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**INFORMATION GATHERING AND
DECISIONMAKING UNDER STRESS**

January 1990

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**Personal Service Agreement No. 7314
Prime Contract No. N00014-88-K-0545**

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1a REPORT SECURITY CLASSIFICATION Unclassified		1b RESTRICTIVE MARKINGS N. A.	
2a SECURITY CLASSIFICATION AUTHORITY N. A.		3 DISTRIBUTION/AVAILABILITY OF REPORT Distribution unlimited Approved for public release	
2b DECLASSIFICATION/DOWNGRADING SCHEDULE N. A.			
4 PERFORMING ORGANIZATION REPORT NUMBER(S) ALPHATECH, Inc. TR-454		5 MONITORING ORGANIZATION REPORT NUMBER(S) Same	
6a NAME OF PERFORMING ORGANIZATION ALPHATECH, Inc.	6b OFFICE SYMBOL (If applicable)	7a NAME OF MONITORING ORGANIZATION Office of Naval Research	
6c ADDRESS (City, State, and ZIP Code) Executive Place III 50 Mall Road Burlington, MA 01803		7b ADDRESS (City, State, and ZIP Code) Arlington, VA 22217-5000	
8a NAME OF FUNDING/SPONSORING ORGANIZATION Office of Naval Technology	8b OFFICE SYMBOL (If applicable) Code 222	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N0001488K0545	
8c ADDRESS (City, State, and ZIP Code) Arlington, VA 22217-5000		10 SOURCE OF FUNDING NUMBERS	
		PROGRAM ELEMENT NO 62233N	PROJECT NO RM33M20
		TASK NO	WORK UNIT ACCESSION NO R&T4429010
11 TITLE (Include Security Classification) (U) Information Gathering and Decisionmaking Under Stress			
12 PERSONAL AUTHOR(S) Entin, E. E.			
13a TYPE OF REPORT Technical	13b TIME COVERED FROM 88/09/01 TO 91/08/31	14 DATE OF REPORT (Year, Month, Day) 89/12/15	15 PAGE COUNT 81
16 SUPPLEMENTARY NOTATION Supported by the Office of the Chief of Naval Research Manpower, Personnel, and Training R & D Program			
17 COSATI CODES		18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP	
		Decisionmaking under stress; Information seeking; Cognitive stress; (K) ←	
19 ABSTRACT (Continue on reverse if necessary and identify by block number)			
→ An experiment to investigate the effects of cognitive stress on decisionmaking performance is described. The paradigm involves a single decisionmaker (DM) whose job is to classify a submarine sonar return as coming from a friendly or enemy boat, on the basis of the difference in average pump noise frequency between the two classes. After being given the value of the unknown submarine's measured pump frequency, the subject may classify the submarine or (for a cost) ask for more information. This information is chosen to be either another raw measurement (probe) or the opinion of an automated consultant. Cognitive stress is operationalized through time pressure and an intrusive secondary task. Two distinct subject populations are used: civilian (engineering firm employees and college students) and military (grade O-4 or above). Four independent variables manipulated: stress level, discrimination difficulty, relative information cost between measurement and opinion, and consultant expertise relative to the subject's measurement. <i>Keywords:</i>			
20 DISTRIBUTION AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS		21 ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a NAME OF RESPONSIBLE INDIVIDUAL John J. O'Hare		22b TELEPHONE (Include Area Code) (202) 696-4502	22c OFFICE SYMBOL Code 1142PS

19 ABSTRACT (contd.)

Across all subjects, DMs sought more information in difficult versus easy discrimination conditions, and followed rational cost-benefit decision rules when choosing between probing and consulting. Cost information was the most important determinant of choice, followed by consultant expertise. In high-stress difficult-discrimination conditions, when DMs requested information they favored the easier-to-process opinion of the consultant. For nonmilitary DMs performance improved with high stress but only in easy discrimination conditions. This indicates that stress can provide some arousal stimuli that motivate the DMs to be more vigilant and work harder. Such behavior is more apt to lead to better performance when conditions are easy rather than hard.

Information-seeking behavior was significantly different for the two subject populations. Military DMs did not request information as much as the civilians under stress. When military DMs did request information, they favored the consultant (versus the civilians' favoring the measurement). Neither stress nor discrimination difficulty influenced this choice for the military DMs. It is postulated that these findings reflect the military DMs' experience in making due with limited information and their experience working in teams. These results indicate that one should strongly consider using military subjects when investigating the information-seeking and decisionmaking processes of military DMs.

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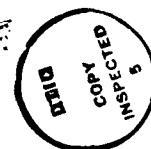
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SECTION 1

INTRODUCTION

Recent tragic events in the Persian Gulf drew sharp attention to human biases and cognitive limitations and underscored the need to better understand the forces that impact decisionmaking and cognitive processes. These events also brought to the forefront the need to examine another variable that can have profound effects on human judgment — stress. The Persian Gulf incident profoundly demonstrated the potential for serious errors of judgment among military personnel operating under conditions of high situational and cognitive stress. In the case of the Vincennes, the crew appeared to exhibit a classic case of confirmatory bias, where all gathered information, regardless of its true disposition, was construed as supporting a predisposed hypothesis of attack. The crew was so sure the enemy would attack that they interpreted all incoming information in light of that bias. Thus, all information appeared to confirm an attack. This "processed" interpretation of the data was the only interpretation transmitted to the captain. The captain sought and considered only the interpreted data of his crew and did not seek any raw measurements of his own, even though this was possible. Based on the available information, the captain acted as only he could, and took hostile actions.

Under more normal conditions such actions would be extremely unlikely. More data correlation would occur, some crew members would challenge the attack bias, and other possible hypotheses and interpretations on the data would be entertained. More than likely, the captain would call for some corroborating independent raw measurements. But, everything was not normal. The attacks earlier that day rested heavily on everyone's mind as did the incident involving the Stark where inaction led to tragedy and disgrace. These thoughts worried and distracted the crew; in addition, many of the crew feared for their safety. There was also a strong impression that decision time was short and growing ever shorter and that a decision

must be made. These are the classic ingredients of stress. We suspect that stress was one of the major contributors to the crew's errors in judgment. Stress can impair a decisionmaker's normal patterns of rational, coherent, and flexible thinking. It also appears that under stress, an individual's immediate memory span is reduced, thinking becomes more simplistic, there is difficulty dealing conceptually with as many categories as when unstressed, and there is a failure to recognize all the options available and to adequately evaluate these alternatives (Janis and Mann, 1977).

1.1 RESEARCH GOAL

The ultimate objectives of this research effort are to improve the understanding of information processing and decisionmaking that arise in the context of command and control of naval battle forces and to develop a quantitative methodology for designing superior organizational structures that support these decision processes. The specific goal of the research is to investigate decisionmaking and information seeking processes in a difficult and stressful environment. The research makes the following contributions:

- Provides quantitative results on how the processes of decisionmaking and information seeking are altered by increases in cognitive stress.
- Provides corroborating findings for an earlier study (Kastner et al., 1989) examining decisionmaking and information seeking.
- Identifies information-seeking strategies and analyzes the errors associated with each.
- Provides a comparison between civilian and military decisionmakers.

1.2 PAST EXPERIMENTAL EFFORT

Kastner et al. (1989) examined the effects of task difficulty, information cost, consultant expertise, and consultant membership (i.e., team member or independent) on the processes of information gathering and decisionmaking. Each of eight subjects assumed the role of an antisubmarine warfare commander and decided if a detected submarine was hostile or friendly. The decision was based on the pump noise signature of the detected submarine. Commanders

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were aware that the friendly submarine's pump noise signature was 370 Hz, the hostile submarine's pump noise signature was either 330 Hz or 360 Hz, and the detection sensors had an inherent error distribution with a standard deviation of 20 Hz. The graphical display used by the subjects is depicted in Fig. 1-1. To aid in the discrimination, decisionmakers could probe (task their sensors for another measurement) or ask the opinion of a knowledgeable consultant. Information requests always incurred a cost. According to the experimental condition, the consultant could be a superior expert to the decisionmaker (i.e., receive better information than the decisionmaker) or equal to the decisionmaker in expertise. Also by condition, the consultant was presented as a team member, where he was aware the decisionmaker had asked for help and had some knowledge of the commander's decisionmaking process, or as an independent, where he had no knowledge of the decisionmaker or his request for help.

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Figure 1-1. Graphical Display Used by Subjects in Kastner et al..

To help guide the experimental design and hypothesis generation, as well as model the decisionmaking task confronting the decisionmakers, Kastner et al. developed the team optimal stopping with communication alternatives (TOSCA) normative model. The TOSCA model is based on an earlier model by Papastavrou and Athans (1986) that is extended to add the probe option. Specifically, TOSCA addresses under what circumstances decisionmakers should stop gathering information and start making decisions, and under what conditions decisionmakers should seek processed information (consultant opinions) rather than raw information (probe measurements). The problem that is solved by the decisionmakers and the TOSCA model is graphically depicted in Fig. 1-2.

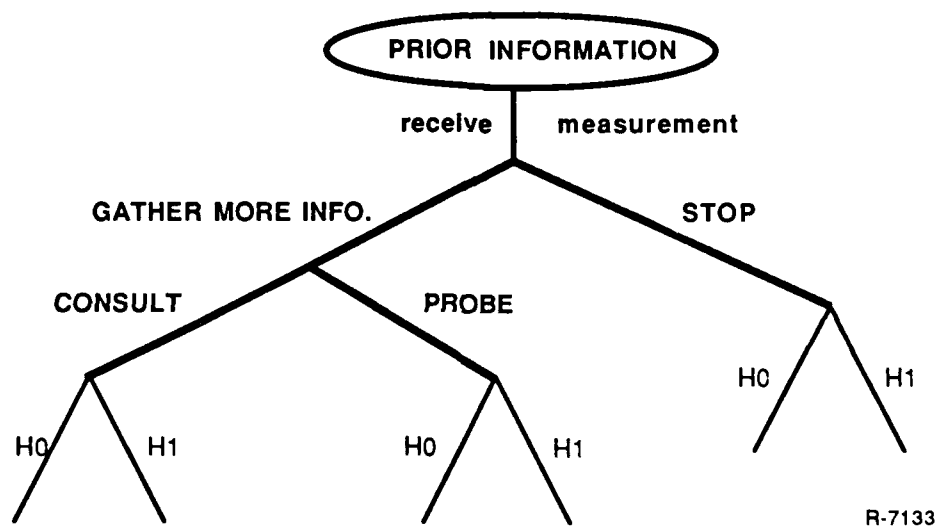


Figure 1-2. The Decisionmaking Problem Addressed by the TOSCA Model.

Figure 1-2 shows that given prior information and a measurement, the decisionmaker must choose whether to stop gathering information and select H_0 or H_1 as correct, or seek more information. If the decision is to collect more information, then the decisionmaker must choose whether to probe for a second measurement or ask for the consultant's opinion. This new information is then folded into the decisionmaker's current estimate to allow selection of H_0 or H_1 . The optimal decision rules employed by the TOSCA model to govern these decisions are characterized as threshold strategies. Figure 1-3 shows how the thresholds are

derived from a set of intersecting expected cost curves, which are derived from detection theory (Van Trees, 1968) and team theory (Marschak and Radner, 1972). One curve determines the cost of stopping and deciding H_1 , while another curve computes the cost of stopping and selecting H_0 . Expected cost curves and the resulting thresholds are also computed for probing and for asking the consultant. Each threshold delineates a decision region. For example, if the initial measurement falls left of the left-most threshold (see Fig. 1-3), the model specifies that the best strategy is to stop gathering information and decide H_1 . Similarly, if the initial measurement is to the right of the right-most threshold, the optimal decision is to stop and decide H_0 . If the initial measurement lies in the region between the two left thresholds or in the region between the two right thresholds, then the optimal strategy is to probe for another measurement. In other words, the cost of probing is worth the expected information gain. Finally, if the initial measurement falls in the region between the two innermost thresholds, then the best strategy is to ask the consultant's opinion. That is, the expected information gain is worth the cost of asking the consultant.

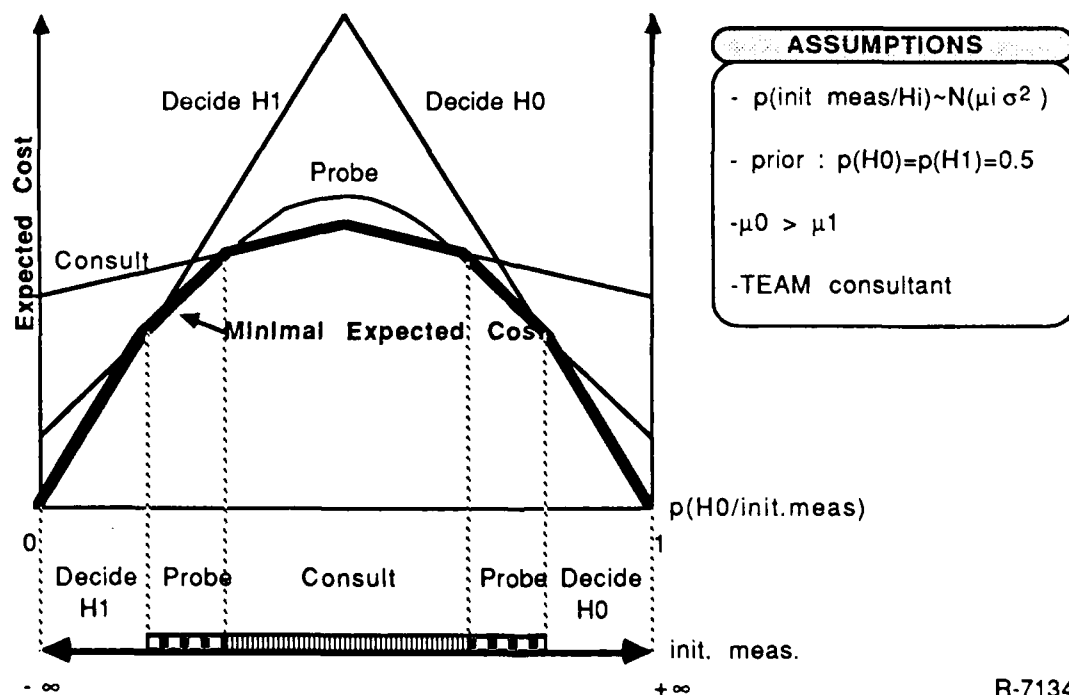


Figure 1-3. Normative Model: Illustration of Threshold Strategies.

Drawing on the TOSCA model and cognitive psychology, the researchers proposed and tested a number of hypotheses. Some of the confirmed hypotheses are that decisionmakers would: choose between probing and consulting using information cost-benefit rules; ask the consultant more often when depicted as a team member; exhibit threshold type choice strategies (similar to that of the normative model); and all things being equal, favor probing to consulting, because a probe measurement provides more bits of information. The main hypothesis that was not confirmed predicted decisionmakers would not seek additional information as often in difficult discrimination conditions. Just the opposite was observed, more requests for information were made in the difficult condition.

In terms of performance, subjects did very well; in fact, they approached the values obtained by the normative model. The subjects achieved this performance, however, using strategies different from those indicated by the TOSCA model.

Discussing the experimental results, Kastner et al. noted that decisionmakers were inclined to seek more information than predicted by the TOSCA model, and this was particularly true for difficult discrimination conditions. When information was sought, decisionmakers favored the processed judgments of the consultant over the raw measurements provided by a probe. Decisionmakers, moreover, sought information even when the benefit of that information was not worth the cost of obtaining it.

These findings were obtained under relatively low-stress conditions. There was no time pressure and relatively few distractors. Although the subjects tended to perform well, their strategies were nonoptimal and in some conditions (e.g., gathering information when it was not worth it) decidedly counterproductive. If these subjects were thrust into a stressful situation, how might their strategies change? Would stress promote further nonoptimal behavior and exacerbate counterproductive strategies? How would performance be affected? Will stress foster more false alarms? These are some of the questions the current experiment was designed to address, building upon the TOSCA experimental paradigm.

SECTION 2

STRESS

Stress is a ubiquitous part of everyday life. It is an inevitable part of the challenges that prompt mastery of new skills and behaviors. Problems arise when stress becomes excessive. The individual then experiences disrupted emotional, cognitive, and physiological functioning. The impact of cognitively induced stress on information processing and decisionmaking processes is the primary focus of this effort, thus, it behooves us to define and operationalize what we mean by stress.

2.1 THREE APPROACHES TO STRESS

Conceptually, stress is a relatively new issue in psychological research and there is some disagreement as to its definition. Cider et al. (1983) describe three approaches or models of stress that might be informative in arriving at an understanding and definition. The response-based model of stress holds that stress is a cluster of disturbing psychological and physiological responses to difficult situations. A second approach, the stimulus-based model, views stress in terms of environmental events or stimuli that cause such responses. The interactional model of stress (Cox, 1978) approaches stress as an imbalance between individual needs and abilities on the one hand and environmental demands on the other.

A prime contributor to the response-based model is Hans Selye and his concept of the General Adaptation Syndrome or GAS (Selye, 1973, 1976). The GAS is a pattern of physiological responses that describes three stages of the body's resistance to prolonged stressors. The three stages — alarm, resistance, and exhaustion — describe how the body rapidly mobilizes its physiological defenses, tries to adapt to the presence of the stressor, and finally exhausts its adaptive energy if the stressors persist. The major strength of the response-based model is its demonstration that many different stressors produce a similar syndrome or

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response (Cider et al., 1983). Cider et al. note that this approach does not, however, describe the characteristics of stressors. To predict if a certain event will produce a stress syndrome, an understanding of the characteristics of stressful stimuli is needed.

The stimulus-based model focuses on three important characteristics of stressful stimuli: 1) overload, 2) conflict, and 3) uncontrollability. When a stimulus becomes so intense that an individual can no longer adapt to it, overload occurs. An important form of overload is work overload. Ivancevich and Matteson (1980) discuss two different kinds of work overload: when there are too many things to do in too little time and when performance standards are so high that work cannot be satisfactorily completed no matter how much time is available. When two or more incompatible response tendencies are simultaneously aroused, conflict occurs. Conflict situations are ambiguous in that the stimulus arousing them does not imply which response tendency is appropriate (Cider et al., 1983). Research conducted with both animals and people show that conflict is capable of producing powerful stress responses. Uncontrollable situations are also highly stressful. Studies such as those of Weiss (1972) show that the stress produced by aversive stimuli may have more to do with one's ability to control the timing and duration of these stimuli than with the actual pain they cause. Moreover, the stressful impact of aversive stimuli can be lessened if people merely believe they have control, as demonstrated by the work of Glass and Singer (1972).

A major asset of the stimulus-based model is in helping predict the sorts of situations individuals will find stressful. The implication is that stress reactions and their detrimental effects can be lessened or eliminated by modifying stimulus characteristics such as overload, conflict, and uncontrollability. The stimulus-based model is limited in that not all individuals find the same stimuli equally stressful. This means individual differences among people must be taken into account in order to predict whether a given stressor will produce a stress response.

The interaction model holds that stress will occur when two conditions are met: the individual perceives a threat to important needs and motives, and the individual is unable to

cope with the stressor (Cider et al., 1983). This model also suggests that the other two models require bolstering with knowledge about individual motives and coping abilities. It is predicted by this position that the amount of stress experienced in any situation will depend on the balance between stressor demands and coping skills. Where there is an imbalance between the two, i.e., when demands exceed coping skills, stress will be high. When coping skills approximate demands, stress will be low. For example, the Mercury astronauts had many good reasons to exhibit substantial amounts of stress. Yet, careful analysis revealed almost no evidence of stress reactions during the flights. A combination of background, personality, and training provided the astronauts with coping skills adequate to the demands of space flight. When confronted with a difficult situation, the astronauts would pause, assess the situation, decide on a course of action, and then follow through (Cox, 1978; Wolfe, 1979).

Accounting for individual differences in the experience of stress is a primary strength of the interaction model. Conversely, the model says little about the nature of stress reactions or the stimulus conditions most likely to produce such reactions.

Drawing on the work of Cox (1978), Lazarus (1976), and McGrath (1970), Cider et al. (1983) offer the following comprehensive definition of stress, "a particular pattern of disturbing psychological and physiological reactions (response-based model) that occurs when an environmental event (stimulus-based model) threatens important motives and taxes one's ability to cope (interaction model)" (p. 489).

