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COGNITIVE TASK ANALYSIS: TECHNIQUES APPLIED TO AIRBORNE WEAPONS TRAINING

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ABSTRACT

This is an introduction to cognitive task analysis as it may be used in Naval Air Systems Command (NAVAIR) training development. The focus of a cognitive task analysis is human knowledge, and its methods of analysis are those developed by cognitive psychologists. This paper explains the role that cognitive task analysis and presents the findings from a preliminary cognitive task analysis of airborne weapons operators. Cognitive task analysis is a collection of powerful techniques that are quantitative, computational, and rigorous. The techniques are currently not in wide use in the training community, so examples of this methodology are presented along with the results.

INTRODUCTION

Cognitive task analysis is an extension of the traditional and rational task analysis with an emphasis on cognition, the process of knowing. The focus of a cognitive task analysis is human knowledge, and the methods of analysis adopted in this study are those developed by cognitive psychologists and applied by Knerr, Morrison, Mumaw, Stein, Sticha, Hoffman, Buede, & Holding (1986); Lesgold, Lajoie, Eastman, Eggan, Gitmore, Glaser, Greenberg, Logan, Magone, Weiner, Wolf, & Yengo, (1986); and Ryder, Redding, Beckschi, & Edwards (1988). This paper explains the role that cognitive task analysis can play in the development of advanced training systems and presents the results of a trial cognitive task analysis using weapon systems operators.

Cognitive task analysis is a collection of powerful techniques used to evaluate knowledge and skill requirements for specific groups of trainees. The term "powerful" is used because these methods are quantitative, computational, and allow a rigorous approach to the study of complex issues related to human expertise. These methods are currently not in wide use in the training community, therefore, several of the methods will be presented in detail.

In order to provide some perspective, it is useful to compare the cognitive approach with Instructional Systems Development (ISD). ISD focuses on the trainee's task performance, while the cognitive approach focuses on the development of expertise. Cognitive task analysis, as shown in Table 1, decomposes knowledge into knowledge structures and mental model; and decomposes cognitive skills into automatic, problem solving, and decision-making skills, encouraging a fine-grained analysis of the knowledge and skills addressed in traditional training development typified by ISD.

Knowledge traditionally refers to the declarative or conceptual portion of expertise. Skills, on the other hand, are generally thought of as the procedures that make up expertise. This paper concentrates on knowledge structures, but it should be noted that there is an equal number of methods and techniques available to analyze mental models and cognitive skills.

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Table 1. ISD versus Cognitive Task Analysis

ISD	Cognitive Task Analysis
Behavior based	Cognition based
Emphasizes performance	Emphasizes expertise
Analyses tasks	Analyses knowledge & skills
Evaluates training effectiveness	Evaluates development of expertise
Addresses training objectives	Addresses skill acquisition

KNOWLEDGE STRUCTURES

In the context of a cognitive task analysis, knowledge structures are the concepts required to perform a job and the organization of these concepts in memory. It is important that designers of training devices understand how novices and experts of specific domains organize knowledge in memory. Such development may be the key to accessing proficient, as opposed to error-prone, human performance by relating new information to the trainee's existing knowledge structures.

Knowledge structures may be represented in a number of different ways for analysis. Multidimensional scaling, hierarchical cluster analysis, and network scaling are examples of representations that emphasize different aspects of the knowledge structure. Multidimensional scaling emphasizes meaningful groupings of concepts in a continuous space. Hierarchical cluster analysis represents concepts as terminal branches in a tree structure showing clusters as well as their hierarchical ordering. Network scaling uses a flexible form of representation where the concepts are nodes and their interrelation is represented by the connecting links. Both hierarchical cluster analysis and network scaling were used in this preliminary cognitive task analysis.

PRELIMINARY COGNITIVE TASK ANALYSIS

The immediate objective of this study was to determine which of several cognitive task analysis techniques would be appropriate for the analysis of weapons operators' knowledge structures. The specific training problem deals with the WALLEYE operator in the post-launch control sequence. This problem was chosen because operators tend to over correct the weapon on the first actual launch resulting in the weapon falling short of the target. The long-term objective is to identify the critical cognitive elements of expert airborne weapons operators across a range of weapon systems.

In order to examine the post-launch control sequence, two groups of subjects were needed: a group that had launched a WALLEYE, and a group that had trained for the weapon system but not launched it. A total of 8 subjects were selected from the F/A-18 and A-7 pilots at the Naval Air Station, Cecil Field. Four of the subjects had launched a WALLEYE and the remaining 4 had equivalent training and experience, but had not launched the weapon.

Four measures were selected from Lesgold et al. (1986) and Knerr et al. (1986) and modified for the domain of airborne weapons launching. These four measures are shown in Table 2.

