A critical focus of this study is the examination of cognitive structures used by the operators in each nation. We are using a number of analytical tools and some questions remain as to the best methods to use to isolate some of the factors that affect performance – but conducting a live cognitive task analysis is a key part of that process.

Opportunities are rare for conducting a detailed cognitive task analysis of submarine operator performance. Most endeavours in this area are driven by the design of new systems or by training needs analysis. This may be the first time that an international comparison of expert performance has been conducted with a view to capturing best practice and proposing user-centred solutions in this way.

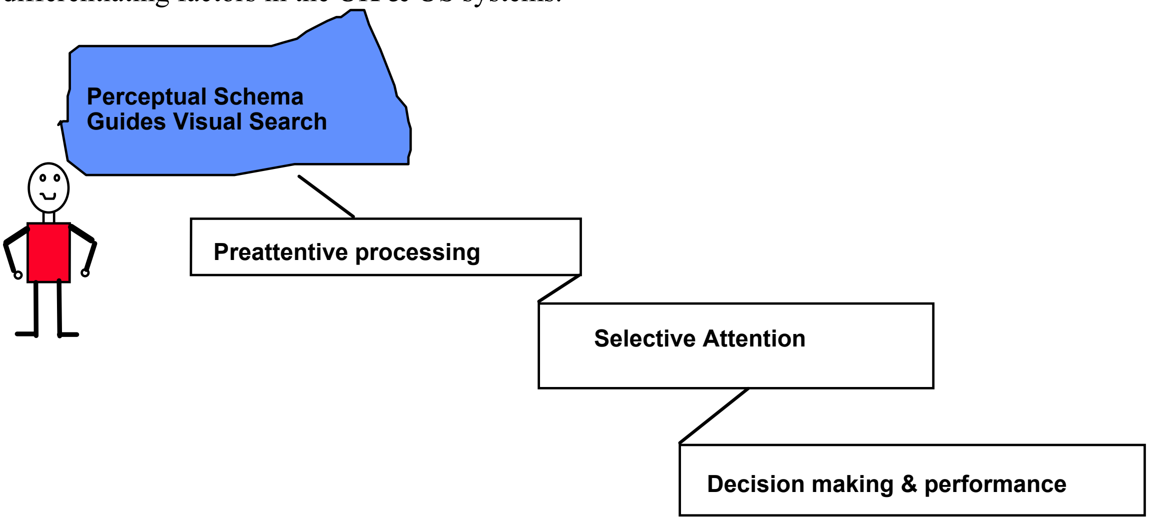
Addressing International Navy Requirements

As a nation, we have high expectations for our Armed Services. We expect our forces to be the best and brightest; to be motivated, well cared for and well trained and, above all, to be effective in combat. But achieving these world-class expectations requires superb organizations, processes, knowledge, and technology not to mention a supply of quality people. Specifically, the **Navy training goal is to achieve expertise in less time**.

The dawn of the Information Age has introduced a wave of change to modern warfare and the way the Navy operates. The accessibility and speed of information, the proliferation of low-cost, highly capable technology, and an increasingly competitive global economy has forced a fundamental shift to a more "network-centric" approach to warfare. Navy training is responding by re-engineering training to a "student-centric" approach to learning that provides more distributed, adaptable, accessible, and deployable training.

Reduced manning and shifts in training

Changes in force structure will mean fewer people to do more complex jobs, combined with the requirement for swift, short-notice response. Emphasis on affordability and readiness is a key to the Navy's training continuum. **Given these goals, we contend that one of the principal benefits of this study will be the development of recommendations that will accelerate the transition of the novice to expert performance levels.** Because there are many distinct differences between the two services that can affect the operator performance, experimental approaches that are sensitive to the similarities and difference have to be developed. Particular issues for our study include recognising the important aspects of operator decision making, fitting individual operator inputs into the team context and highlighting the differentiating factors in the UK & US systems.



Capturing expertise is always a challenge requiring an experimenter to capture the ways in which a domain specific expert uses their knowledge to extract meaningful information from an embedded signal such as a sonar lofargram. However, scientists have provided evidence that cognitive expertise guides pre- attentive processes and demonstrated perceptual processes play a pivotal role in the development of an expert's mental model. For example, it has been shown that expert players perform better because they have mastered the ability to recognize patterns of events (i.e. features) on a chessboard. During the first few seconds of play, chess masters attend specifically to those features that represent new positions (Newell & Simon, 1972). This finding suggests that expert chess masters use their knowledge and recognition of features as cues to guide their visual decision making (deGroot, 1965). Thus, the expert's memory is an array of perceptual sets that represent information that has been indexed/categorized as a unit according to the problem-solving situation with which they are confronted.