2.2 STRESS-INDUCED COGNITIVE DISRUPTIONS

Under stress, particularly high stress, persons may experience such an inordinate amount of cognitive constriction and perseveration that their thought processes are disrupted (Janis and Mann, 1977). Normally, during periods of nonstress, our thinking is essentially rational, logical, and flexible. During periods of stress, thinking is often dominated by worries about the consequences of our actions and by negative self-evaluations. One's normal patterns of organized, logical, and coherent thinking are impaired. Individuals in stressful

environments report worrying about possible failure and about their own inadequacies. This, in turn, interferes with thinking about the tasks they have to perform (Spielberger, 1979). High levels of stress disturb individuals' ability to concentrate and the process of selective attention, i.e., the ability to concentrate on specific stimuli while ignoring other irrelevant stimuli. In such stress situations, persons report being distracted both by obsessive thoughts of failure and by external stimuli. Obviously, poor concentration impairs an individual's performance and decisionmaking ability.

Stress-induced memory impairment is most likely due to the deterioration of the ability to transfer information from short-term to long-term memory. The rehearsal process (necessary for short- to long-term transfer) appears to be disrupted under stress, leading to frequent confusion about the sequence of events (Rimm and Somervill, 1977).

Janis and Mann (1977) report the immediate memory span of individuals is reduced and their thinking becomes more simplistic. That is, they cannot deal conceptually with as many categories as when they are unstressed. People fail to recognize all the options open to them and fail to use remaining resources to evaluate adequately those alternatives of which they are aware. Under high stress people are likely to search frantically for a solution, persevere in their thinking about a limited number of options, and then stick tightly to a hastily contrived solution that appears to promise immediate relief.

In summary, stress is capable of disrupting a variety of cognitive functions. This implies that decisionmaking, which usually requires a combination of good concentration, flexible thinking, intact memory, and visual imaging, will be significantly affected by stress.

2.3 OPERATIONAL DEFINITION OF STRESS

Employing the stimulus-based model to characterize the stress-inducing stimuli to be manipulated, we focus on the three attributes of overload, conflict, and uncontrollability. One component of overload that will be easy to manipulate in the experimental paradigm is time pressure. The constant worry of being able to finish in the allotted time is stressful. In the

high-stress condition, subjects are informed that they will have a fixed time by which to make their determination of enemy or friendly. To keep subjects constantly aware of the time limit, a time-bar is added to the display screen. Each four-second passage of time is denoted by a beep. Subjects who do not complete the trial in the allotted time receive a score of 0 for that trial.

The addition of a secondary task to the experimental paradigm invokes all three stress-inducing stimuli associated with the stimulus-based model. The secondary task cuts deeply into a subject's residual resources or capacity not utilized in the primary task (Ogden, Levine, and Eisner, 1979; Rolfe, 1973). Ogden et al. and Rolfe also note that a secondary task can serve as a loading task; thus, decrement variations in the secondary task can be used to infer differences in the primary task demand. A conflict is also created as subjects, at various times, have to decide which task must be immediately attended. Subjects, moreover, have little or no control over the appearance of the secondary task, thereby creating some sense of uncontrollability. Lastly, the secondary task is intrusive and distracting to the performance of the primary task.

In summary, the two manipulation components of stress — time pressure and secondary task — are used to provide a significant induction of cognitive stress.

SECTION 3

METHOD

3.1 OVERVIEW

The experimental paradigm is a modification of the team-optimal stopping with communication alternatives (or TOSCA) paradigm employed by Kastner et al. (1989). The review of Kastner et al. in subsection 1.2 clearly indicates that the TOSCA paradigm is reliable and provided a viable means for investigating hypotheses concerning information gathering and decisionmaking processes.

As an abstraction of an anti-submarine warfare (ASW) detection problem, the paradigm requires subjects assuming the role of an ASW commander to decide if a detection is a hostile or friendly submarine. This decision is based on the pump noise signature of the detected submarine. Commanders are told that the friendly submarine's pump noise signature is always 370 Hz and the hostile submarine's pump noise signature is either 330 Hz or 360 Hz. The detection sensors are described as having an inherent error distribution with a zero mean and a standard deviation of 20 Hz. To aid in the discrimination, task commanders may probe (i.e., task their sensors for another measurement) or ask the opinion of a knowledgeable "team-member consultant." Subjects are aware that either resource has a cost associated with it and, under certain conditions, the consultant will receive better information than them.

Stress is induced by imposing a specific deadline (time pressure) and requiring the commanders to attend to an intrusive second task. At the beginning of every stress trial, a vertical time bar appears. The time bar starts at 24 seconds and decreases at 1-second intervals. After the passage of every 4 seconds, a beep is sounded. At 4 seconds into each stress trial, the secondary task window appears. The secondary task is presented as a communication task where the commander is shown the value of a pump noise measurement supposedly taken from

a second contact. After noting its value, the commander transmits the detected pump noise measurement to another platform. Ten seconds later, the pump noise measurement is transmitted back for verification. During a stress trial, participants must complete the secondary task along with the primary discrimination task in the allotted time.

3.2 SAMPLES

Participants for the experiment are drawn from two distinct populations civilian and military. The civilian sample consists of nine male and female volunteers from an engineering firm and college students. The engineering employees range in age from 25 to 30 years, are well educated, and have decisionmaking responsibilities within the company. The college students range in age from 18 to 21 years and are engineering or science majors. Seven male officers, either instructors or students at the Naval War College in Newport, Rhode Island, comprise the military sample. All the military participants are at grade O-4 or above. Participants work independently and experience four to five hours of training and data collection.

3.3 VARIABLES MANIPULATED

Four independent variables are operationalized and manipulated. **Stress** varies the workload and time pressure facing the participants. During low stress, subjects have no time deadline and no other task but the primary discrimination task to complete. Under conditions of high stress, subjects face a specific deadline of 24 seconds. In addition, they must complete a secondary communication task along with the discrimination task. **Discriminability** varies the ease with which enemy and friendly submarines can be discriminated from one another by their pump noise signatures. The two levels are easy — pump signatures are two standard deviations apart (330 Hz for the enemy and 370 Hz for the friendly), and difficult — pump signatures are half a standard deviation apart (360 Hz for the enemy and 370 Hz for the friendly). **Information cost** manipulates the cost incurred when asking the consultant for an opinion (C) relative to probing (P). The three levels are: $C < P$ — cost of asking the consultant is less than that of probing for a new measurement (5 and 15, respectively); $C = P$ — cost of asking the

consultant is equal to the cost of probing (5 and 5, respectively); $C > O$ — cost of asking the consultant is greater than that of probing (15 and 5, respectively). **Consultant expertise** is operationalized in terms of the consultant's measurement error relative to the commander's (subject's) measurement error. The two levels are high expertise — consultant's measurement error is half the commander's (i.e., half the measurement standard deviation) and equal expertise — consultant's and commander's measurement errors are equal (i.e., same measurement standard deviation).

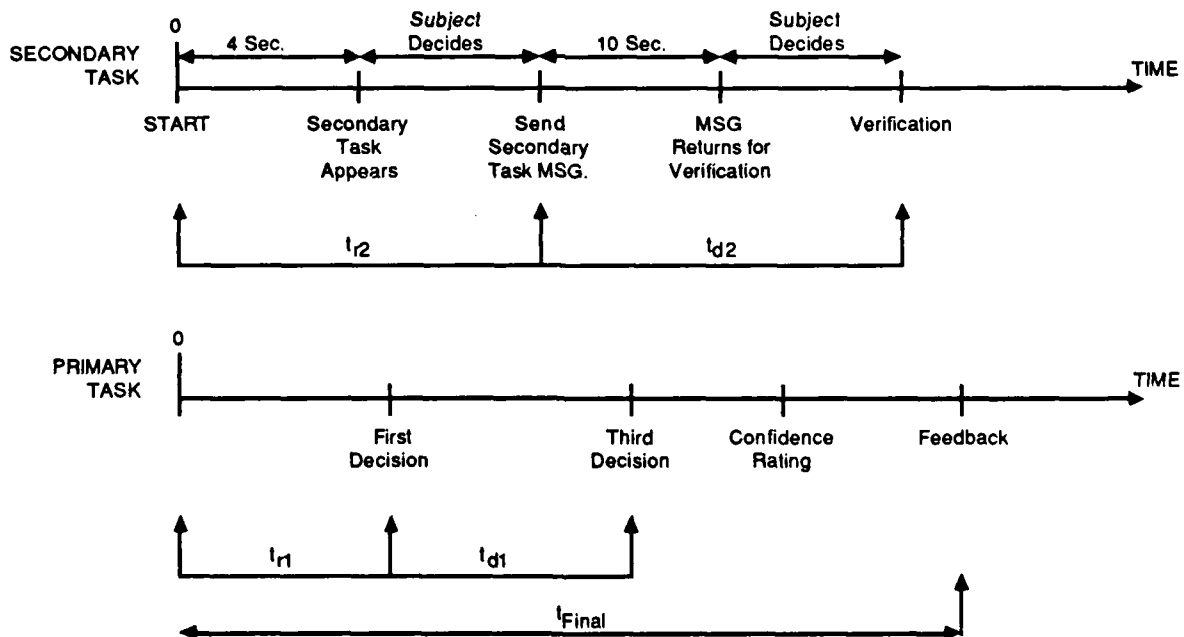
3.4 VARIABLES MEASURED

Several dependent variables are devised to record the timings and processes of information gathering, decisionmaking, and outcome. The information gathering and decision-making measures are associated with one of the three overt decisions commanders are called on to make. The first decision records if subjects stopped information gathering after the initial measurement and decided if the detected submarine is enemy or friendly, or elect to gather more information. The data yields the percentage of times subjects requested additional information. The second decision records if commanders probe for a new measurement or ask the opinion of the consultant. The percentage of times the subjects probe is computed from these data. The third decision records whether the commanders decide the detected submarine is an enemy or a friendly. These latter data are used to compute the percentage of times the commanders correctly identified the submarine. The outcome of the detection task is evaluated and a feedback score generated. This reward score is computed in the following way: 100 points minus 80 points for being wrong minus information costs. Thus, if the commander correctly identified the submarine and no additional information is requested, the reward score is 100. If the commander incorrectly classified the submarine, but uses no additional information, the reward score is 20. If the commander is wrong and incurs an (additional) information cost of 15, then the reward score is 5. After each discrimination decision, commanders render a rating

as to their confidence in their decision. These ratings are made on a seven-point scale where 1 equals very low and 7 equals very high confidence that the decision about the detected submarine is correct.

Figure 3-1 shows the various timing measures recorded. All intervals are measured in seconds. The five measures are:

- t_{final} , the interval from the onset of a trial to the end of a trial.
- t_{r1} (reaction to primary task), the interval from the onset of a trial to the first decision.
- t_{d1} (decision for primary task), the interval from the first decision to the third decision (i.e., enemy or friendly).
- t_{r2} (reaction to secondary task), the interval from the onset of a trial until the subject reacts to the secondary task by sending the pump noise measurement.
- t_{d2} (decision for secondary task), the interval from the transmission of the secondary pump noise measurement until the subject sends the verification of the measurement.



R-7872

Figure 3-1. Timeline Showing the Five Time Intervals Measured and Recorded.

3.5 WORKLOAD ASSESSMENT

To assess workload, each participant completed the Subjective Workload Assessment Technique or SWAT (Reid et al., 1988) scale at the conclusion of each experimental condition. The assessment process using SWAT involves two distinct phases. Phase one is carried out prior to data collection. Following prescribed procedures (Reid et al., 1981), each participant performs a card sort to develop a unique workload scale for themselves. Each card contains a different combination of the three workload dimensions: time load, mental effort load, and psychological stress load. In turn, each workload dimension is described in terms of three levels: low, moderate, and high. Thus, participants sort a set of 27 cards (3 levels of time $\times$ 3 levels of mental effort $\times$ 3 levels of psychological stress), so that they are rank ordered according to the level of workload described.

The second phase occurs during data collection. At the end of each experimental condition, participants rate the workload they just experienced according to the three dimensions of time load, mental effort load, and psychological stress load. Ratings are done on a three-point scale (low, moderate, high) for each dimension. Using software provided by Reid et al., each SWAT score, which consists of one number from each of the three dimensions (e.g., 1, 2, 2; representing a 1 for time load, a 2 for mental effort load, and a 2 for psychological stress load), is converted to a percent workload score on the participant's unique scale. Zero percent represents very low workload, while 100 percent represents very high workload.

3.6 EXPERIMENTAL PARAMETERS

The values needed for the initial pump noise measurement, probe measurement, and measurement for input into the consultant algorithm are randomly generated from a Gaussian distribution with appropriate mean and standard deviation. For each trial, it is first decided if the submarine will be an enemy or a friendly (ground truth) by sampling a uniform random distribution of zeros and ones (i.e., probability of an enemy submarine is 0.5). If the submarine is to be an enemy, then an initial pump noise value is drawn from the enemy's Gaussian distribution. Depending on the discriminability condition, this distribution has a mean of

330 Hz or 360 Hz and a standard deviation of 20 Hz. The friendly submarine distribution always has a mean of 370 Hz and a standard deviation of 20 Hz. If a probe measurement is required, it is drawn from the same distribution as the initial measurement.

Generation of the measurement used by the consultant is done in a similar fashion. If the consultant and the commander are equal in expertise, then the input value to the consultant algorithm is randomly generated from the same distribution as the initial measurement. When the consultant is a better expert than the commander, an input value is drawn from a Gaussian distribution with a standard deviation of 10 Hz (and mean appropriate to the submarine type — enemy or friendly).

The generation of all measurement values is done only once. All subjects see the same measurements, albeit in different orderings according to experimental condition and replication.

3.7 PROCEDURE

Prior the onset of the experiment, all subjects first read "Instructions for the TOSCA-II Simulation Game" (a copy of these instructions are in Appendix A). These instructions provide an overview of the task, describe the subject's role, and provide a motivational induction to take the simulation game seriously, try hard, and do well. Subjects next read "Instructions for the TOSCA-II Simulator" (a copy of these instructions are also in Appendix A). The second set of instructions are designed to tell the subjects in specific terms what to do and how to do it. Each area of the display screen is described and its function explained. Feedback, scoring, timing, and the secondary task are also explained. Lastly, subjects are reminded to complete the SWAT scale at the end of each experimental condition.

Subjects work at their own Apple Macintosh microcomputer and make all entries via the mouse (or, if they choose, a track ball). For a low-stress trial, the display shown in Fig. 3-2 appears, while for a high-stress trial, Fig. 3-3 shows the display. For low stress, a trial begins when an initial measurement appears on the screen (e.g., a pump noise signature of 382 Hz).

ALPHATECH, INC.

T O S C A I I

Condition Code: 2121
Trial Number: 1
Name: TRAINING1

INTEL

Enemy pump noise 330 Hz
 Friendly pump noise 370 Hz
 Sensor Standard Deviation
 Yours 20 Hz
 Consultant's 20 Hz

COMMAND AREA

Initial Measurement 365 Hz

Enemy Friendly ?

Probe Consultant

1 2 3 4 5 6 7
☐ ☐ ☐ ☐ ☐ ☐ ☐
 Low Confidence High

Feedback

REWARD

Initial Meas.

	Reality	
	Enemy	Friendly
En.	100	20
Pred.		
Fr.	20	100

Probe

	Reality	
	Enemy	Friendly
En.	95	15
Pred.		
Fr.	15	95

Consult.

	Reality	
	Enemy	Friendly
En.	85	5
Pred.		
Fr.	5	85

Figure 3-2. Screen Used in Low-Stress Conditions.

T O S C A I I

Condition Code: 1211
Trial Number: 1
Name: TRAINING4

INTEL

Enemy pump noise 330 Hz
 Friendly pump noise 370 Hz
 Sensor Standard Deviation
 Yours 20 Hz
 Consultant's 10 Hz

COMMAND AREA

Initial Measurement 341 Hz

Enemy Friendly ?

Probe Consultant

1 2 3 4 5 6 7
☐ ☐ ☐ ☐ ☐ ☐ ☐
 Low Confidence High

Feedback

TIME LEFT

24 Sec.
 12 Sec.
 0 Sec.

REWARD

Initial Meas.

	Reality	
	Enemy	Friendly
En.	100	20
Pred.		
Fr.	20	100

Probe

	Reality	
	Enemy	Friendly
En.	95	15
Pred.		
Fr.	15	95

Consult.

	Reality	
	Enemy	Friendly
En.	95	15
Pred.		
Fr.	15	95

COMMUNICATION AREA

376 Hz. Send

Yes
No

Figure 3-3. Screen Used in High-Stress Conditions

The commanders indicate if they think the detected submarine is an enemy or a friendly, or more information is desired (first decision). If more information is requested, the commanders indicate if they desire a probe to obtain another measurement or the opinion of the consultant (second decision). At all times, the screen clearly displays the cost of each course of action, as well as the consultant's expertise vis-a-vis the commander. After a determination of enemy or friendly (third decision), subjects enter their confidence rating and then request feedback as to the correctness of their decision. The procedure is similar for high-stress trials except the subjects must also complete the secondary task. This entails noting the secondary pump noise measurement, sending the measurement, and then (ten seconds later) verifying that the pump noise measurement returned is in fact the one that was sent. Feedback in these cases also includes whether the commander's verification action was correct.

At the end of an experimental condition, a message appears on the display screen directing subjects to complete a SWAT scale for that condition. In all 24 SWAT scales are completed.

3.8 DESIGN

A complete crossing of the four independent variables — stress, information cost, consultant expertise, and discriminability — yields 24 experimental conditions (i.e., $2 \times 3 \times 2 \times 2$). The design is completely within-subjects, in that each subject experiences all 24 conditions in a partially counterbalanced, partially random ordering. The experimental conditions are organized by the stress factors into four blocks (two low and two high) and presented to the subjects in an ABBA or BAAB counterbalanced ordering. Within each stress block, discriminability is also ordered in ABBA or BAAB counterbalancing. The remaining factors are randomized within each block. Each experimental condition is replicated 15 times for a total of 360 trials for a civilian subject and 7 times for a total of 105 trials for a military subject.

SECTION 4

EXPERIMENT RESULTS

4.1 MANIPULATION CHECKS

4.1.1 The Stress Induction

A primary goal of the experiment is to observe decisionmaking under stress. Thus, it is important to confirm that a condition relatively high in cognitive stress was produced. To check the veracity of the high-stress manipulation, we turn to the workload ratings. It is expected that a successful stress manipulation will produce higher workload ratings in the high-stress rather than low-stress condition. In the civilian sample, subjects reported a mean workload score of 38 percent under high stress and a score of 25 percent under low stress. The difference in the expected direction is significant at $p < .04$ (one-tail). Similarly, military decisionmakers reported a mean workload score of 32 percent under high stress and a score of 17 percent under low stress. In this case, the difference is significant ($p < .06$, one-tail) in the expected direction. It appears safe to say that the stress manipulation had a significant effect and the effect is as expected.

4.1.2 The Discrimination Manipulation

Using similar procedures, it is also possible to examine the manipulation effectiveness for the discriminability factor. If successfully manipulated, this factor will produce higher workload ratings in the difficult versus the easy-discrimination condition. As anticipated, subjects in the civilian sample reported significantly higher mean workload ratings in the difficult than easy-discrimination condition (means equal 43 percent and 21 percent, respectively; $p < .004$). A weaker, but essentially similar, pattern of results is found for the military sample (means equal 27 percent for difficult and 22 percent for easy discrimination conditions;

$p \leq .07$, one-tail). We conclude that the discrimination manipulation produced an easy and difficult condition as desired.

4.1.3 A Confirmation of Findings

INFORMATION-SEEKING STRATEGIES

The analyses to be described first compare the information-seeking strategies observed in the present experiment (which we will call TOSCA-II) to those observed by Kastner et al. (1989) in the first TOSCA experiment (to be referred to as TOSCA-I). The comparison is performed with data collected for the civilian sample in low stress. These are the conditions most comparable to those of TOSCA-I.

As we can see from Fig. 4-1 in the easy-discrimination condition, decisionmakers in TOSCA-II exhibit a weaker propensity to make a decision as to the hostility of the detected submarine without requesting additional information than decisionmakers in TOSCA-I. The pattern of results for TOSCA-I and II, seen in the difficult discrimination condition, is also similar. For TOSCA-I, decisionmakers ask for more information twice as often as not seeking more data while for TOSCA-II, the ratio is 5-to-2 in favor of requesting more information. Thus, the initial patterns of information seeking appear quite similar for the two TOSCA experiments.