Table 2. Measures Evaluated During this Study

Measure	Objective
Sorting measure	categorize task-related concepts
Recall measure	differentiate task structuring
Protocol analysis	categorize operator knowledge
Rating measure	determine difficulty and skill type

Sorting of WALLEYE Related Terms

The sorting measure was tested as an exploratory tool in the analysis of 50 WALLEYE-related terms. These 50 concepts included parts of the WALLEYE as well as procedures in launching the weapon. The underlying assumption of the sorting approach is that individuals organize concepts mentally based on characteristics that can be categorized. Generally, novices will organize concepts by their superficial characteristics while experts organize those concepts by experience-based characteristics. For this study, only experts were being evaluated, and the primary point of interest was a general view of how these terms were organized.

Subjects were given a pack of 50 cards with a concept printed on each. They were asked to sort them into meaningful piles according to how they would normally organize the terms. The results of the sorting were placed in a 50 by 50 matrix based on the distance between each pair of concepts. The content of the matrix was subjected to a number of analyses.

The cluster analysis helped to identify the terms that were sorted consistently by all eight subjects. What follows is a list of these concepts:

airspeed
altitude
dive angle
envelope
headwinds
launch range
launch speed
range to target
sun angle

These results indicate the importance of the pre-flight briefing for the WALLEYE operator. This briefing plays a particularly important role with the WALLEYE for two reasons. First, this weapon with its visual guidance system, is constrained by environmental conditions such as visibility and sun angle, and these constraints must be analyzed at the pre-flight briefing. Secondly, the WALLEYE is used infrequently, the pilots depend on the pre-flight briefing to review the critical aspects of the weapon system. The need for a pre-flight briefing points to a distinction that may affect future training. It appears that there are two kinds of knowledge to be treated differently in the training process. One, the core knowledge, must be maintained in active form; and the other knowledge can be assimilated at a pre-flight briefing. The specifics of these two types of knowledge could be identified by a cognitive task analysis to support future training for airborne weapons operators.

Recall of WALLEYE Subtasks

The second measure evaluated in this study was the recall measure of the subtasks in a dual airplane WALLEYE launch. In this type of launch, the weapon airplane pilot releases the weapon, and the pod airplane pilot corrects the aimpoint following weapon release. The motivation for attempting the evaluation of this second measure was that if the instrument is indeed sufficiently sensitive to differentiate between the two groups, the knowledge structures of those pilots who have launched can be revealed, and the knowledge structures of those who have not, can be enhanced in the course of training.

The subjects were shown a list of subtasks presented in random order. They were asked to recall these terms in the order in which they are normally performed. During this task, the pod pilot's main display on the F/A-18 was the Digital Display Indicator. The pod pilot should slew the WALLEYE as little as possible making sure that the angle of attack of the weapon is not too large.

Background data gathered on the subjects revealed that the two groups had similar backgrounds in terms of formal training, years of aviation experience, and flying hours. However, those who had launched a WALLEYE had about twice as many captive carry flights as those who had not.

In a procedure similar to the one described in Knerr et al. (1986), the beginning time for each subtask was recorded. Two 8 x 8 matrices were prepared, one with the interresponse times of the pilots who had launched an operational WALLEYE, and a second for those pilots who had not launched the weapon. The data from these two matrices were subjected to cluster analysis, and the results for the group who had launched the WALLEYE are shown in Figure 1.

Keeping in mind that the sample size is too small to compute significant differences, there are some interesting and observable distinctions between those who have launched the WALLEYE and those who have not (See Figures 1 and 2). The clusters for the pilots who have launched a WALLEYE are close together. This is a general characteristic of greater expertise. In addition, the pilots that have not launched the WALLEYE (See Figure 2) show a greater tendency to cluster subtasks by their surface features. For example, they group "Cue for good video" with "Cue for release," probably based on the term "Cue."

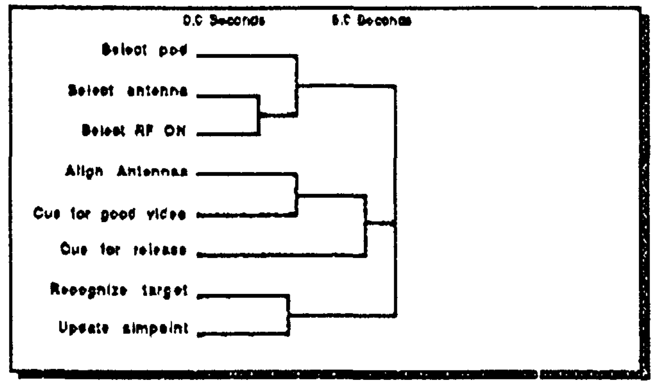

Figure 1. Cluster Analysis of Recall Data for Pilots Who Have Launched a WALLEYE

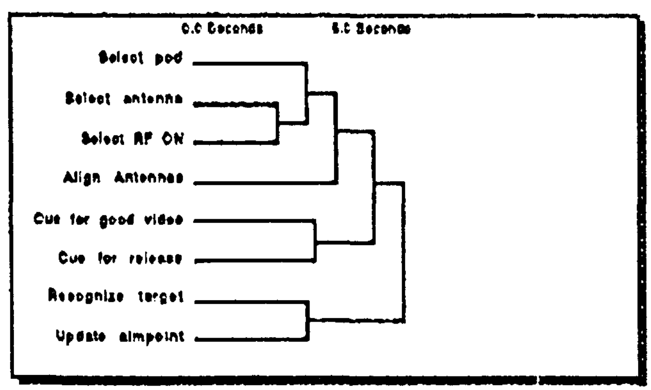

Figure 2. Cluster Analysis of Recall Data for Pilots Who Have Not Launched a WALLEYE