Although the study of expertise remains an important topic for the development of enhanced training systems, the need to address cultural and technology differences in training is more often an overlooked issue. However, the development of integrated multi-national teams requires a greater understanding of cultural and technological. This is especially the case when nations are looking toward developing an integrated command and control environment that will support network-centric warfare. Specifically, there is a critical need to develop a common language during the training period that will support the exchange of inter-personal communications, as well as technological communication. That is, as nations move toward international operations there is a critical need to focus on the role of training for the international arena that will secure both expert levels of performance and operational superiority.

We believe that this study is an important first step toward that goal. We contend that a thorough understanding of training techniques, technology and cultural differences is required in order to integrate the skills and knowledge of experts on an individual and team level. A multi-level approach to training will provide a cost-effective means of training available on-demand and just-in-time to ashore and deployed personnel that will support both national and international force operations.

Performance Analysis

Naturalistic Decision Making and Cognitive Task Analysis (CTA)

One of the principal methods of capturing knowledge and information processing strategies used by experts in task performance is cognitive task analyses (CTA). Capturing expertise is an essential step in the design of decision support systems such as command and control display designs. In order to design a usable display system, one must first understand how expert operators approach a task. Specifically, it is important to understand how the operator seeks information presented on a visual display. Cognitive task analysis provides a means of capturing the cognitive component of expertise that is a critical component for designing a usable system or successful training and operations.

Cognitive task analysis includes knowledge elicitation and representation and provides a valuable tool for examining performance with tasks that require cognitive expertise. One important benefit of using CTA is that it affords the opportunity to assess the expert's changing perspective during task performance. This process provides a window to view the expert's use of information in a dynamic setting. For example, the expert operator viewing the lofargram changes his strategy in relation to the dynamic nature of the representations on the display screen.

It has been my privilege to employ a technique for understanding cognitive processing that provides a means of extrapolating different approaches used by expert during task performance. Namely, "Naturalistic decision making" (**NDM**) is used to describe the way people use their experience to make decisions in field settings (Klein, 1998). NDM has been applied to the processes and strategies employed among firefighters, emergency room staff, pilots and military commanders. In contrast to traditional decision paradigms, which focus on outcome, NDM focuses on the way that information influences the onset of the decision event. Critical to this approach is the role of Recognition-Primed Decision-making (RPD) model of NDM, is the fact that expert decision-making is a pattern-recognition process. According to the recognition-primed decision (RPD) model, rapid decisions are made by recognizing a pattern of events and either reacting without considering alternative actions or by taking the time to consider alternative actions (i. e. less effective in time pressured events). In the latter case, the decision-maker considers other courses of action, while he seeks more information to clarify or confirm his interpretation of the situation.

Cognitive task analysis includes knowledge elicitation and representation and provides a valuable tool for examining performance with tasks that require cognitive expertise. One important benefit of using CTA is that it affords the opportunity to assess the expert's changing perspective during task performance. This process provides a window to view the expert's use of information in a dynamic setting. The study includes several levels of analysis, including organisational issues (from tactics to career patterns), technical issues (e.g. levels of automation and interface design), and measures of individual performance (process and outcome) – including some physiological measures (heart rate). Applied Cognitive Task Analysis (ACTA){1} is being used as a common tool in both the US & UK studies, but we are also conducting interviews, observations and measurements of individual trainees and individual experts and of experts operating in teams. Our approach to trying to answer these questions, includes the following: addressing a common set of problems (i.e. target classification & TMA location); using the same CTA approach (ACTA) with a Simulation Interview based upon a common scenario; complementing this with a graphical approach; experimentation using common target stimuli.

Observational Analysis

The US and UK navies have been generous in making Subject Matter Experts, training systems and other facilities available to us. Our study includes observation of how individual novices and experts tackle sonar and TMA tasks. As well as draw upon verbal reports, we can observe and record the steps that they make during target detection and classification to see the differences in process and performance that can arise and to see how they relate to effective performance. We can also collect performance data. As well as observing individual operators ashore, the study will include observation of expert sonar operators in action in command team trainers and at sea.