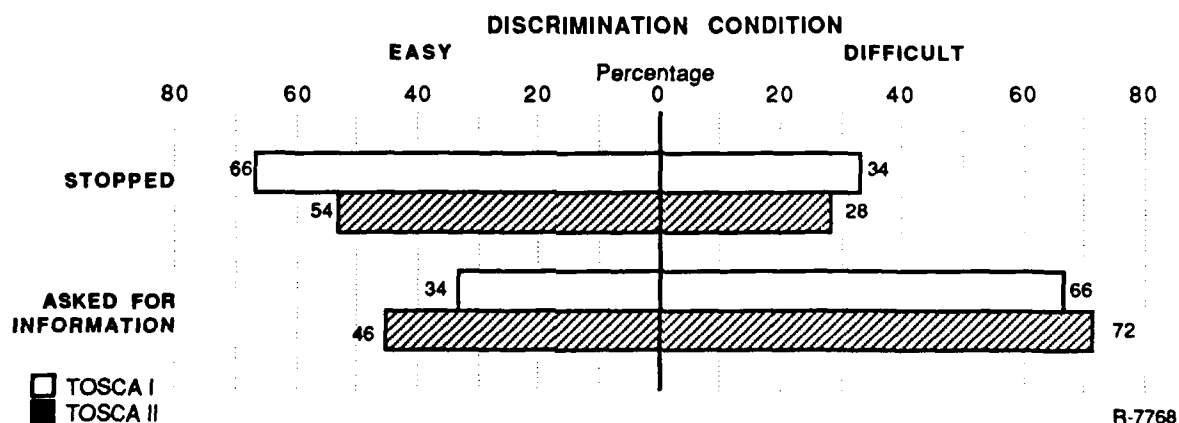
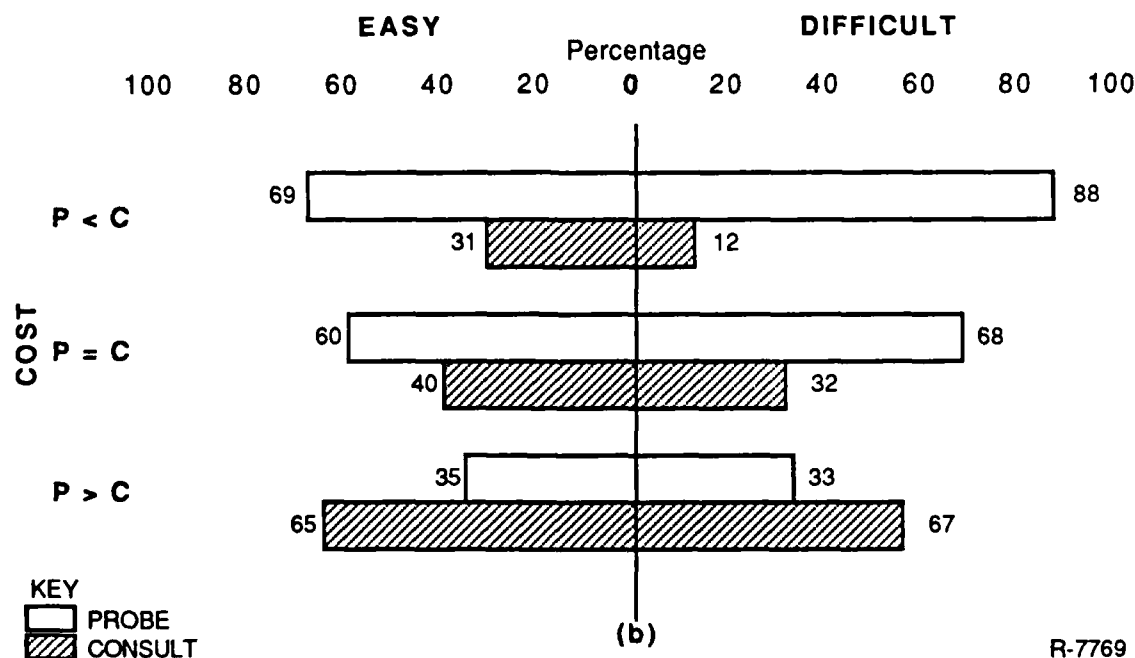
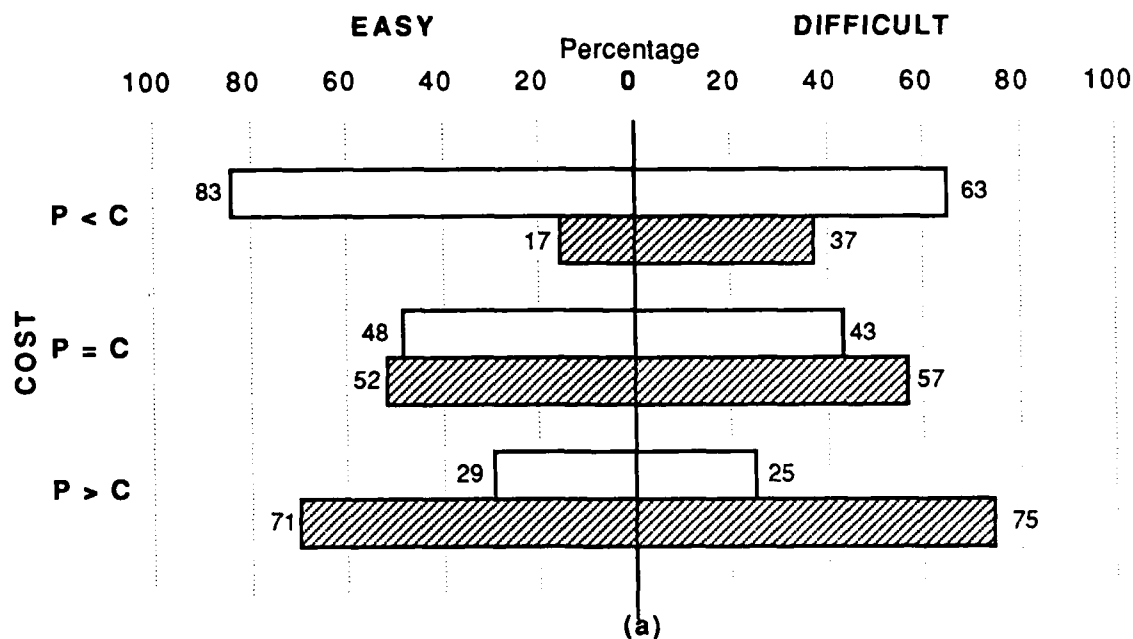


Figure 4-1. Information Requests for TOSCA-I and TOSCA-II Experiments Compared.

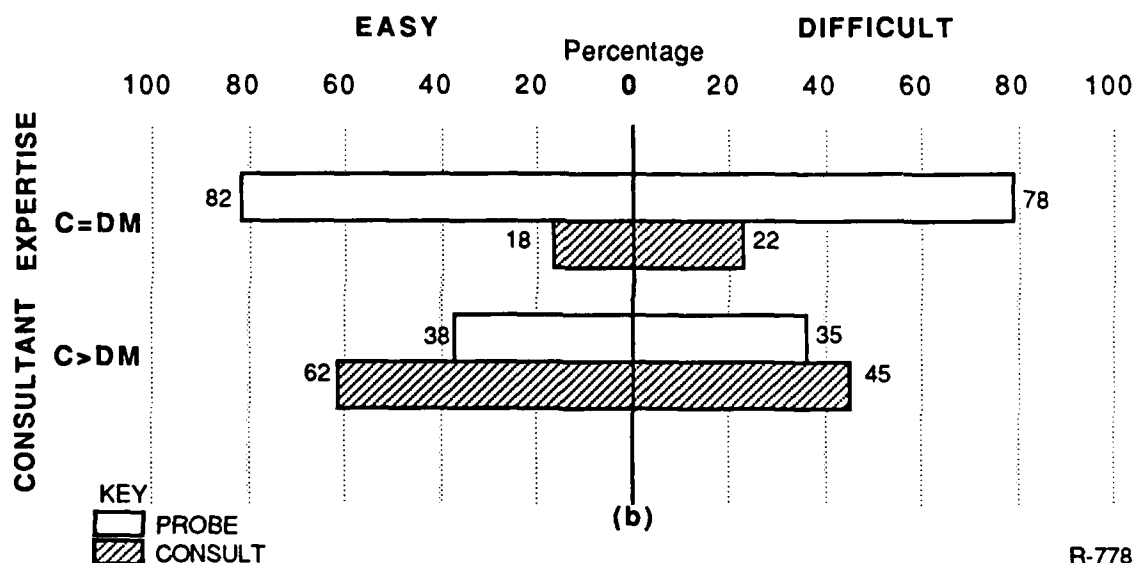
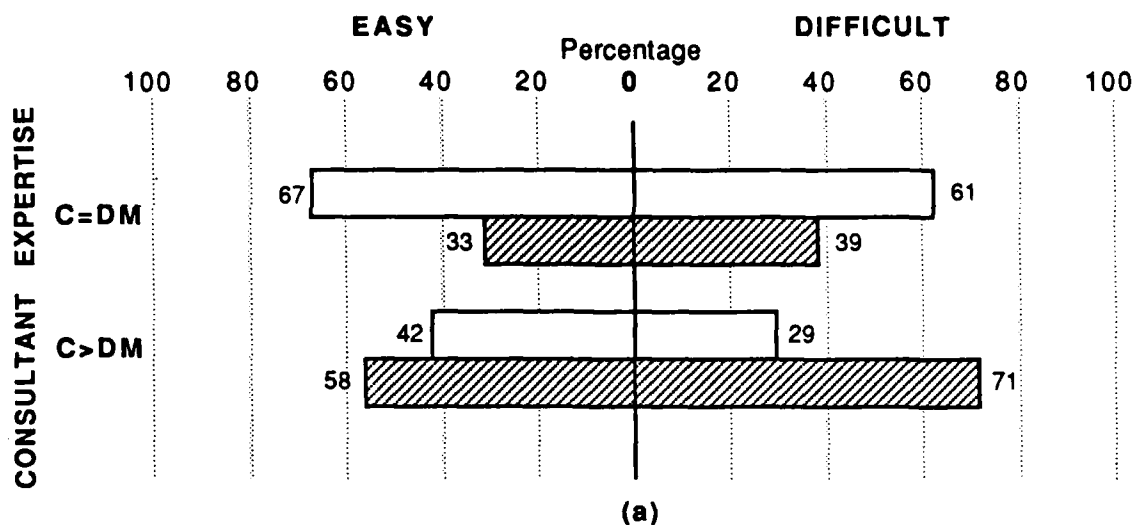
The effects of cost on information seeking in TOSCA-I are presented in Fig. 4-2a. The comparable findings from TOSCA-II are shown in Fig. 4-2b. Note that the general patterns of results, for the conditions where probing was less expensive or more expensive than consulting, are similar across experiments. When probing is less expensive, a majority of decisions favor probing. When consulting is less expensive, a majority of decisions favor consulting. Moreover, this is true regardless of the discrimination condition. The pattern of results ceases to be similar when the condition of equal cost is examined. In TOSCA-I, decisionmakers appeared to be indifferent or show a weak tendency toward consulting, when the costs of probing and consulting are equal; while in TOSCA-II, participants show a definite preference for probing in both discriminability conditions. In the easy condition, the ratio is 3-to-2; while in the difficult case, the ratio is 2-to-1, both in favor of probing. That such a bias would exist, when the consultant is equal in expertise and consulting costs the same as probing, was hypothesized in TOSCA-I. It was argued that decisionmakers would favor the raw data of the probe over the processed information provided by the consultant, because there are more "bits" of available information in a raw measurement. This hypothesis was confirmed by the results of TOSCA-I. Perhaps in the current experiment, this tendency is more strongly expressed. It was also hypothesized (Kastner et al., 1989) that some motivation may exist for participants to strive to maintain as much control over the decision process as possible (see Trope, 1975, and Trope and Brickman, 1975). These issues will be taken up subsequently.

TOSCA-I results confirmed expectations that decisionmakers would turn to the consultant for help more frequently when the consultant is superior in expertise, and that when no difference in expertise exists, decisionmakers would favor probing. Figures 4-3a and 4-3b show that TOSCA-II findings strongly corroborate these results. In the easy discrimination conditions, the results are identical between experiments, while in the difficult discrimination case, the pattern of results is similar.



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Figure 4-2. Decisions to Probe or Consult as a Function of Cost and Discriminability for TOSCA-I(a) and TOSCA-II(b).



R-7783

Figure 4-3. Decision to Probe and Consult as Function of Consultant Expertise and Discriminability for TOSCA-I(a) and TOSCA-II(b).

The next comparison examines information-seeking strategies as affected by the independent variables cost, expertise, and discriminability. Figure 4-4a presents the results obtained from TOSCA-I and Fig. 4-4b shows the current findings of TOSCA-II. In the easy discrimination condition, the pattern of results is quite similar, with one exception. When the consultant and decisionmaker are equal in expertise and the consultant is less expensive,

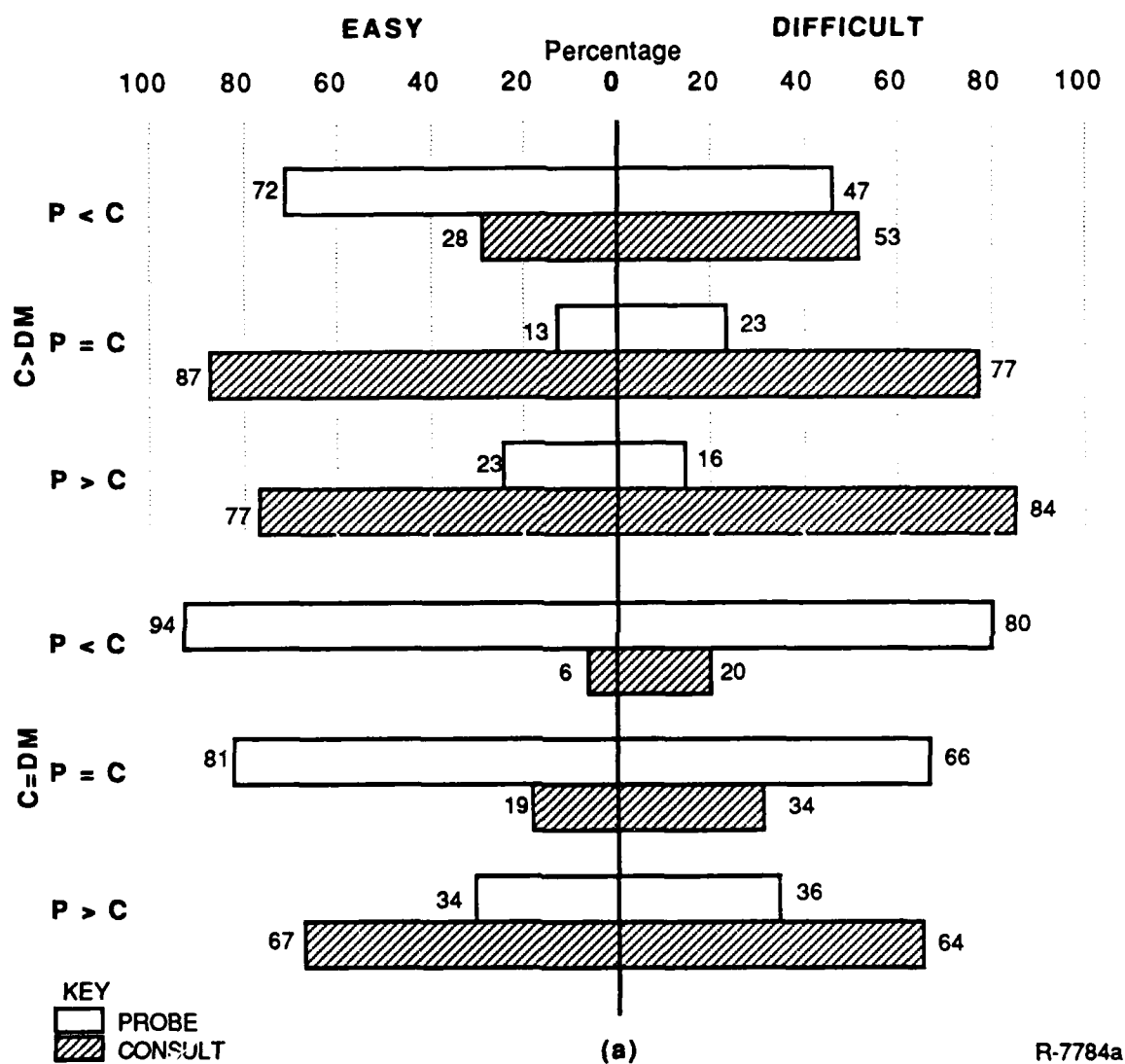


Figure 4-4a. Decision to Probe or Consult as a Function of Cost, Expertise, and Discriminability for TOSCA-I.

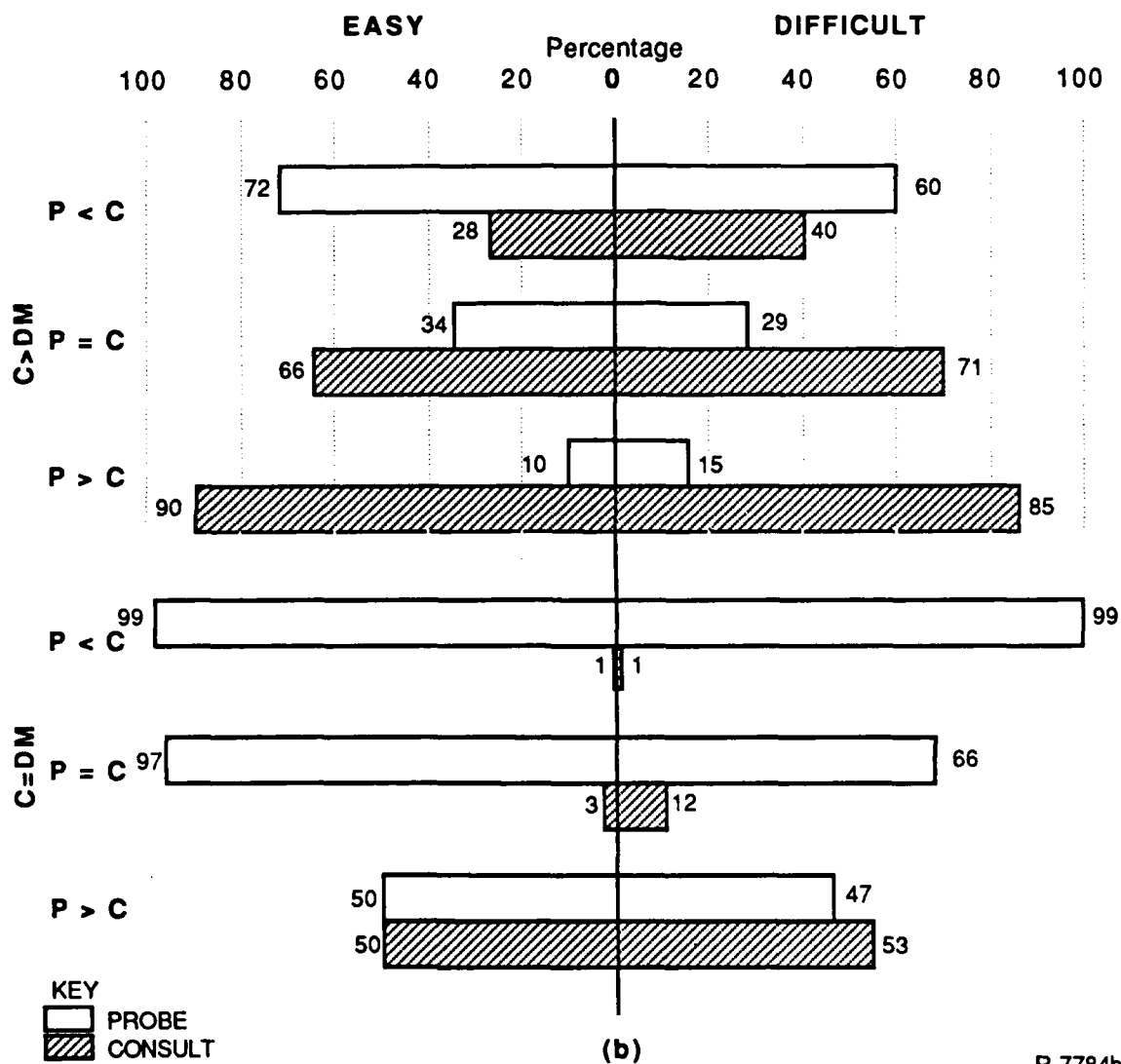


Figure 4-4b. Decision to Probe or Consult as a Function of Cost, Expertise, and Discriminability for TOSCA-II.

subjects show no preference for probing over consulting in TOSCA-II while in TOSCA-I, decisionmakers selected consulting by a 2-to-1 margin. Results under difficult discrimination show a reasonably good match between the two experiments. The one reversal occurs when the probe is less expensive and the consultant is a better expert. In this condition, TOSCA-II decisionmakers choose probing 3-to-2 over consulting, while TOSCA-I decisionmakers slightly favor consulting. Another mismatch, but not a reversal, occurs when consulting is less expensive and no difference in expertise exists. The results from TOSCA-I show a clear preference for consulting, but TOSCA-II decisionmakers are indifferent about probing or consulting in this condition. It is interesting to note that all the mismatches are due to a greater propensity for TOSCA-II decisionmakers to probe than consult. A discussion of this issue will be taken up later.