This kind of grouping is typical of pilots without launch experience, and distinguishes them from subjects how have launched the WALLEYE. Subjects of the later category grouped "Cue for good video" with "Align antenna."

Protocol Analysis of Operator Knowledge

In order to determine the types of preflight planning and operation knowledge possessed by WALLEYE pilots,

Table 3. Protocol Coding Scheme

<u>Physical</u> (knowledge about the ability to recognize, name, and describe WALLEYE or its components)
1. label or name of the device
2. controls and indicators
3. external layout and appearance
4. internal layout and appearance

<u>Functional</u> (knowledge of the purpose or role of WALLEYE or components for tracking tasks)
1. function or purpose

<u>Operational</u> (knowledge about how WALLEYE or components work)
1. internal structure and mechanisms
2. external behavior (input-output function)
3. inputs, outputs, and connections
4. power source and requirements
5. how to operate the device to achieve goals

<u>Applicability</u> (knowledge about situations in which WALLEYE or its components are used)
1. measures to control the outcome
2. approaches to the task
3. experience-based suggestions
4. procedures for troubleshooting
5. preventive measures

subjects were asked to describe the target characteristics they take into account, and to emphasize those that would track well and those that would not track well.

Pilot responses to the questions were recorded on tape, transcribed, and separated into propositions, that is statements having fixed truth values. A coding scheme was devised that incorporated the categories used by Lesgold et al. (1986) (based on Weld's (1983) taxonomic levels of device knowledge) with Kieras' (1988) types of knowledge that people have about equipment. The categories are listed in Table 3.

The four major categories, *Physical, Functional, Operational*, and *Applicability*, reflect different types of knowledge that the verbal protocols might reveal in the subject's understanding of pre-flight planning. *Physical* propositions name or describe different WALLEYE components used in planning, for example, the description of WALLEYE as a point target weapon. *Functional* propositions reveal goal-oriented information concerning the purpose of specific components. A functional proposition might reveal an understanding of the goal of pre-flight planning, for example, to determine the expected size of the target. *Operational* propositions reveal knowledge about how the component works, e.g., the subject might explain how sun angle affects the pilot's ability to track a target. The *Applicability* category is situation-oriented. It includes specific approaches to troubleshooting and controlling the outcome of tasks. For example, "I have seen them when we have launched one and it actually hit the shadow on the ground..."

Verbal protocols were discussed and classified according to knowledge types by the two authors with backgrounds in linguistics and psychology. A description of the results is found in Table 4. The coding was done without knowledge of which subjects had actually launched a WALLEYE.

Table 4. Protocol Coding Results: Number of Propositions by Category

	WALLEYE Launch Experience	
Verbal Response Categories	Launch Experience	Launch Naive
Physical	38	18
Functional	7	6
Operational	23	22
Applicability	15	10
Totals	83	56

Examination of the frequencies in each category reveal a higher number of propositions for the subjects who had actually launched a WALLEYE missile. For both groups, functional responses were lowest. The launchexperienced group verbalized the highest amount of physical knowledge as a percentage of the total propositions 46%. Operational knowledge was 28%, and applicability 18%. The launch-naive group had the same ordering except for a higher number of operational (39%), as compared with physical knowledge (32%). The frequency of knowledge categories may be explained by the wording of the question, which may have led subjects to respond by the naming and describing characteristics rather than functional aspects.

Because of the small sample size, no significance tests were computed. Nevertheless, certain differences were evident to the authors as they coded the data. Expert answers were better organized and easier to follow, seeming to reveal a logical thought sequence. By contrast, subjects who had not launched the WALLEYE seemed to respond with vague, bookish examples focusing disproportionately on certain aspects of the process. These subjects were harder to code, their protocols being more difficult to break down into propositions. Based on these patterns, the coders were able to guess at the experience level of 7 out of the 8 subjects.

CONCLUSIONS

This study identified and tested three techniques that can be applied to airborne weapons training. The research is, however, of a preliminary nature and the refinement of the instruments that is now possible will lead to thorough cognitive tasks analysis. Some of these refinements include a more structured recall task where respondents are asked to recall specific subtasks rather than asked to recall all parts of a task and a protocol question that gives more control to respondents in structuring their responses. Cognitive task analysis is a promising series of techniques that will provide valuable data for those analyzing or developing weapons training systems.

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