Decision Analysis Using ACTA, interviews are being conducted with individual trainees and experts to identify the cognitive skills and the cues and strategies that are used in sonar and TMA tasks. This method is flexible and inclusive and is well suited to accommodate the kinds of contextual factors that are important to these tasks and the differences that are a feature of this comparative study. It focuses on the decision-making processes and on the cognitive structures that individuals use. One complementary method being considered is Job Process Charts (JPCs). This provides a simple way of identifying the separate contributions of man and machine to the task processes (Tainsh 1982) {4}. As the US and UK use different systems and may have different degrees of dependency upon man and machine systems or upon individual and team processes to achieve similar tasks, this should be a useful way of highlighting important differences. In line with ACTA procedures, Task Diagrams and data for a Knowledge Audit are being elicited from novice and expert operators. Their normal use is to identify the cognitive structures that are used in a job. With submarine operators, standard operating procedures (SOPs) provide a detailed formal definition of the minimum set of steps and functions that should be executed. SOPs are normally available to all operators during the task and they identify much of what operators *should* do. Part of our task will be to identify what operators actually do. Operators may do less than is recommended; they may execute tasks in a different sequence, and they may use additional cues and responses. They may follow SOPs exactly, but expert operators may weigh and judge items of information differently. As our study includes an examination of how individual novices and experts tackle the sonar tasks, it will highlight the acquisition of cognitive strategies and identify which cues and strategies effective operators use. The scenario for a Simulation Interview is being developed. This will be defined in terms that are equally applicable to tasks that operators from US and UK submarines might execute. The scenario will be used to provide a common context for UK & US CTAs - so that the data from task diagrams, knowledge audits and cognitive demands tables are comparable. The format for the CDT will be amended, as recommended, in order to meet the specific requirements of this study. The changes are to serve two main aims: better to reflect the specific content of this study; and to provide a common format for data collection and reporting that will facilitate comparisons between the results of the parallel studies

Experimental Analysis The experimental analysis will include several components. We want to measure performance in a number of ways and to link these measures with background factors. For example, we will correlate training scores with individual factors such as age and experience. We hope also to link our CTAs to aspects of individual process and outcome in order to generate hypotheses for subsequent testing. We are mindful of the pitfalls of trying to account for differences in individual performance when so many variables are uncontrolled. Therefore we hope to generate a set of standardised stimuli – probably representative submarine sonar signals in different degrees of noise – and analyse the perceptual and cognitive strategies used by US and UK experts and novices in the same task (e.g. target detection).

We are also examining physiological processes during task performance. Masakowski has been measuring the heart rate of trainees during different tasks as a means of identifying the influence of stress on performance. Together with the other sources of qualitative data, this would be the main source of information for recommending alternative, more user-centered, screen displays. We know that some of the screen displays are counter-intuitive – for example, some relative compass bearings are displayed on a linear, rectangular display rather then on a traditional 360° compass rose. In other cases, there is the capacity for operators to display several windows simultaneously, but with limitations on the capacity for them to select and increase the size of windows of interest. Different systems have different degrees of automated aiding and we are in a position to see what effect this has on the cognitive strategies that are used.

The way that the command team utilizes individual operators' inputs may be an additional factor. McDevitt studied a number of sonar teams and found a significant relationship between the use of cognitive procedural rules and performance. As teams became more expert, they used more rules. He found that a test of declarative knowledge (i.e. *knowing* the rules) did not predict team performance. However, after extensive practice (over a 14-day period) teams learned how to *use* more rules in their TMA and this enhanced performance. There was no significant difference in the performance scores in Sonobuoy Localization or in the rules-use in this type of scenario.

Military Analysis The process of translating the research findings into recommendations and changes that will be usable by the US and UK navies we have called military analysis. Initially this will focus on identifying best practice for training and skill development. Subsequently, this will address the design of human machine interfaces – especially to recommend display designs that enhance non-expert performance and training time. A longer-term goal is to design automated training systems that incorporate *expert* decision making strategies in order to enhance training, performance and knowledge management during long term deployment. We hope that the results will lead to a greater understanding of the impact of cultural and technology differences in training, as well as recommendations to improve training techniques that facilitate future multi-national efforts, exercises and operations. We trust that our results will be used by all nations to develop an integrated approach to training. An integrated approach to training is one that will incorporates best practice in techniques, advanced technology and an understanding of the influence of stress and cultural differences on human performance and decision-making in the field. In turn, these should lead to increased team performance and operational superiority