It was hypothesized for TOSCA-I that decisionmakers would choose between probing and consulting according to the following cost-benefit arguments:

- If decisionmaker and consultant are equal experts, decisionmakers will select the least costly information source.
- If the costs of probing and consulting are equal, then decisionmakers will seek information from the (superior) consultant.
- If cost and expertise are both equal, then decisionmakers will probe, because a three-digit measurement provides more bits of information than a single opinion.

The obtained results confirmed all predictions and it was concluded that decisionmakers perform some kind of information cost-benefit analysis following the above three rules to decide what information source to choose.

For comparable conditions, it is expected that decisionmakers in the current experiment will follow the same cost-benefit decision rules. Table 4-1 shows the outcomes for both TOSCA-I and TOSCA-II. It appears that TOSCA-II decisionmakers follow the same cost-benefit decision rules as decisionmakers in TOSCA-I. The only exception occurs when the consultant and decisionmakers are equal in expertise and the consultant is cheaper. The cost-benefit decision rules imply consulting and TOSCA-I decisionmakers followed suit, but

TABLE 4-1. PREDICTED AND OBTAINED RESULTS FROM TOSCA-I AND TOSCA-II FOR THE INFORMATION COST-BENEFIT DECISION RULES

COST EXPERTISE		P < C		P = C		P > C	
		EASY	DIFF	EASY	DIFF	EASY	DIFF
CONS > DM	PREDICTED	? *		C		C	
	OBTAINED TOSCA - I	P	C (?)	C	C	C	C
	OBTAINED TOSCA - II	P	P	C	C	C	C
CONS = DM	PREDICTED	P		P		C	
	OBTAINED TOSCA - I	P	P	P	P	C	C
	OBTAINED TOSCA - II	P	P	P	P	P	?

N.B. No specific predictions are made for Easy or Difficult discrimination conditions.

* Essentially it is not possible from the cost-benefit decision rules to determine if cost or expertise will prevail.

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TOSCA-II participants select probing or show no preference. This is another demonstration that TOSCA-II subjects show a marked tendency to probe over consult. As stated above, this issue will be discussed later.

DECISION PERFORMANCE

TOSCA-I reported two significant findings nested within the two discriminability conditions, one dealing with information cost and the other dealing with consultant expertise. A comparison of performance between the two studies for information cost is presented in Fig. 4-5. The pattern of results obtained for TOSCA-I and TOSCA-II appears quite similar. The most noticeable difference occurs when the probe is least costly. In this case, performance of the TOSCA-II subjects falls ten percentage points below these reported for TOSCA-I. These differences, however, coupled with other small differences do not lead to the same

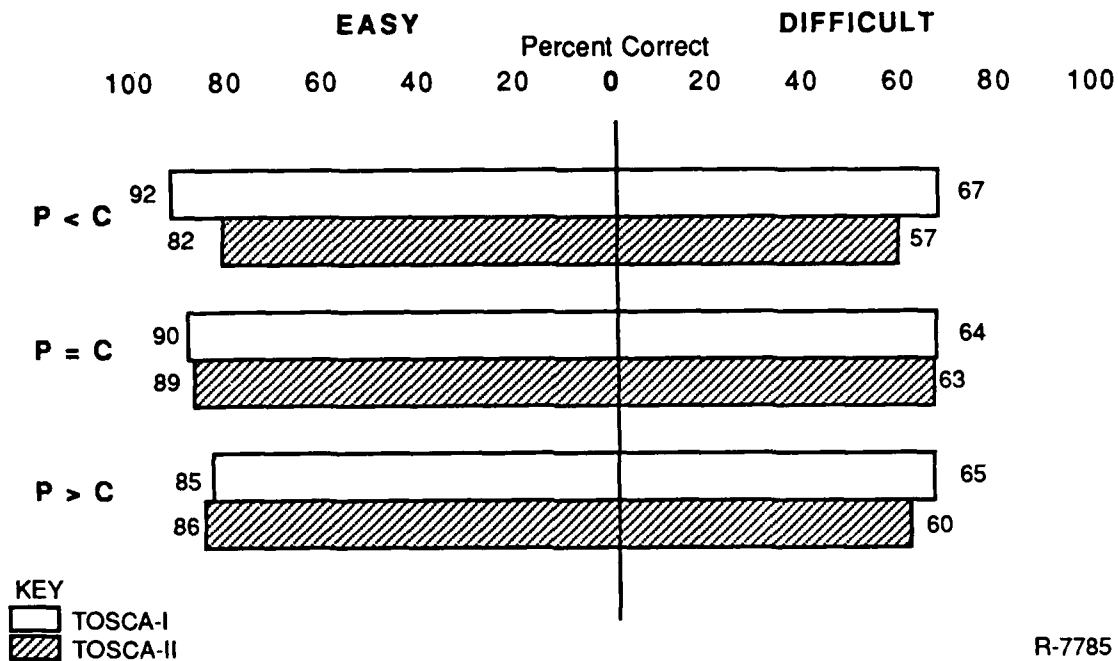


Figure 4-5. Performance as a Function of Cost and Discrimination for TOSCA-I and TOSCA-II.

conclusions. That is, based on TOSCA-I findings it was concluded that because the decisionmakers consulted more when the probe was most costly than in the other two cost cases, decisionmakers must not be getting as much information as they need from the consultant to make good discriminations. In TOSCA-II, the probing and consulting strategies across cost conditions appear the same, but decisionmakers do not seem to use the richer probe information as effectively as their counterparts in TOSCA-I.

The results reported by each experiment for consultant expertise are compared in Fig. 4-6. Once again, the pattern of results seems quite similar. However, the significant difference in performance found for TOSCA-I, favoring the consultant when more expert over the equal expert consultant when in the easy discriminability condition, is not found in TOSCA-II. The means are in the same direction, but the difference is not significant. In the difficult discrimination condition, the performance of the two expertise conditions in TOSCA-II are the reverse of those observed for TOSCA-I. That is, in TOSCA-II the performance in the equal expertise condition is superior to that of the consultant-more-expert condition while the

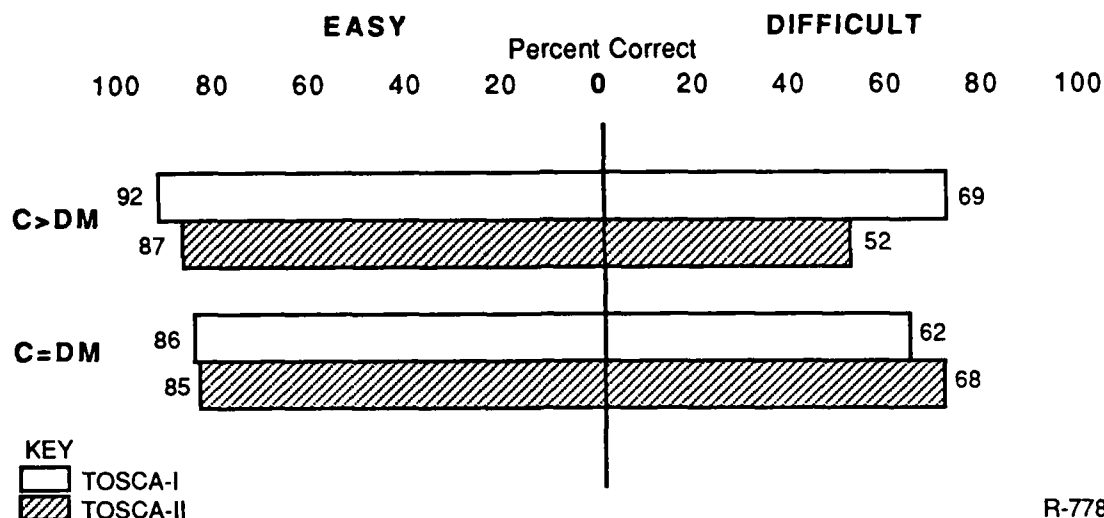
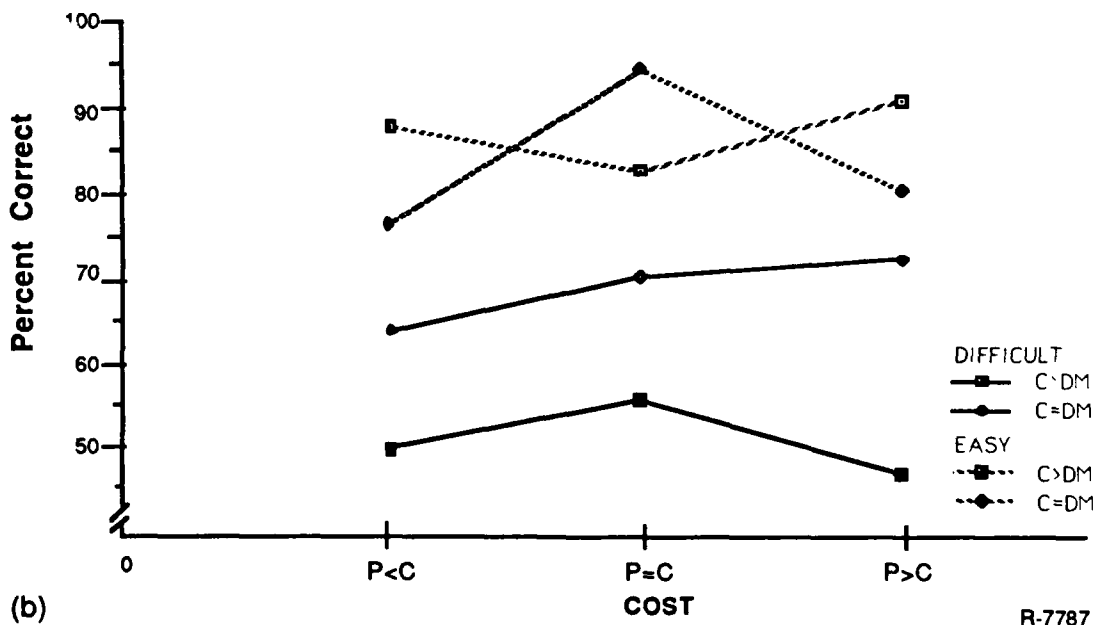
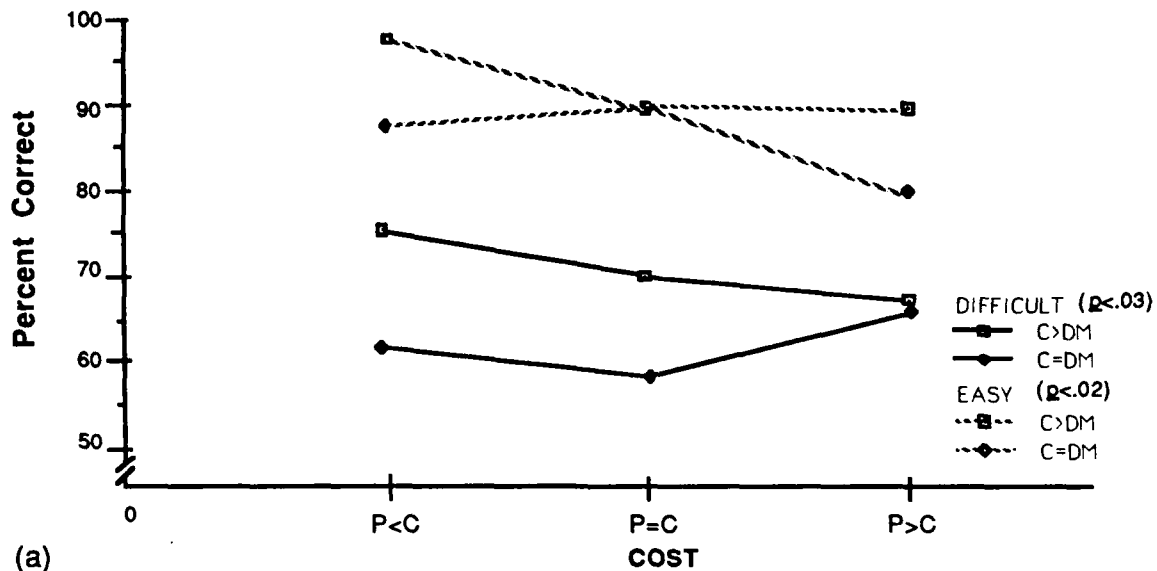


Figure 4-6. Performance as a Function of Expertise and Discriminability for TOSCA-I and TOSCA-II.

performance of this latter expertise condition was superior in TOSCA-I. Decisionmakers do take advantage of the better consultant in the more expert consultant condition and consult more; but, the consultant still faces a difficult discrimination (as do the decisionmakers) and his advice may not be as good as the richer probe information enjoyed in the equal-expertise condition, where the favored strategy is probing.

TOSCA-I also reported significant cost-by-expertise interactions that are shown in Fig. 4-7a. For comparison, the performance of these conditions for TOSCA-II are depicted in Fig. 4-7b. One might construe that the patterns of results for the easy-discrimination condition are vaguely similar between the two experiments. Both show that the consultant-more-expert condition achieves better performance scores than the equal-expertise condition where probing is less or more expensive than consulting. In contrast to TOSCA-I results, TOSCA-II findings show that performance in the equal-cost condition is superior for the equal expertise case. Result patterns for the two experiments appear quite different in the difficult-discrimination condition. The most obvious difference occurs where probing is more costly than consulting. For TOSCA-I, the performance of the two expertise levels were the same, while in TOSCA-II, the equal-expertise case shows considerably better performance than the consultant-more-

expert case. Once again, it seems that consultants in difficult-discrimination conditions cannot provide as good information as a probe.



R-7787

Figure 4-7. Performance as a Function of Cost, Expertise, and Discriminability for TOSCA-I(a) AND TOSCA-II(b).

SUMMARY

The information-seeking strategies of probing and consulting are quite comparable between experiments. Although a few anomalies exist, by-and-large the information-seeking strategies observed for TOSCA-I are corroborated by the TOSCA-II findings. This further reinforces the argument that decisionmakers apply a kind of cost-benefit analysis when deciding among the different information-seeking strategies.

The picture for performance is different. While some of the patterns look similar, there are enough differences to lead to different conclusions in TOSCA-II. TOSCA-II decisionmakers seem less able to employ all the information available in a probe's measurement and suffer more from the consultant's poorer performance in difficult discrimination conditions.

4.2 ANALYSIS OF DECISIONMAKING PERFORMANCE AND INFORMATION-SEEKING STRATEGIES FOR THE CIVILIAN SAMPLE

4.2.1 Information Seeking

Part of the discussion examining information-seeking strategies appears in the previous subsection (4.1.3), where such strategy patterns are compared for TOSCA-I and TOSCA-II. In this section we will look more deeply, examining the effects of stress as well as the other independent variables. To best gauge the effects of stress, the remaining three independent variables are analyzed within conditions of high and low stress.

In situations of low stress, decisionmakers, as shown in Fig. 4-8, requested information significantly more often in the probe-less-costly and equal cost conditions and requested the least amount of information in the probe-more-costly condition ($p < .01$). High stress apparently induces more noise (error) into the situation, as the patterns of information requests are similar, but do not reach acceptable significance levels.

It is interesting to note that across all conditions, decisionmakers request information more than 54 percent of the time and they request information equally in low- and high-stress situations. When the probe is more costly than the consultant, however, decisionmakers seem

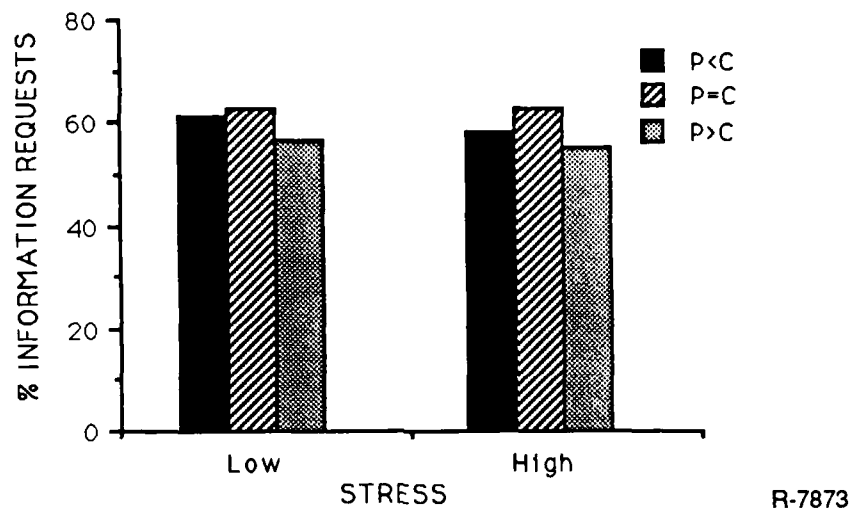


Figure 4-8. Percent Information Requests as a Function of Cost and Stress for the Civilian Sample.

a bit more reluctant to ask for additional information. It is as if they have some reluctance to ask the opinion of the consultant, even when the consultant is cheaper.

This aversion to ask the consultant seems evident in the expertise findings. There is no increase in tendency for decisionmakers to request more information in conditions where the consultant is a better expert compared to the equal expertise condition; and this is true under low and high stress. In fact, there is no evidence that decisionmakers make more information requests in cases where the consultant is cheaper than the probe and a better expert than the decisionmakers. Information requests are flat across the various joint conditions of cost and expertise, regardless of stress conditions. One would expect that higher expertise and a cheaper consultant would entice people to ask for more information than in conditions that lack one of these assets. This does not seem to be the case. We will be in a better position to discuss reasons for this behavior when the patterns of probing and consulting are addressed.

Figure 4-9 shows information requests for the easy- and difficult-discrimination conditions in low and high stress. Under low stress, decisionmakers request significantly more information in difficult- than easy-discrimination conditions ($p < .02$). The addition of high stress further increases the desire to seek information under difficult- than easy-discrimination

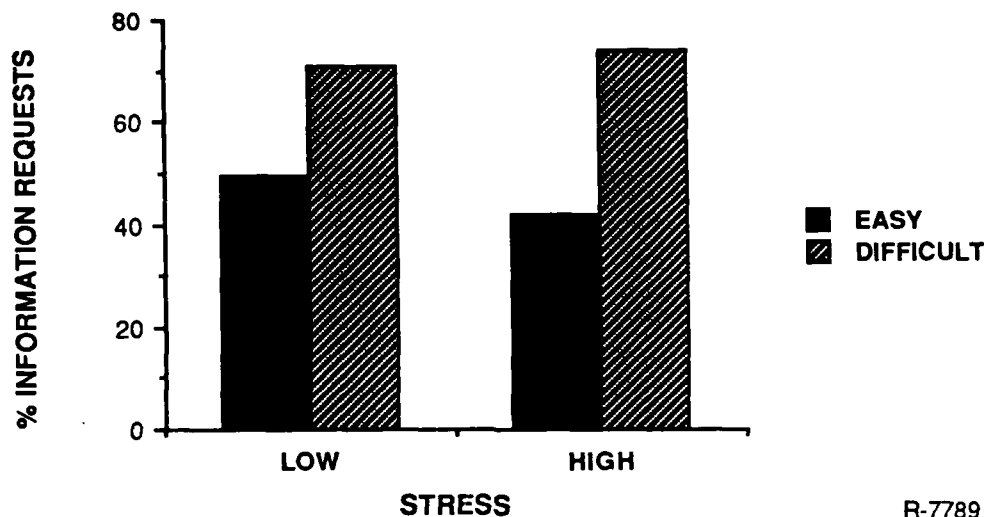


Figure 4-9. Percent Information Requests as a Function of Discriminability and Level of Stress for Civilians.

conditions ($p < .001$). The results reported earlier in TOSCA-I that decisionmakers seek more information in difficult- than easy-discrimination conditions is supported, and it appears that stress further increases the desire for information.

Discriminability and cost also play a role in information requests, but only in high stress. Figure 4-10 shows that the pattern for the discriminability-by-cost interaction under low stress is similar to the pattern under high stress, but not as extreme. Essentially, under high stress the difference between easy- and difficult-discrimination conditions, when the probe is less expensive, is significantly greater than the same contrast when the probe is more expensive ($p < .05$). In high-stress difficult-discrimination situations, decisionmakers request additional information 75 to 80 percent of the time when the probe is cheaper or equal in cost to consulting. However, when the probe is more expensive than the consultant, information requests drop sharply in the difficult-discrimination condition. This is another indication that decisionmakers avoid asking for information when cost conditions favor the consultant.

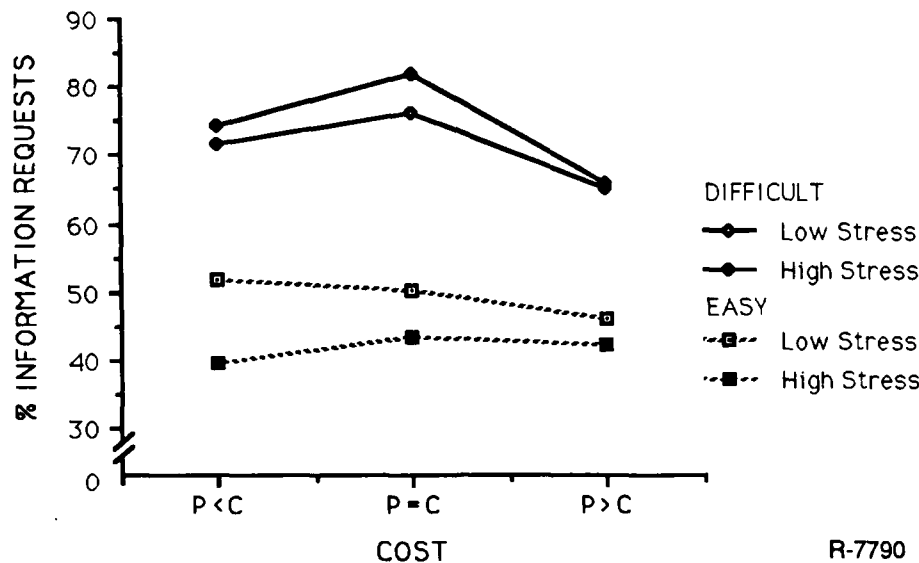
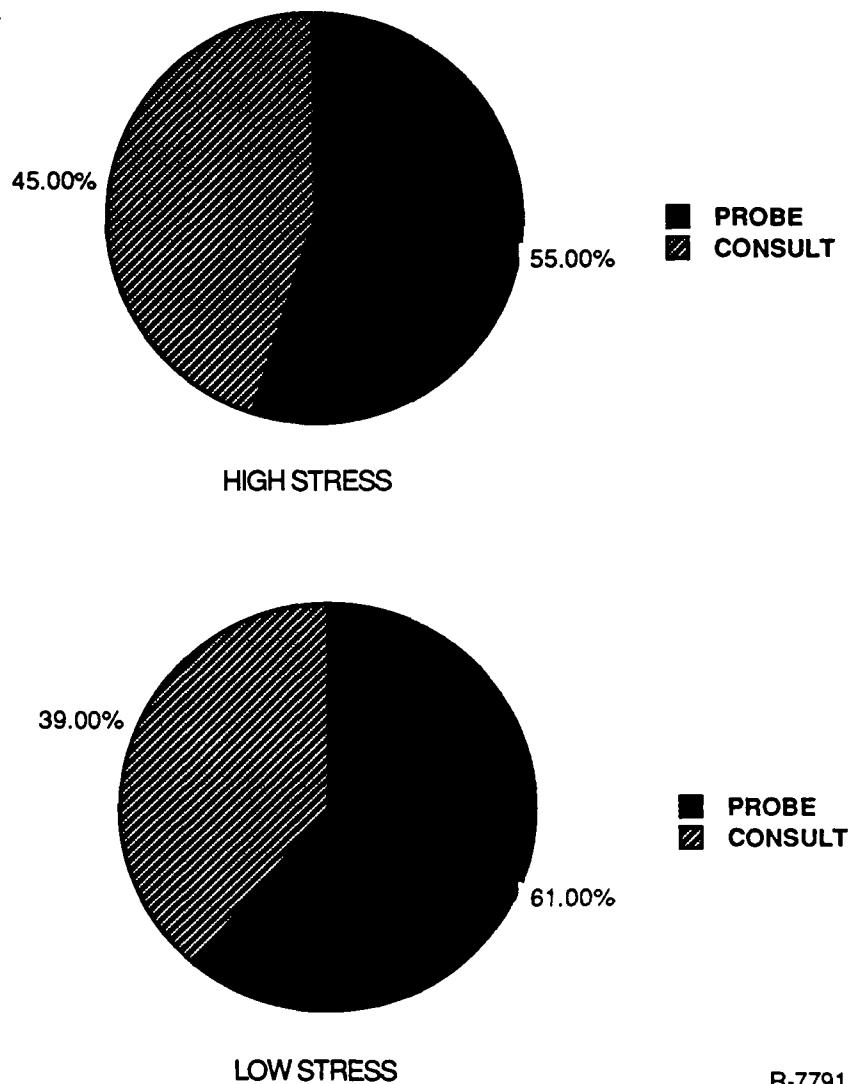


Figure 4-10. Percent Information Requests as a Function of Cost, Discriminability, and Level of Stress for Civilians.

4.2.2 Probing and Consulting Strategies

Figure 4-11 depicts two important results. First, decisionmakers probe a majority of the times they request information (i.e., more than 58 percent of the time). Secondly, results also show that participants probe significantly more in low- than in high-stress situations ($p < .05$). Apparently, decisionmakers turn away from the probe and increase consulting in stressful situations. Under such conditions they may feel the consultant's processed opinion is easier than a raw measurement to incorporate into their current position.

The probing and consulting strategies for the three cost conditions vary significantly in low- and in high-stress situations ($p < .001$, respectively). Moreover, the same pattern of probing and consulting is seen in low and in high stress. Decisionmakers probe extensively when it is lowest in cost (83 percent of the time) and consult most when the consultant is cheapest (70 percent of the time). In the equal-cost condition, participants favor probing 62 percent of the time. As reported in the TOSCA-I experiment, participants are sensitive to the cost of information and, other things being equal, turn to the source that is the cheapest. In the equal-cost condition, however, decisionmakers are not indifferent as they were in TOSCA-I;



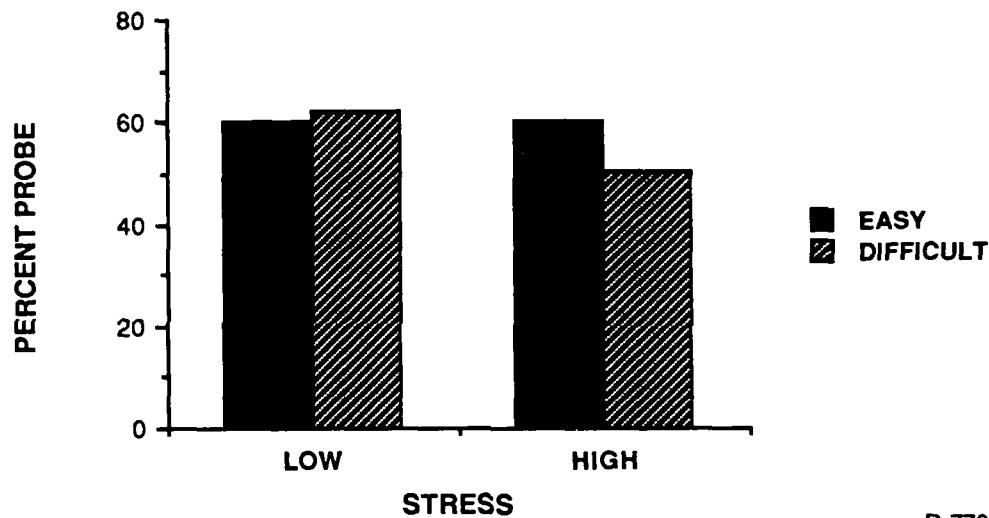
R-7791

Figure 4-11. Information Source Used Under High and Low Conditions of Stress by Civilian Sample.

instead they favor probing 62 percent of the time. The pattern of probing and consulting observed for the cost condition is, however, unchanged by stress.

Similarly, the probing and consulting strategies observed in the expertise conditions are also unaffected by stress. In low- and high-stress situations, decisionmakers consulted a majority of the times when the consultant is the superior expert, and probe a majority of the time when the consultant and decisionmaker are equal in expertise ($p < .002$, respectively).

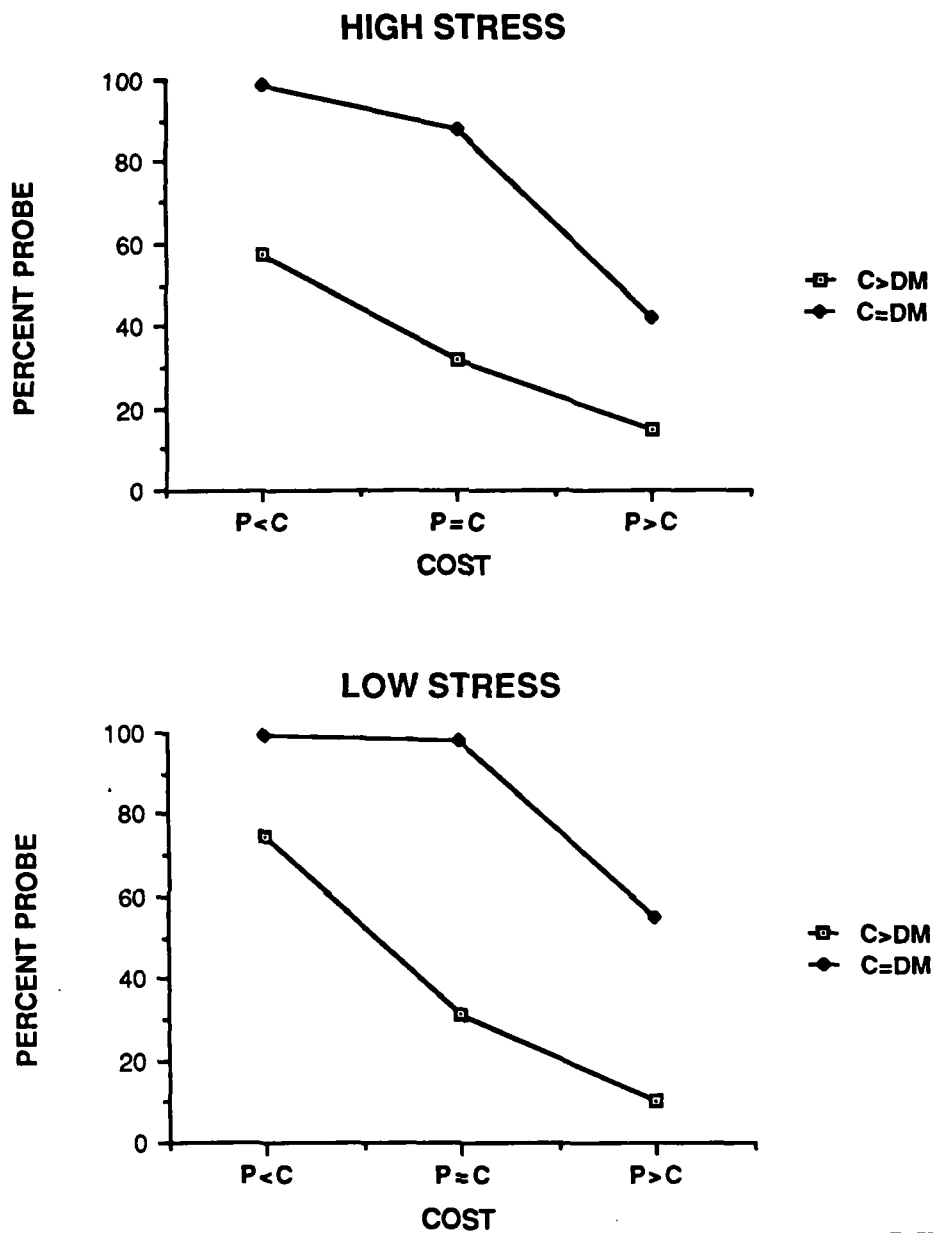
The tendency for decisionmakers to turn to the consultant in adverse conditions is further evident in Fig. 4-12. Under low stress, participants probe for their additional information about 61 percent of the time in easy- and difficult- discrimination conditions. In high-stress situations, the tendency to probe falls about 17 percent in the difficult-discrimination versus easy-discrimination condition ($p \leq .05$). Clearly, decisionmakers are turning away from probing in conditions of high-stress and difficult task. As we have suggested before, we believe participants are turning to the easier-to-assimilate consultant opinion when the situation they are in becomes cognitively loaded.



R-7792

Figure 4-12. Percent Probing as a Function of Discriminability and Level of Stress for Civilian Samples.

Probing and consulting strategies are affected by the joint effect of cost and expertise; but, as Fig. 4-13 shows, the effect of stress on this interaction is subtle. At first, it may appear that the patterns seen for high and low stress are alike. Careful inspection, however, reveals some interesting differences. Examine the difference in probing between the equal expertise and consultant-better-expert condition when probing is less expensive and stress is low. Probing decreases when the consultant is a better expert by about 25 percentage points. A 45 percentage point drop in probing occurs when the consultant is a better expert and also cheaper



R-7793

Figure 4-13. Percent Probing as a Function of Cost, Expertise, and Level of Stress for Civilians.

than the probe. Remember a drop in probing means a commensurate increase in consulting. These differences in probing and consulting are as expected. Being able to turn to a better (if expensive) expert may allure decisionmakers some of the time, and turning to a better and less expensive expert is even more alluring. High stress, however, appears to change this

tendency. When the probe is less expensive, a 41 percentage point drop in probing is observed when the consultant is a better expert, while only a 28 percentage point decline is seen when the consultant is cheaper. When experiencing high stress, decisionmakers seem to place a higher premium on the consultant's being expert than cheap.

4.2.3 Decision Performance

In this subsection we examine how well decisionmakers perform the discrimination task under stress. The performance variable in this case is the reward score. Recall that this score reflects correctness as well as the cost of information requests.

Analysis of performance brings to light an unexpected finding: decisionmakers appear to perform better under stress. In high-stress, the reward score is 77.5 while in low stress, the reward score is 74.5 ($p < .001$). This small but significant difference occurs, we believe, because stress tends to arouse participants and make them more vigilant (see Janis and Mann, 1977). This increase in arousal, other things being equal, motivates participants to work a little harder at the discrimination task resulting in a better performance score (Yerkes and Dodson, 1908).

Cost of information appears to significantly impact performance ($ps < .002$); however, the pattern of results is quite similar under high- and low-stress conditions. Essentially, decisionmakers perform best in the equal-cost condition, while performance in the probe-more-costly and least-costly conditions is about the same. The ratio of probing to consulting in the equal-cost case is more balanced compared to the other cost conditions. Perhaps this particular blend of information sources yields the best of the probe's richer information and the easier-to-incorporate consultant's opinion.

Figure 4-14 shows the participant's performance, by expertise level for low- and high-stress situations. When stress is low, participants achieve best in the equal-expertise condition ($p < .001$). The obverse is true under high stress, where participants do best when the consultant is a better expert ($p < .001$). Recall that decisionmakers probe substantially in the

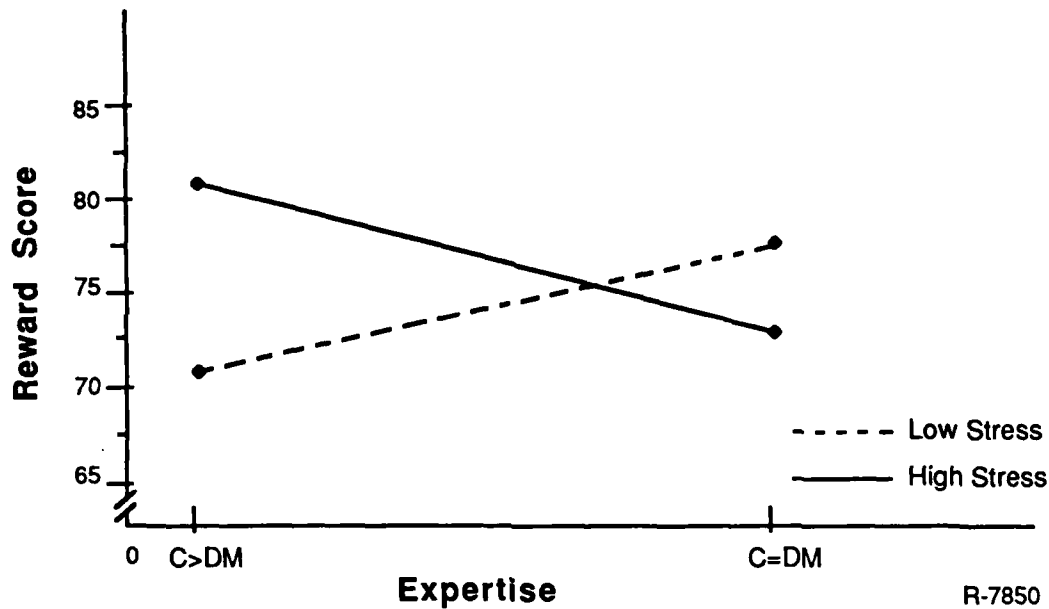


Figure 4-14. Reward Score as a Function of Expertise under Low- and High-Stress Levels for Civilian Sample.

equal-cost condition and consult more when the consultant is a better expert. We speculate that, under low stress, decisionmakers are less cognitively loaded and have more time (or cognitive capacity) to use the information-rich probe. They have the opportunity to interpret the information and fold it into their current belief about the discrimination task. However, when the situation is stressful, less time (or cognitive capacity) is available to deal with the probe; thus the available information is not effectively used, and decisionmakers do better with the processed opinions of the consultant.

The performance levels of decisionmakers are significantly better when the discrimination task is easy than difficult ($p < .007$) and this difference seems unaffected by stress. Closer scrutiny reveals that while performance is the same for difficult discriminations (a score of 64 in both low and high stress), participants performed significantly better under high stress (scores of 90 versus 85 for low and high stress, respectively) when the discrimination task is easy ($p \leq .05$). We speculated that the better overall performance reported earlier for the high-stress condition is due to an increase in arousal or motivation. It now appears that increases in

arousal or motivation foster better performance only when the discrimination task is easy and not when the task is difficult.

Figure 4-15 shows the combined effects of cost and expertise on reward score for the low-stress level. Little performance difference is observed among the three cost levels when in the consultant-a-better-expert condition. In the equal-expertise condition, however, performance varies over the cost levels with the best performance occurring at the equal-cost level. These differences are not observed under high levels of stress.

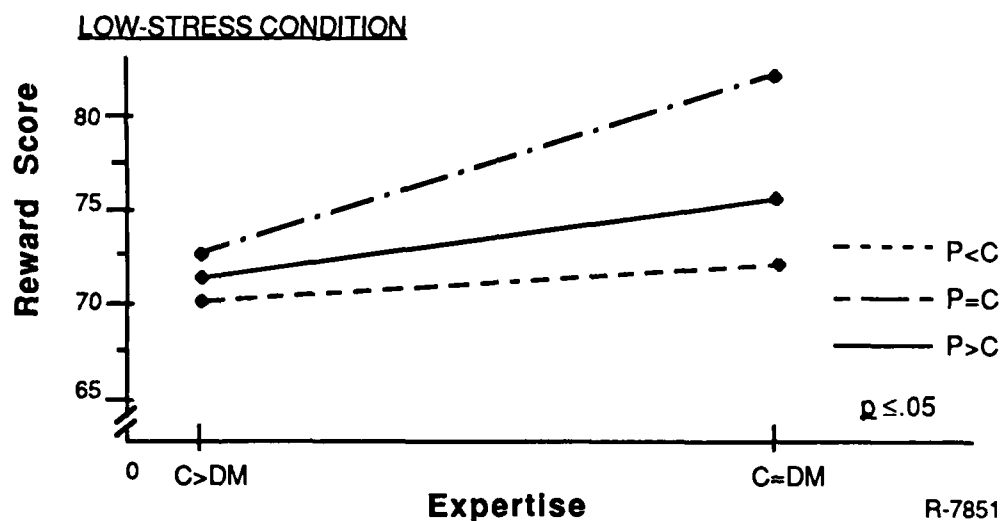


Figure 4-15. Reward Score as a function of Cost and Expertise under Low Stress for Civilian Sample.

Inspection of the probing and consulting patterns, as well as the workload data, sheds no light on why the equal-cost condition should perform better than the other two cost levels in the equal-expertise situation. Participants probe heavily in the equal-cost condition (98 percent), but also do so when the probe is least expensive (99 percent), yet these two treatments show quite different performance outcomes. Reported workloads for these treatments are also about the same. Only further experimentation will resolve this issue.

There appears to be no significant joint effects of cost and discriminability when stress is low, but a significant interaction is observed when stress level is high ($p < .004$). Figure

4-16 shows that the performance levels for the three cost conditions are almost the same when discrimination is easy, but considerable differences in performance among the cost levels is seen when the discrimination condition is difficult. In this situation, performance is best in the equal-cost condition, while the performance levels for the other two cost treatments are about equal. Results discussed earlier showed that civilians probed predominately in the probe-least-expensive condition and consulted predominately in the consultant-least-expensive condition; however, they probed and consulted about equally in the equal-cost condition. In this high-stress difficult-discrimination situation we surmise that this balance of probing and consulting provided the decisionmakers with the best blend of easy-to-use information from the consultant and rich information from the probes, leading to better performance.

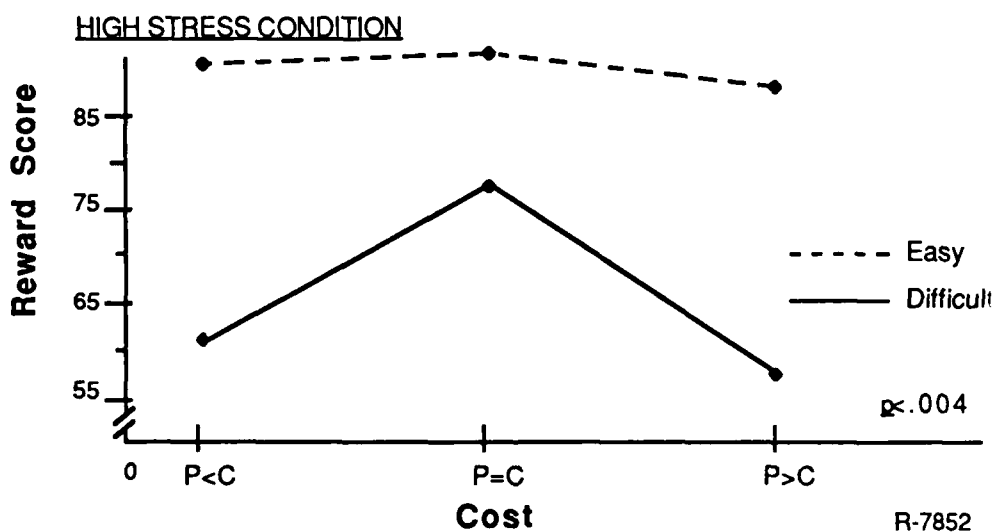


Figure 4-16. Reward Score as a Function of Cost and Discriminability under High Stress for Civilian Sample.

The joint effect of expertise and discriminability impacts performance in both low and high levels of stress. In low stress (see Fig. 4-17), performance at both expertise levels is about the same under easy discrimination, while in difficult discrimination performance is best when the consultant and decisionmaker are equal in expertise as compared to the level where the consultant is a superior expert ($p < .001$). Figure 4-17 also shows that under high stress

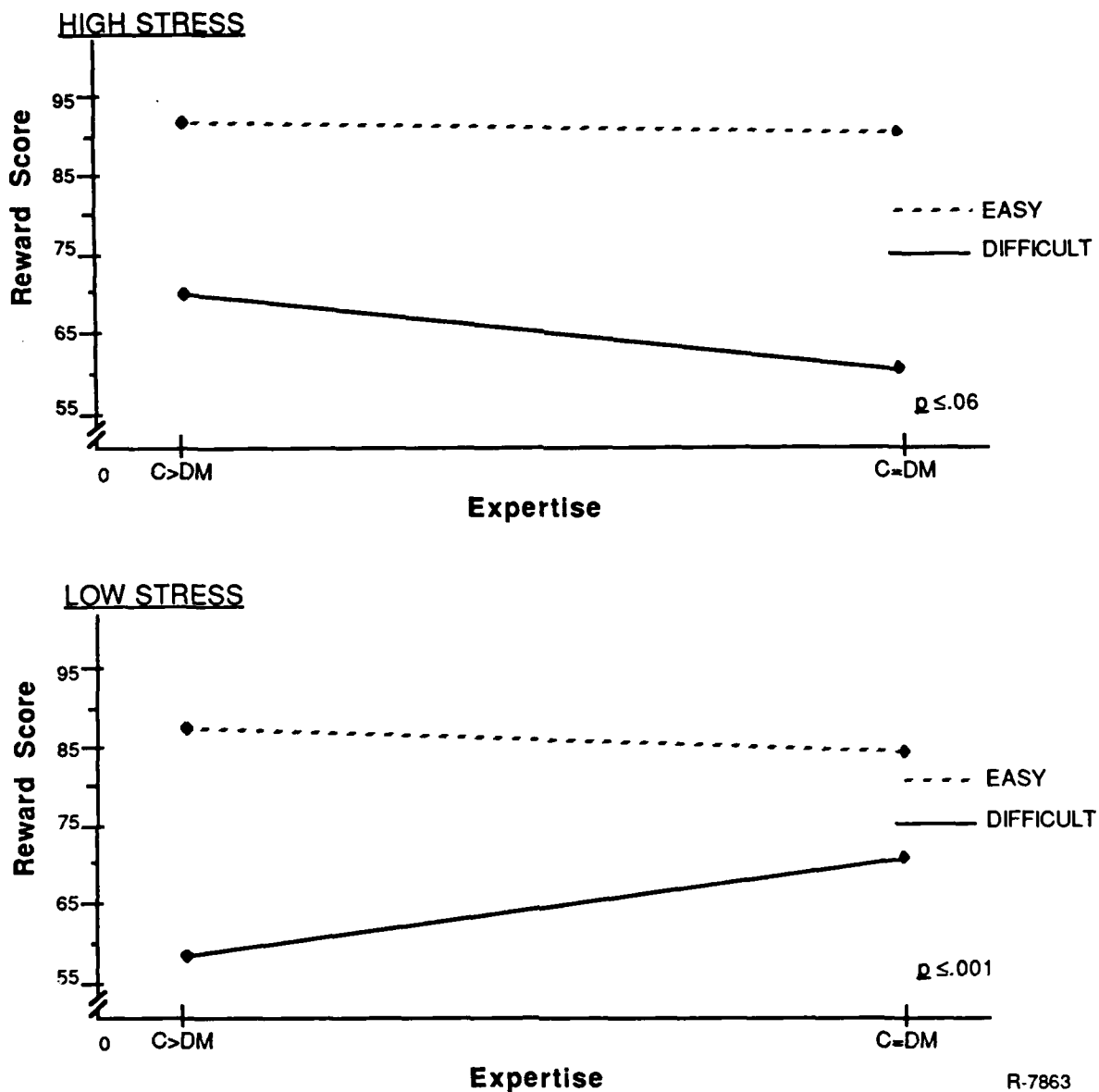


Figure 4-17. Reward Score as a Function of Expertise, Discriminability, and Level of Stress for Civilian Sample.

the difference between the two expertise conditions is twice as large in the difficult- versus easy-discrimination situation (difference of 4.8 versus 9.7, respectively, $p < .06$). Moreover, in contrast to the difference seen in low stress, under high stress the consultant-a-better-expert condition performs better than the equal-expertise condition, when discriminations are difficult. Looking back, we see that decisionmakers probed heavily in the equal-expertise, difficult-discrimination treatment. Under low stress, decisionmakers have the time to extract the

information available in the probe's measurement. Under high stress, participants heavily consulted in the consultant-a-superior-expert condition, when discriminations are difficult. In this time-critical situation, subjects do better when they can use the processed information of the superior expert.

4.2.4 Workload

The analysis of subjective workload parallels the analysis of performance. That is, the effects of the various independent variables on subjective workload scores are observed nested within low- and high-stress conditions.

The effect of information cost on workload for both the high- and low-stress conditions is presented in Fig. 4-18. The three cost treatments appear to have no affect on workload when stress is low, while a significant effect of cost is observed under high stress ($p < .02$). In conditions of high stress, participants report low workload when the probe and consultant are equal in cost. It was noted earlier that participants exhibited higher performance in the equal cost condition than the other two cost levels. This performance result was explained by the fact that subjects probed and consulted equally in the equal cost condition, and it was speculated that perhaps this particular blend of information sources provided the best information supplied by probing or consulting. We feel a similar explanation holds for workload. Because cost favors neither probing or consulting in the equal cost condition, participants feel free to probe when they think a probe will help (i.e., provide the most useful information) and consult when they think consulting will yield the best aid. In contrast, situations where one source of information favored by cost over the other, participants feel compelled to turn to the cheaper source, even when they feel the more expensive source might be more useful. This cognitive conflict undoubtedly creates some stress and hence higher workload. In conditions that are free of cost considerations, subjects feel they can turn to whichever source will be most useful; this in turn creates less stress and lower workload.

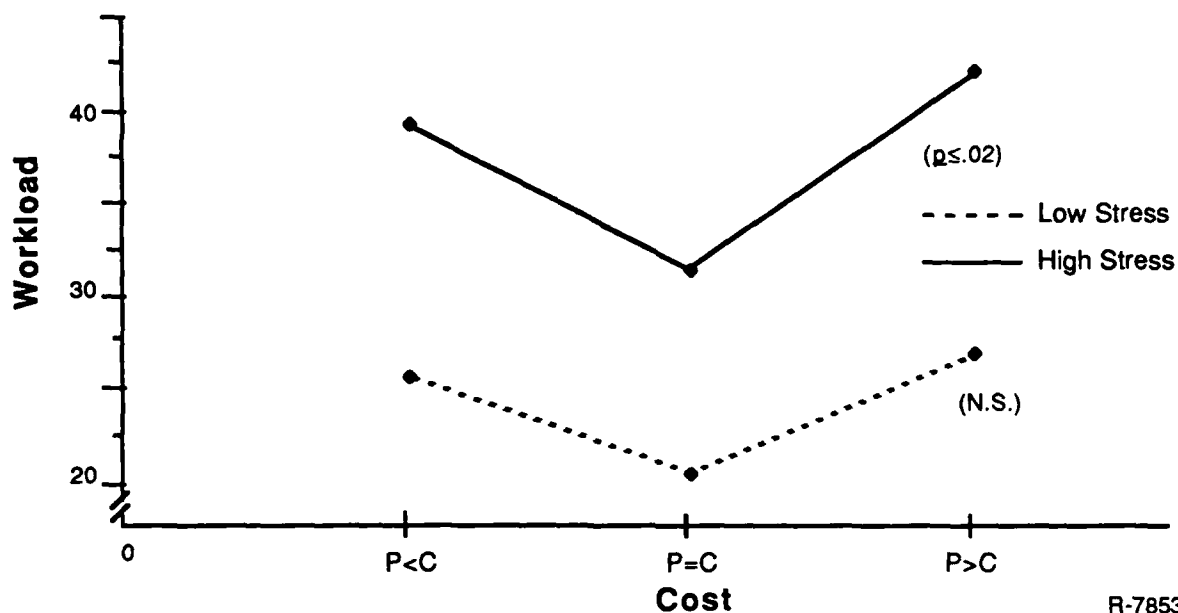


Figure 4-18. Workload as a Function of Cost and Stress for the Civilian Sample.

Consultant expertise does not appear to affect workload when stress is high, as depicted in Fig. 4-19. This figure also shows that in low-stress situations marginally higher workload rating are given when the consultant is a better expert ($p < .07$). In this case, higher workload may be due to feeling obligated to ask the consultant, because he is a better expert, even when one really does not wish additional information or feels a probe would yield more useful information.

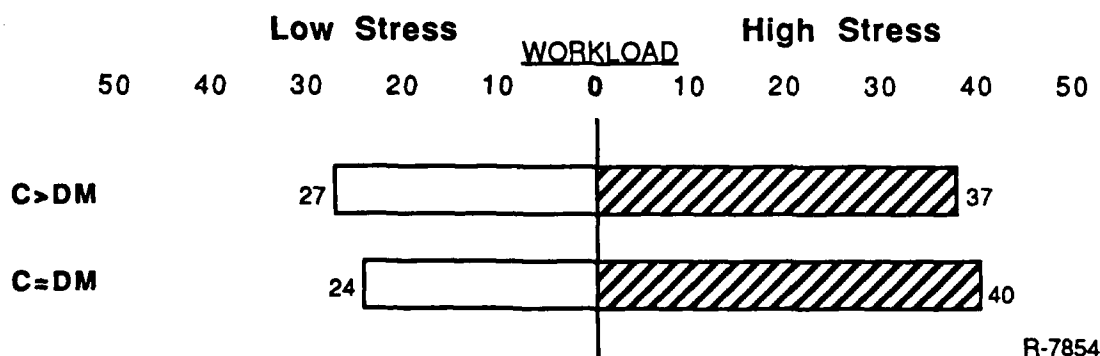


Figure 4-19. Workload as a Function of Expertise and Stress.

As expected, discriminability has a significant impact on workload regardless of stress level. Under both high- and low-stress levels, higher workload ratings are obtained in the difficult-discrimination condition ($p_s < .008$ and $.003$, respectively) because it is (in fact) more difficult to discriminate enemy from friendly submarines when their respective pump noise signatures are only half a standard deviation apart.

The joint effect of expertise and discriminability does impact workload, but only under conditions of low stress ($p < .04$). In Fig. 4-20 we see that when discrimination is easy, reported workload is about the same in the equal expertise and consultant-a-better-expert conditions. When discrimination is difficult, higher workload is reported when the consultant is a better expert than when the consultant and decisionmaker are equal in expertise.

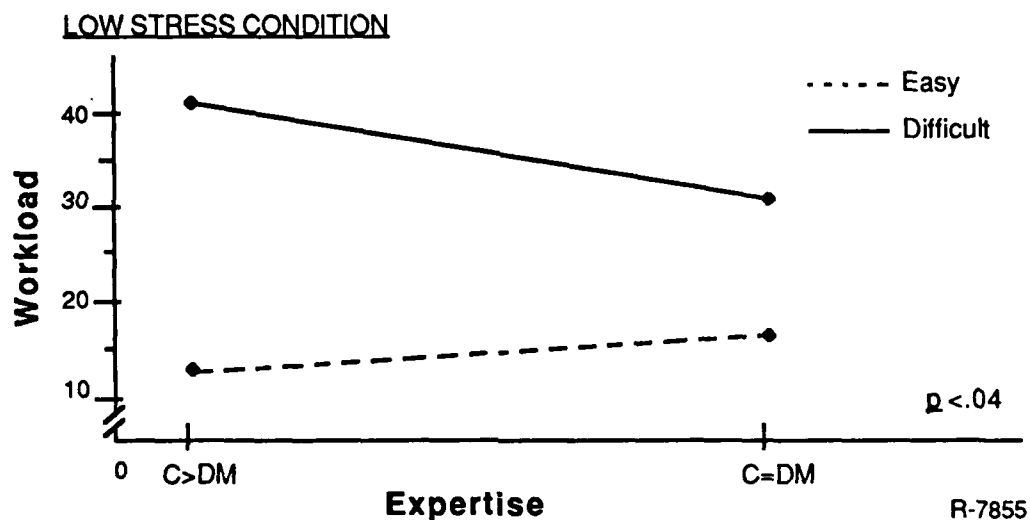


Figure 4-20. Workload as a Function of Expertise and Stress for Civilian Sample.

The marginally significant result, reported earlier showing higher workload when stress is low and the consultant is a better expert is now better defined. It is when discriminations are difficult and subjects feel more compelled to ask for additional information, that subjects report higher workload. We now surmise that two sources of pressure or stress may be aroused and feed feelings of workload. One arises from the demand to ask the consultant for help when he is a better expert (even in conditions where one might not wish to), and the other from

expending extra effort to obtain and integrate additional needed information. It is not possible to discriminate between these two sources, but either leads to higher reported workload.

4.3 CIVILIAN AND MILITARY DECISIONMAKERS: COMPARISON OF DECISION STRATEGIES

4.3.1 Premise

As we gathered our data about information-seeking and decisionmaking strategies, we contemplated a question pertinent to issues of external validity: would trained decisionmakers, particularly those with military experience, act the same way as our samples drawn from industry and academia? After all, it is our intention to generalize our findings to a military population. In an attempt to address this issue, a military sample was obtained from the Naval War College, Newport, RI. In most regards, we expect the Navy sample to act like our civilian sample. There are several predicted differences, however. Based on discussions with Capt. Frank Snyder (Ret.), a faculty member at the Naval War College, we hypothesize that Navy decisionmakers will be willing to make decisions with less information than the civilian sample. This is predicted because military-experienced decisionmakers continually must make decisions based on insufficient information. Thus, they are used to it and become conditioned to work in this manner. We also expected that military decisionmaking experience would help decisionmakers deal with stress. Thus, we predicted that our Navy sample would be less affected by stress than our civilian sample.

4.3.2 Comparison of Information-Seeking Strategies Under Stress

The first analyses explore the differences in information seeking for the military and civilian samples. Figure 4-21 shows that civilians requested information equally in high- and low-stress situations, while the military sample showed a marginal tendency to request additional information more under low stress ($p < .09$). Perhaps, more germane, it was hypothesized that under stressful conditions, military decisionmakers would seek less information than the civilian decisionmakers. This hypothesis is strongly confirmed, as shown in Fig. 4-22.



Figure 4-21. Information Request as a Function of Stress for Both Samples.

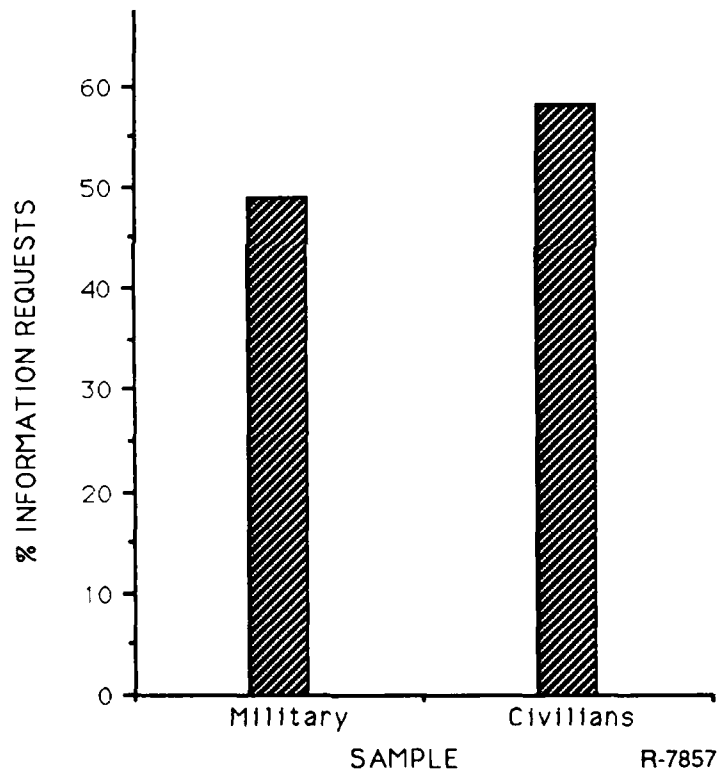
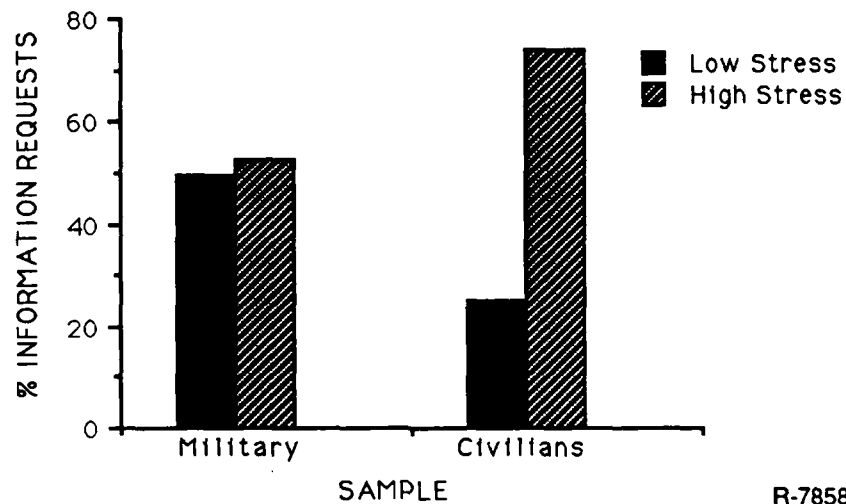


Figure 4-22. Information Seeking Under High Stress for Military and Civilian Samples.

In the stress condition, military personnel requested additional information only 48 percent of the time, while civilian decisionmakers asked for more information 58 percent of the time

($p < .001$). When the discrimination condition was difficult in addition to stressful, the difference is more dramatic, as shown in Fig. 4-23. Military decisionmakers requested information 51 percent of the time, but civilians elicited more information 74 percent of the time ($p < .001$).



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Figure 4-23. Information Request Under Stress and Difficult Discriminations for Military and Civilian Samples.

We speculate that the specific training, as well as experience, afforded military decisionmakers has often forced them to make decisions with a paucity of information. Thus, they have developed a strategy and a willingness to make decisions with a limited amount of information. A bromide we heard quoted about Navy commanders sums it up, "Maybe incorrect but never indecisive."

Cost appears to affect information seeking differently in the two samples. Civilians requested the most information (63 percent) when the costs of probing and consulting were equal (see subsection 4.2.1). Military decisionmakers show an opposite trend by requesting additional information least often (46 percent) in the equal-cost condition ($p < .01$). Military personnel, on the other hand, sought information the most (55 percent) when the consultant cost less than the probe, while civilians requested the least amount of information (55 percent)

in that cost condition. Results show that high stress flattened the differences among the three cost conditions for the civilians.

Discriminability appears to have less effect on information seeking for military decisionmakers than for the civilians. Civilians increased their information seeking by 60 percent in the difficult-discrimination situation, but the military sample exhibited only a marginally significant 18 percent increase in the same condition ($p < .08$). The pattern to seek more information in difficult-, as compared to easy-discrimination conditions is essentially unaffected by stress in both samples. However, within the difficult-discrimination condition, stress causes a 5 percent increase in information seeking for civilians and a 12 percent decrease in information seeking for military decisionmakers. We are not sure why the combination of stress and difficult discrimination causes the military decisionmakers to decrease their information seeking. Perhaps the combination of these two factors further reinforces their preexisting tendency to make decisions with the information at hand.

The joint effect of cost and expertise significantly impacts information seeking in the military sample ($p < .02$), but not for the civilians. As shown in Fig. 4-24, when the probe is least expensive, military decisionmakers request more information in the equal-expertise condition than the consultant-a-better-expert condition, while more information is requested in the consultant-a-better-expert condition than the equal-expertise condition when the probe is most costly. This is the pattern seen under low stress, and although mitigated to some extent, the same pattern is seen under high stress. Stress, however, seems to affect the equal-cost condition differentially. Under low stress, more information is requested when the consultant is a better expert, but the obverse is true when stress is high.

It was expected that participants would request more information when the consultant is cheaper than the probe and also a better expert. Subjects can get good information at low cost. This does not appear true for the civilians. We think this is because the civilians were biased against asking the consultant. Military subjects show a propensity to request more information when the probe is less expensive than the consultant and the consultant is equal in expertise to

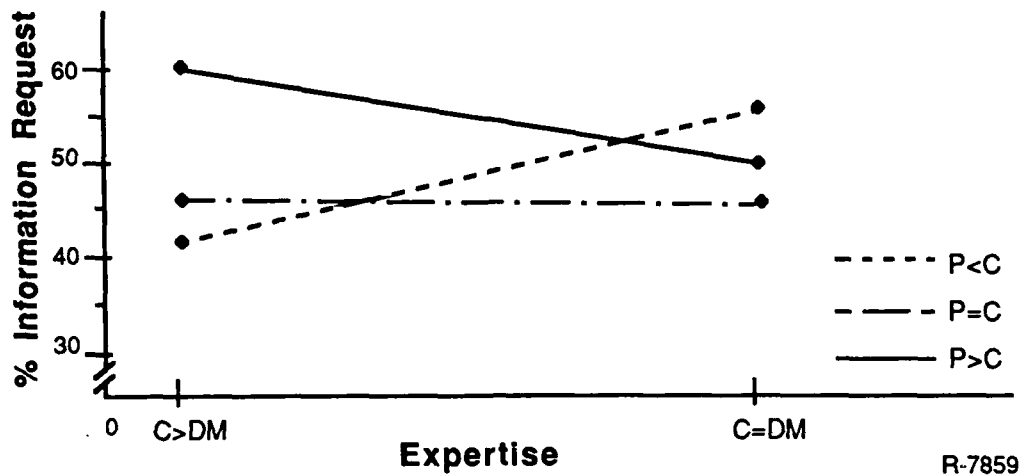
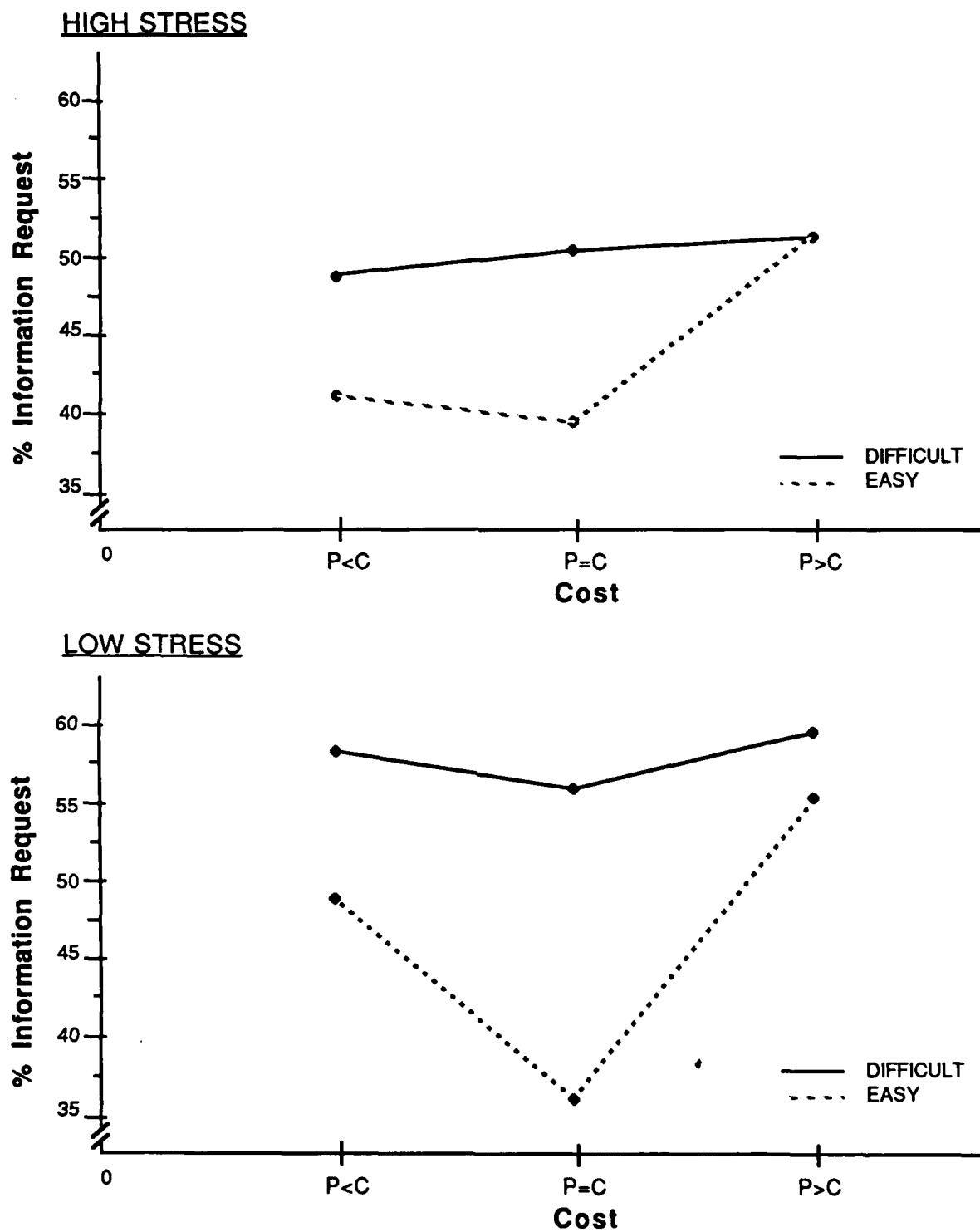


Figure 4-24. Percent Information Request as a Function of Cost and Expertise for the Military Sample.

the decisionmaker, and this is because military decisionmaker tends to probe under such conditions. It is unclear why the civilians do not follow suit.

The military sample's pattern of results, depicted in Fig. 4-25, for the effects of cost, discriminability, and stress differs in several ways from the civilian's pattern shown earlier in Fig. 4-10. For the civilian sample, stress appeared to increase information requests in difficult-versus easy-discrimination conditions. The opposite is true for the military sample, where high stress seems to mitigate the differences between difficult- and easy-discrimination conditions. For military decisionmakers, the largest difference in information requests occurs in the equal-cost condition (under both low and high stress), while for the civilian, the difference in information requests is about the same in probe-less-expensive and equal-cost conditions. One similarity between the samples: the difference between difficult- and easy-discrimination conditions, as to information requested, is smallest in the probe-more-expensive-than-consultant cost condition.

Once again, we see that the military decisionmakers' response to stress and difficulty is to reduce the amount of information seeking. This is exactly opposite to civilian decisionmakers, but is consonant with our described beliefs concerning the training of military



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Figure 4-25. Percent Information Requests as a Function of Cost, Discriminability, and Stress for Military Decisionmakers.

commanders. Why military decisionmakers request more information in difficult discrimination conditions, when the cost of probing is equal to that of consulting, is more difficult to explain. We will delay the discussion of this effect until the patterns of probing and consulting are examined more closely.

The combined effects of expertise and discriminability did not influence civilian decisionmakers' information seeking regardless of stress level. This is also true for military decisionmakers in low-stress situations, but under high-stress situations an interesting pattern develops. As Fig. 4-26 shows, under high stress more information seeking occurs in the easy- versus difficult-discrimination condition with expertise equal, while the opposite is true in the consultant-a-better-expert situation. Moreover, in this latter expertise condition, high stress appears to increase the difference between easy- and difficult- discrimination conditions by differentially reducing the number of information requests in easy discriminations. So although high stress still has an overall decreasing effect on information seeking in the military sample, the effect is considerably less in the difficult-discrimination condition when the consultant is a better expert. At this expertise level, high stress appears to have decreased information requests more in the easy-discrimination situation than has been previously observed. We feel this is due to the willingness of the military decisionmakers to turn to the consultant when seeking information, particularly when the consultant is a better expert than themselves. This will be taken up again when the pattern of probing and consulting is examined.

4.3.3 Comparison of Probing and Consulting Patterns

Overall, civilians showed a preference for probing over consulting (58 percent versus 42 percent, respectively), while military decisionmakers showed the opposite trend consulting 57 percent of the time. In high-stress conditions, civilians tended to consult more than they do in low-stress conditions, but stress did not influence information source for the military sample.

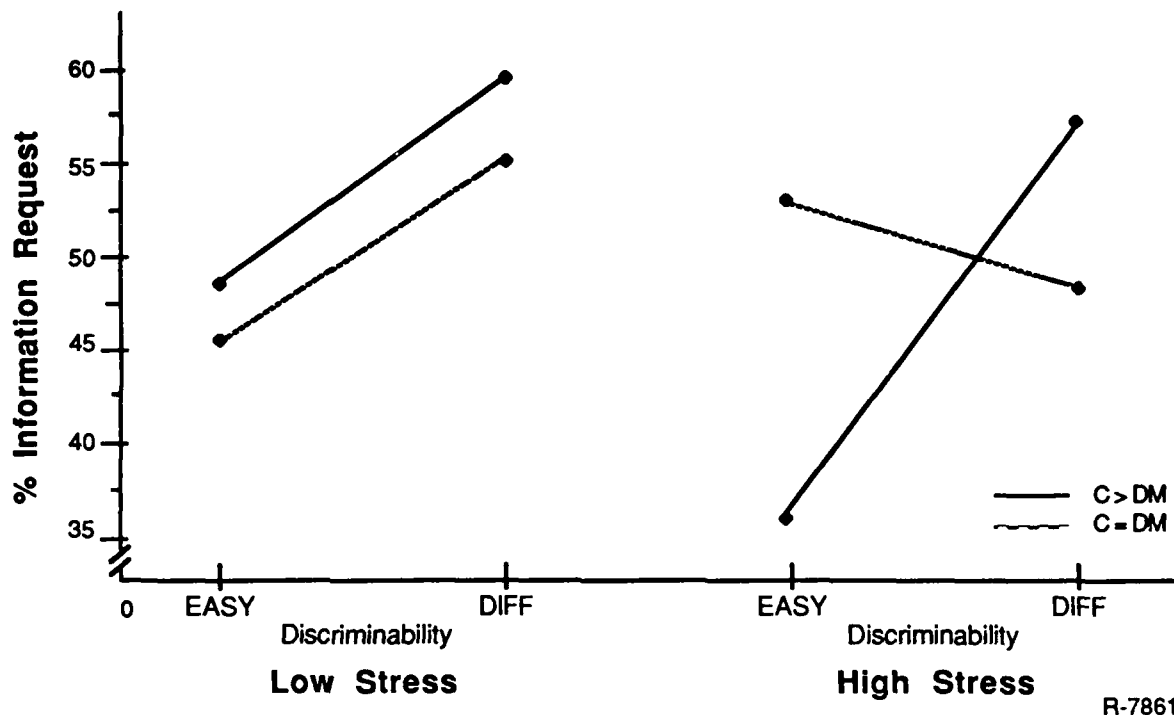


Figure 4-26. Percent Information Requests as a Function of Expertise, Discriminability, and Stress for Military Sample.

As we saw before, the information-seeking strategies of military decisionmakers are unaffected by stress alone. When they do seek information, however, they favor the consultant. This may be due, in part, to their long experience and training working in teams.

The effects of cost and expertise on information source, regardless of stress level, appear the same for both samples (see subsection 4.2.2 for a description). Discriminability shows some variability and interacts with stress differentially for the two samples. Civilians tended to probe more in the easy- versus difficult-discrimination situation, but military personnel showed no such difference. The difference in probing preference evidenced by the civilians became stronger under high stress. Under low stress, no difference in information source existed. Once again, none of these effects observed for civilians are evident in the military sample. Military decisionmakers do not significantly favor probing or consulting as a function of stress and discriminability.

Examining the combined effects of cost and expertise, it is again clear that military decisionmakers consult more in about every condition; otherwise the pattern of results for these independent variables is the same for the two samples. Essentially, this pattern shows increased consulting with increases in the cost of probing, and this is true for high- and low-stress situations. The other remaining independent variable combinations did not produce significant effects for either sample.

4.3.4 Comparison of Performance

Across all conditions, the final reward scores for military and civilian decisionmakers are almost identical (about 75, on a 0-to-100 scale). Civilians, however, show better performance (as described previously) under high versus low stress, and military decisionmakers show the opposite tendency, performing better under low than high stress ($p < .04$, one tail).

Under both high- and low-stress levels, civilian performance peaked in the equal-cost condition compared to the other two cost conditions (see subsection 4.2.3). Information cost appears to have no effect on the performance of military decisionmakers, and this is true under both levels of stress.

Expertise impacts performance the same way for both samples. That is, under high stress, higher reward scores are attained when the consultant is a better expert than when the consultant and decisionmaker are equal in expertise, while under low stress, higher performance occurred in the equal-expertise condition than in the consultant-a-better-expert condition. We explained this outcome for the civilians by noting their probing and consulting pattern and how this pattern interacted with stress (see subsection 4.2.2). Essentially, the higher probing rate observed in the equal-expertise condition provides more useful information under low stress, and the higher consulting rate seen in the consultant-a-better-expert condition supplies easier-to-use information for the high-stress situations.

The military and civilian samples' patterns of performance for discriminability by stress are the same. Specifically, higher performance occurs in the easy- versus difficult-discrimination treatment, regardless of stress level.

The performances of military and civilian personnel do not appear to be affected the same way by the joint effects of cost, expertise, and stress. Figure 4-27 shows the performance of military decisionmakers as a function of cost and expertise under low stress. When the probe costs less than consulting, military personnel perform better in the consultant-a-better-expert versus equal-expertise condition. Civilians, on the other hand, showed no difference in performance for the same treatments (see Fig. 4-15, subsection 4.2.3). From earlier discussions, we recall that civilians probed very heavily in both expertise conditions, while military decisionmakers probed only half as much in the condition where the consultant is a better expert. In fact, military personnel consulted twice as often as civilians in this condition. A probe yields richer information, but the decisionmaker must be able to utilize it all to get the full benefits. Perhaps the increased amount of easier-to-use processed information provided by the expert consultant enabled the better performance of military decisionmakers in the consultant-a-better-expert condition versus the equal-expertise condition.

Figure 4-27 also shows that military decisionmakers perform better in the equal cost versus the probe-more-expensive treatment in the consultant-a-better-expert condition. Performance increases for the military personnel for both these cost levels in the equal expertise condition. The increase, however, is steeper for the probe-more-costly level; thus the difference in performance for the two cost conditions is "washed out" in the equal-expertise situation. Interestingly, this increase in performance parallels an increase in consulting. It would appear that the consultant's processed information is being more efficiently applied than the probe's information. High stress levels reduce to nonsignificance all the differences seen in low stress, and this is true for both samples.

The combined effects of cost and discriminability do not appear to impact the performance of either sample when stress is low. In high-stress situations and difficult-discrimination

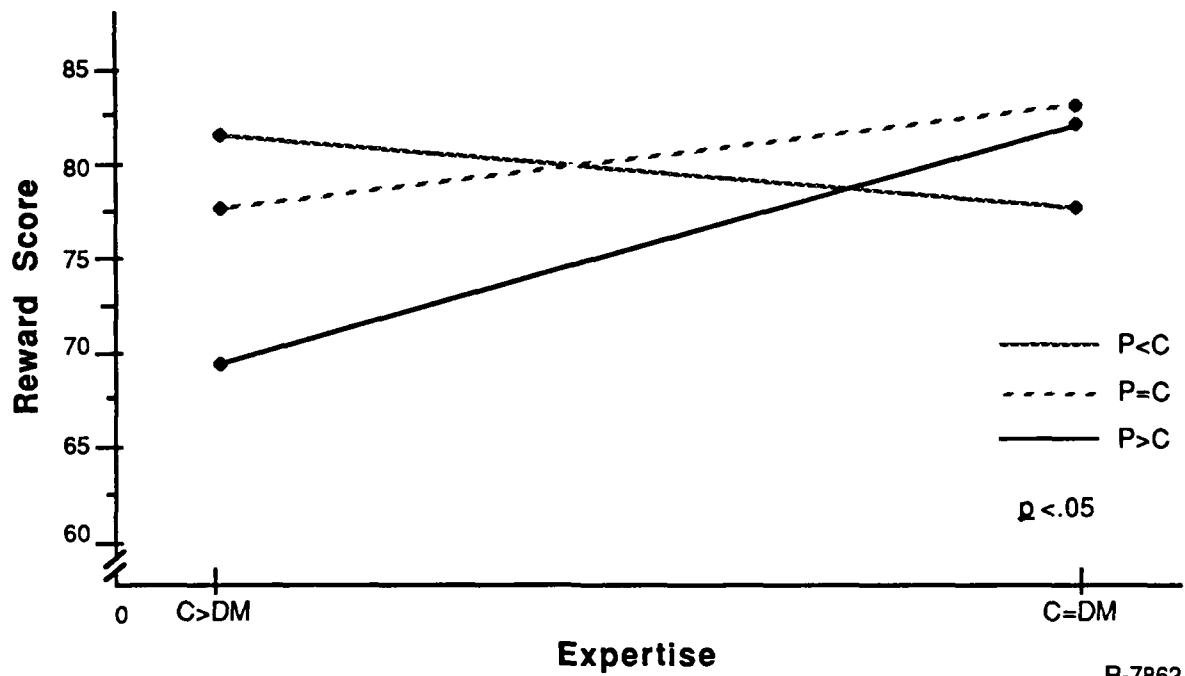


Figure 4-27. Reward Score and Function of Cost, Expertise, and Low Stress for Military Sample.

conditions, civilians performed best in the equal-cost condition compared to the other two cost conditions. Moreover, the difference in performance between the difficult- and easy-discrimination situations for equal cost is half of what it is in the other two cost conditions. The performance of military decisionmakers appeared unaffected by cost and discriminability under high stress.

For the civilian sample expertise, discriminability, and stress significantly affected performance. No effects of these factors were found for performance in the military sample.

SECTION 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 MAJOR RESULTS

It was hypothesized that decisionmakers in the current study and the earlier TOSCA-I study would choose between probing and consulting according to a cost-benefit consideration. Cost of information would be the most important determinant of choice, followed by consultant expertise. Thus, if decisionmakers and consultants were equal experts, decisionmakers would select the lest costly information source; if the cost of probing and consulting were equal, then decisionmakers would seek information from the superior consultant; and if cost and expertise were both equal, then decisionmakers would probe, because a three-digit measurement provides more bits of information than a single opinion. Results of the current study match those of the earlier TOSCA-I and show that decisionmakers closely follow these cost-benefit decision rules. To strive to obtain the best information at the lowest cost is obviously a wise course of action and parallels what an optimal decisionmaker would do.

Based on the findings of TOSCA-I, it was also hypothesized that decisionmakers would seek more information in difficult versus easy conditions. Strong support for this hypothesis is found in the data. In low-stress situations decisionmakers significantly sought more information in difficult discrimination conditions. Under high stress, this tendency became even stronger. Also as hypothesized, in high-stress and difficult-discrimination situations when decisionmakers requested information, they turned more often to the easier-to-use processed information of the consultant than the probe's raw measurement.

Another factor that influences this proclivity of information seeking is information cost. In difficult, high-stress, and cheap-probe conditions, decisionmakers sought additional information about 80 percent of the time. All this information seeking, however, does not always

bear fruit. The performance results show that heavy probing or consulting did not always yield the best outcomes. Often the equal-cost condition, where decisionmakers tended to probe and consult somewhat equally, yielded the best performance scores. This finding seems to indicate that decisionmakers can not always derive or use all the information that is offered by a probe's measurement, sometimes they probe when they should seek the easier-to-use processed information of the consultant, and sometimes they ask for information in situations where additional information is not going to be very helpful (e.g., asking the consultant in difficult discrimination conditions, where the consultant's information is not better than the decisionmakers'). In short, decisionmakers tend to request information in situations where it is not wise or very useful and are not very optimal in extracting or using the information supplied.

When considering whether or not to request information, decisionmakers seemed more reluctant to ask for information when the consultant was cheapest than when the probe was cheapest. In fact, decisionmakers did not request more information in cases where the consultant was cheaper than the probe and a better expert than the decisionmaker. It seems as if decisionmakers are reluctant to give up control of the decisionmaking process. That is, if a decisionmaker makes a decision without requesting additional input, or asks for another measurement that is then interpreted by them and integrated into their position, decision outcomes (particularly successes) are personally attributed. If the consultant is asked, then the decisionmaker must share the success with the consultant.

Once, however, the decision is made to request additional information, much of this bias against asking the consultant dissipates. The cost by expertise by level of stress interaction clearly shows that decisionmakers turn to the consultant when he is cheaper than the probe or a better expert than him, or both. Under high stress, it is also clear that decisionmakers place a higher premium on the consultant's being expert than being cheap.

Unexpectedly, it was found that decisionmakers performed better under high than low stress. It soon became clear, however, that performance was only better in high stress when discrimination conditions were easy. Apparently, stress possesses arousal stimuli that motivate

the decisionmakers to be more vigilant and work harder. Under easy discrimination, more vigilance or harder work can lead to better performance more easily than under difficult-discrimination conditions.

It was hypothesized that military decisionmakers will request less information than civilians when under stress. Results strongly confirm this expectation. Under high stress, civilian decisionmakers requested additional information 21 percent more often than military decisionmakers. If conditions were both stressful and difficult to discriminate, civilians asked for information 65 percent more often than military personnel. It would seem that the training and experience afforded military commanders has conditioned them to work with the information at hand and to request additional information sparingly.

Military decisionmakers did not favor the same information source as civilians. Civilians showed a decided preference to probe, while military personnel preferred to ask the consultant. Moreover, in high-stress conditions, civilians tended to consult more than they did in low-stress conditions, but stress (or discriminability) did not influence information source for the military sample. This tendency for military personnel to favor the consultant over probing may be due, in part, to their long experience and training working in teams.

Overall, civilians tended to perform slightly better than the military decisionmakers. This is probably due to the greater amount of information civilians requested. There is, however, some evidence that military decisionmakers used the different information sources more efficiently: tending to probe when the probe would be more helpful, and consult when consulting appeared it would be more useful.

5.1.1 Conclusions

Clearly, stressful situations changes the way decisionmakers strive to reach decisions. Stress alters the information-gathering strategies they use and affects their decision performance. Perhaps one of the clearest findings is that, under stress and/or a difficult-discrimination condition, decisionmakers (civilians) increase their requests for additional

information to help reach a decision. It is also evident from the results that decisionmakers afforded military training and experience behave differently from military-naive decisionmakers. Military decisionmakers did not show the tendency to request additional information in stressful and difficult situations. Instead, they tended to make do with the information they had. If researchers wish to study the information-seeking and decisionmaking processes of military decisionmakers, these results argue that military-experienced personnel should serve as subjects.

5.2 RECOMMENDATIONS

5.2.1 Time Analysis

Extensive timing data were recorded throughout the experiment. For example, the lengths of time it took subjects to decide if they wished additional information, to select which information source to choose, and to integrate all available information and come up with a decision regarding submarine hostility were recorded. Unfortunately, current limits in time and resources preclude analysis of these data. We hope some time in the future to perform a thorough analysis of the timing data. We are encouraged to do this by preliminary analyses that indicate that: 1) various experimental treatments affected the timing measures differently and 2) the two population samples differ as to the amount of time taken to reach certain decisions. The results patterns are likely to be quite complex, and extensive work will be required to extract clear findings and allow unambiguous interpretations. We feel, however, the effort will be worth it, as further insights into decisionmaking under stress may be gleaned.

5.2.2 Improved Manipulation of Stress-Inducing Factors

While the stress manipulations were effective in significantly influencing information-seeking behavior, they did not generate very high levels of stress (or workload). The subjective workload ratings provided by our subjects as a result of the imposed time limit and secondary task were at the lower end of the workload scale. The mean subjective workload reported was 32 percent, while under the most difficult and stressful condition (high stress and

difficult discrimination), the mean workload score was 49 percent. It is evident that we have yet to observe information seeking and decisionmaking under truly high levels of stress.

To address this situation, we need to reexamine our secondary task and develop a new form that is more demanding and intrusive, yet realistic. Another avenue to explore is the possibility of operationalizing and manipulating several different stress-inducing variables at once, instead of just two. Two new candidates worthy of consideration are the appearance of unexpected but highly damaging events, provided through intel messages or patterns displayed on a map, and the difficulty or complexity of the information to be interpreted. This would introduce additional diversity to stressor types as well.

It should also be noted that the current study observed information seeking and decisionmaking in a relatively static environment. We recommend that the study of decisionmaking under stress be transitioned to a dynamic environment. A dynamic simulation would be more realistic, provide additional avenues to devise and operationalize stressors, and provide a greater variation of situations to observe information seeking and decisionmaking.

5.2.3 Study of Strategies

The introduction of a dynamic decisionmaking environment will have another advantage. Up to this point, decisionmakers have been afforded a very limited repertoire of strategies from which to choose. Our static simulation has constrained the number of options we can offer decisionmakers. The dynamic environment will allow for a greater number of, and hopefully more realistic, strategies at the decisionmakers' disposal. We will, thus, be able to observe how stressed decisionmakers really behave.

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APPENDIX A INSTRUCTIONS

INSTRUCTIONS FOR THE TOSCA-II SIMULATION GAME

TASK AND GOALS

You are the **commander** in charge of protecting the naval battle group from enemy submarines. Nuclear submarines are usually detected and identified by their circulator pump noise. The reactor aboard a submarine must be constantly cooled to prevent melt-down; thus, the circulator pump is never shut down. Different types of submarines have different styles of pumps and, hence, different pump noises.

Your principle task is to decide if a detected submarine is hostile or friendly. Intelligence informs you that two submarines are operating in the area about the battle group. One submarine is a **friendly attack boat** and has a **pump noise of 370 Hz**. The other submarine is a **hostile Victor boat** and has a **pump noise of 330 Hz**. On some occasions the hostile submarine will be a **Sierra** with a **pump noise of 360 Hz**. Intelligence will tell you in each condition whether the enemy is a Victor or Sierra class submarine.

As commander you know that the detection sensors are **not** perfect, ocean conditions can inject error, and the enemy can take actions to increase this error. On average, however, you can expect an error distribution around the true pump measurement that is zero mean, normal in shape, and has a **standard deviation of 20 Hz**. Figure 1 illustrates this graphically. This means that 68 percent of the time the sensors will report a pump noise measurement that is within plus or minus 20 Hz of the true pump noise. On rarer occasions the sensors' report may vary even more from the true pump noise.

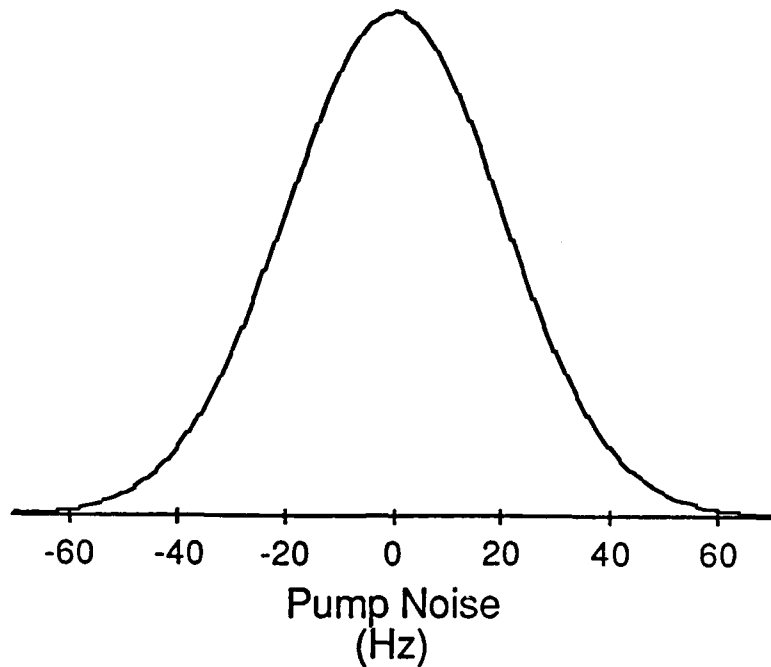


Figure 1. Distribution of Error Around The True Pump Noise.

Specifically, your task is one of discrimination and decision making. For example, assume intelligence tells you that the hostile submarine in the area is a Victor class (with a pump noise of 330 Hz) and you receive a measurement based on a single detection of 345 Hz. Given this information and the knowledge of the sensors' accuracy you must decide if the detected pump noise came from the enemy or friendly submarine (with a pump noise of 370 Hz).

IMPORTANCE OF CORRECT IDENTIFICATION

The correct determination of enemy or friendly submarine is an important decision and should **not** be taken lightly. If you **correctly** identify the submarine as **friendly**, no prosecution activities are initiated, you save resources, and the friendly submarine is left to accomplish its mission. If you **correctly** identify the submarine as an **enemy**, then prosecution activities are immediately initiated and there is a good chance the enemy will be located and deterred (or destroyed) before it can do damage.

On the other hand, if you **incorrectly** identify the submarine as **friendly**, then an enemy submarine is left free to attack and damage the battle group. If you **incorrectly** identify the submarine as **hostile**, then prosecution activities are initiated against a friendly submarine. This is a **needless waste** of valuable scarce resources and the **possibility of fratricide** exists.

ADDITIONAL INFORMATION, COST, AND CONSULTANT CAPABILITIES

Because these decisions are important you have recourse to additional information, if you deem it necessary, to help you make these decisions. Two resources are available, **but at a cost**. You can task the sensors to take another measurement or you can request the opinion of a "consultant" (i.e., another experienced commander on a different platform who receives information independent of yours) as to the identity of the detected submarine. Based on the situation, cost is incurred whenever you choose to use either resource. The cost of tasking the sensors can be greater than, less than, or equal to the cost of asking the opinion of the consultant.

On some occasions the consultant has better measurements (i.e., smaller standard deviation about the true pump noise) than you. In these cases it is expected that, on the average, the consultant would make better decisions than you. At other times, the measurement qualities for you and the consultant are equal. In these cases neither of you has an advantage over the other. Note that although the consultant strives to be perfect, this is unattainable. The consultant does make mistakes. There are also times when the consultant cannot reach a decision, and will return a message of, "I do not know."

The consultant is aware that you have asked for assistance and takes this fact into account when formulating an opinion. That is, the consultant does not know your specific pump noise measurement, but speculates on what measurement you must have received to lead you to ask for assistance. This speculation (or measurement estimate) along with the consultant's own independent measurement is combined to form the consultant's opinion.

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AWARDScore

After each trial you will receive a score assessing how well you used your resources and performed the task. Cost and the award score are related. Everyone starts each trial with a fixed amount of resources. If no costs are incurred and the submarine is **correctly** identified, the award score is **100 percent**. If, however, the submarine is **incorrectly** identified then a portion of the initial resources are used-up or wasted. It is estimated that an error consumes **80 percent** of the initial resources. Thus, the award score is **20 percent** in such cases.

Requesting the opinion of the consultant or tasking the sensors for another measurement cost either 5 or 15 percent of the initial resources depending on conditions. In these instances, if the submarine is **correctly** identified the award score is either **95** or **85 percent**, respectively.

If, however, an error is made, that is the submarine is **incorrectly** identified, **80 percent** of the remaining initial resources are wasted. In this instance the award score is **15** or **5 percent**, respectively.

Based on the new information (either another measurement of the pump noise or the consultant's opinion) you must reach a decision regarding the detected submarine. After each determination you must rate your confidence, i.e., the probability that your decision is correct (on a seven point scale, where **1 equals very low** and **7 equals very high confidence in the decision**). Feedback as to the correctness of each of your decisions and the award score is given at the conclusion of each trial.

TIME LIMITS AND AN ADDITIONAL COMMUNICATION TASK

On some occasions you will be able to perform this discrimination/decisionmaking task without any specific time limit and with no other duties to interfere with performing the task. At other times, conditions will impose a specific time limit. On those occasions a **time bar** will appear to help you budget your time. Budgeting will be important, because during these instances you will also be responsible for another task in addition to the detection task. This **additional communications** task will require you to send another pump noise reading from your

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sensors, taken on another target, to a different platform. Then, after some delay, you will have to verify that the correct message was sent.

When the communication task is present it must be completed along with the detection task in the time given. **Failure to complete either task in the given time period will result in failure on both tasks, and zero award.**

Please consider each trial and decision carefully. Your performance will be compared to an optimal algorithm, so try to do your best. Your work will be taken as the full measure of your ability to do this task.

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INSTRUCTIONS FOR THE TOSCA-II SIMULATOR

PROCEDURE

These instructions are designed to help you learn how to use the simulator and perform the decisionmaking task. Please locate Figure 1. Figure 1 presents one of the displays you see while performing the task.

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Figure 1

TOSCA-II Display

The band at the top of the screen displays, from left to right, the condition code, the trial number, and your name. During training, your name is replaced by Training. The number following your name tells what session you are currently performing. There are four sessions.

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INTEL Window

The window labeled INTEL (upper left of screen) provides intelligence information. Information about the pump noise signature of the friendly submarine and the pump noise signature of the enemy submarine known to be operating in the area are displayed. The window also provides data on sensor error for you and your consultant. This is the error known to be inherent in the sensor hardware employed.

The information displayed in this window is crucial to proper decisionmaking. You should constantly monitor this window. Moreover, you want to be immediately aware when the enemy pump noise signature changes signifying a different submarine and when the standard deviation of the consultants error distribution changes indicating a different sensor quality. Failure to monitor and consider the information displayed in this window can lead to poor decisionmaking.

COMMAND AREA Window

The COMMAND AREA window is located just below the INTEL window. In this window information is requested and decisions issued. The mouse is used to do both.

At the start, **Initial Measurement** was black. When you clicked on it, it turned gray and the **Enemy**, **Friendly**, and **?** labels turned black indicating what you are to consider next. If you click on either **Enemy** or **Friendly** (as well as, **?**), this row of labels turns gray. If you click on **?**, the **Probe** and **Consultant** labels turn black. After you have decided which type of information you desire and clicked on it, **Enemy** and **Friendly** turn black again.

Following your Enemy/Friendly decision you enter your confidence that your decision is correct. Once again, click the mouse on the numbered boxed that best reflects your confidence in your decision. Rate your confidence carefully. This is how the commander communicates to others (e.g., his superiors) how seriously they should consider his decision. Do not transmit misinformation. Once you have clicked on a confidence box, the **Feedback** label turns black. Before you click on the feedback button, you can change your confidence decision by

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clicking on another numbered box. When you click on **Feedback** the trial ends and you are given feedback on how you did for that trial.

REWARD Window

This window on the right side of the screen describes the cost of making an error, the current cost of a probe, and the current cost of asking the consultant. Each of three 2x2 tables gives the cost and subsequent reward score when the information associated with that table is requested. If you use only the initial measurement and your decision is **correct**, that is, you choose enemy and it is an enemy submarine or you choose friendly and it is an enemy submarine - no additional resources are used, thus your reward score is 100%. If you choose **incorrectly**, errors cost 80% of your resources, thus your reward score is 20%.

The Probe and Consultant tables are computed in a similar fashion. Sometimes the cost of a probe or asking the consultant is 5%, other times 15% of your resources. Assume that you ask for additional information. In the cases where probing or consulting costs 5%, and you choose **correctly**, you earn a score of 95%. If, however, you choose **incorrectly**, you earn a score of 15%. In cases where the cost of probing or consulting is 15% and you choose **correctly**, your score is 85%. An **incorrect** choice would earn you only 5%.

Monitor the information in this window carefully. To make proper decisions you need to consider what additional information would cost. You also need to consider what cost differential exists (if any) between the two different information sources (i.e., probe and consultant).

Display for Timed Trials

Locate Figure 2. Figure 2 shows the display when trials are timed and the communication task must also be performed. Before going on to the two new windows, examine the windows already described. Note, some of the alternative information and values that can be displayed.

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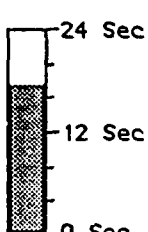
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Figure 2

TIME LEFT Window

The time bar appears when you must complete the submarine discrimination task and the communication task in 24 seconds. The time bar displays the number of seconds remaining to complete both tasks. A beep occurs at four second intervals.

COMMUNICATION AREA Window

The communication task requires that you send a sensor reading from your sensors, taken on another target, to a different platform (ship). To transmit the sensor measure when it appears, click on the "send" button. The measure disappears and the send label goes gray. You are transmitting this data because the other platform's sensors are impaired.

To insure that the measurement was received correctly, the other platform send back to you the value they received. It takes about 10 seconds for your transmission to be received and for their transmission back to you to be received. If you receive the same measure you trans-

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mitted, you verify this by clicking on the **yes**, otherwise you click on **no**. Note, when the measurement is received for verification it is displayed and a blackened verify button, followed by **yes** or **no**, appears.

There are several issues to keep in mind about the communication task.

- 1) After you request an initial measurement, there is a four or five second delay before your sensors can take a measurement on the new target and display it.
- 2) Be cognizant of the measurement value you transmit, so you can verify it later.
- 3) It takes nine or ten seconds for you to transmit a measurement and to receive a value back to verify.
- 4) If you send the measures too late in the trial, you may **not** have enough time to complete the verification process.

To complete a timed trial within the 24 second limit, you must complete both the discrimination task and the communication task. The feedback button will **not become active** (turn black), until both tasks are completed. You must also click on the feedback button within the allotted time. During a timed trial you receive feedback on the discrimination task and your verification correctness.

Note, that on any given trial, there is a 50/50 probability that a detected submarine is hostile. Please work quietly by yourself. At the end of each 15 trial block, you will receive a message to fill out a **SWAT** recording form; please do not forget, also do not forget to put the condition code at the stop. After filling out the **SWAT** form turn it face down and do **not** refer back.

Start with **TRAINING 1**. Complete all the training trials in this block.

THANK YOU AND GOOD LUCK.

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