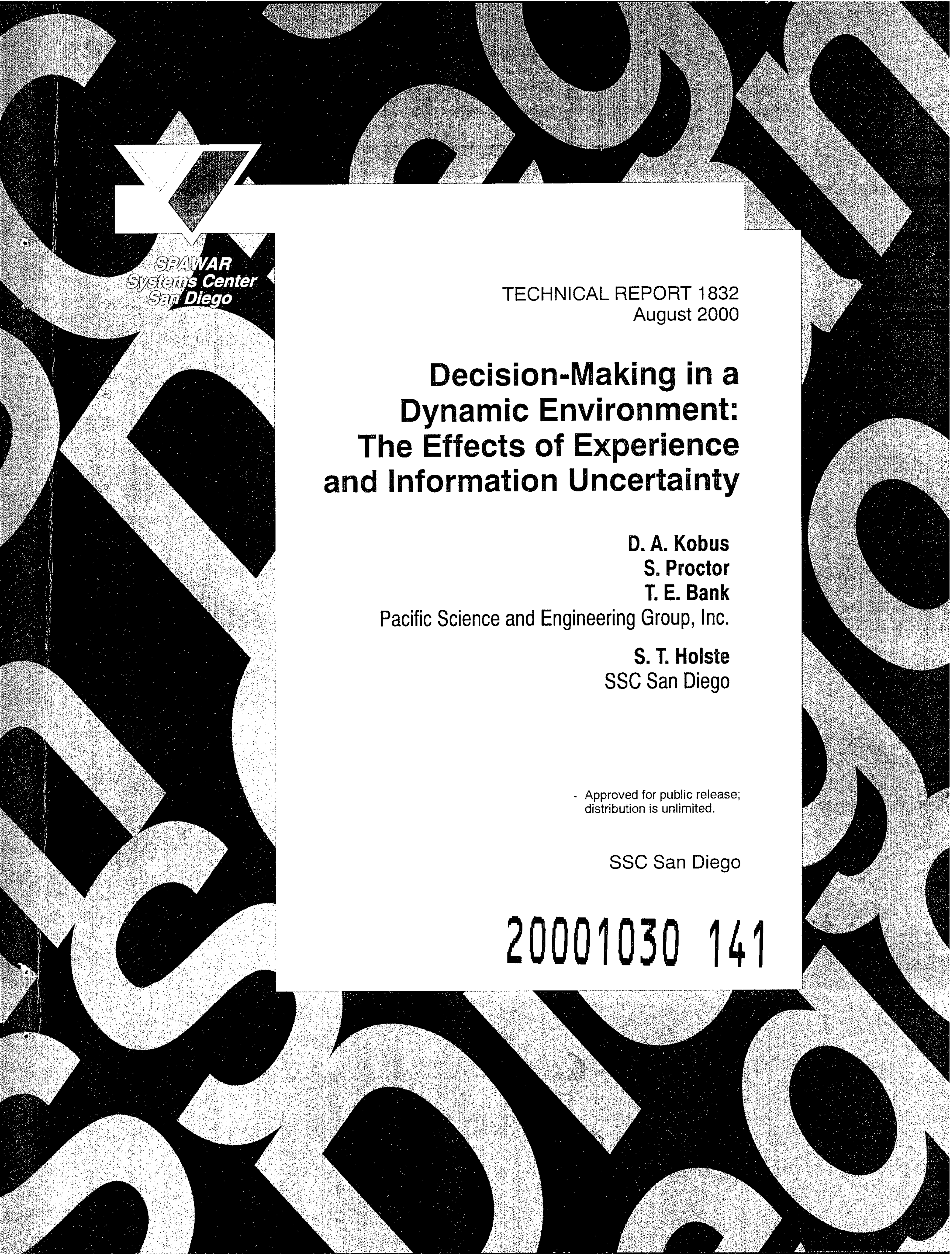

SPAWAR
Systems Center
San Diego

TECHNICAL REPORT 1832
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ADMINISTRATIVE INFORMATION

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JA

SUMMARY

OBJECTIVE

The purpose of this research was to investigate decision response times in a dynamic tactical scenario in which participants interacted with a virtual command-post environment. Fifty-two Marines with varying amounts of command-post experience assessed the situation as it developed, determined tactical leverage points, formed a plan of action, and submitted battle orders. Two scenarios, which differed in the level of certainty in the information provided, were studied. The tactical decision process was modeled and analyzed in the following sequential, cognitive stages: situation assessment, course of action selection, course of action execution.

RESULTS

Results show that the time required to assess the situation was significantly different between the experience groups ($\underline{p} < .05$), revealing that the High-Experience group took considerably longer than the Low-Experience group to assess the situation. However, once the assessment was complete, the selection of a course of action (COA) was significantly faster for the High-Experience group than the Low-Experience group. In addition, a statistically significant main effect of Task Certainty was found indicating that COA selection under conditions of Low Certainty took significantly longer than under conditions of High Certainty. Time required for COA execution indicated a significant main effect of Experience ($\underline{p} < .05$), a main effect of Task Certainty approaching statistical significance ($\underline{p} = .067$), and a statistically significant interaction ($\underline{p} < .05$). These results indicate that the time needed to execute the COA, once determined, is significantly less for the highly experienced individuals under conditions of low certainty. However, under conditions of high certainty, no statistically significant time differences were found distinguishing the High- and Low-Experience groups. The High-Experience group was significantly more accurate than the Low-Experience group for developing an appropriate COA.

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INTRODUCTION

Timely and effective decision-making is essential to the success of any military operation. It is for this reason that the Department of Defense spends considerable time and resources to develop the decision-making processes of U.S. military personnel. Two general models have been used to describe the decision-making process: (1) Analytical Decision-Making (ADM) and (2) Intuitive or Naturalistic Decision-Making (NDM).

ADM has a longer history than NDM and has been studied more thoroughly in the laboratory setting. Historically, this method of decision-making has been explained in terms of probability of a particular outcome. This method generally relies on a logical analysis of the situation upon which the decision is based and thus uses analytical or computational procedures. This approach requires the individual decision-maker to evaluate all options, weigh the cost and benefits of each, and identify a course of action that will lead to the best-expected outcome (Bergstrand, 1997). This has been the traditional method used by the military in training decision-makers to collect and analyze information and to then generate a variety of candidate solutions to the tactical problem. Each of the solutions is evaluated based upon pre-established criteria. The solution with the best fit is then selected as the unit's course of action, and appropriate orders are then issued. This method can provide excellent results given reliable information, well-understood selection criteria, a clearly defined objective, and plenty of time. Nonetheless, there are clear disadvantages to this method, especially for the military. In combat or tactical situations, information is often unreliable and inaccurate, leading to situation ambiguity or uncertainty. Rarely is there time to complete the time-consuming decision-making process presumed by the ADM method. The high uncertainty found in real-world situations raises questions about the utility of ADM for applied tasks, which has led to many studies attempting to find an appropriate decision-making model for the natural environment.

Shafir (1994) indicated that, in real-world decision-making, experts do not have (nor do they take) the time to assess all possible alternatives. Instead, they restrict their processing to an ideal set of options for further review. Other studies have repeatedly demonstrated that the classical model involving purely mathematical formulations of probabilistic or rational assessment do not capture the complexities of human decision-making in the field (Jungermann, 1997; Kahneman, Slovic, and Tversky, 1985). Although the process of decision-making has been investigated for centuries, only in the last few decades have investigators systematically addressed how decisions are made in a dynamic, real-world environment.

Decision-making strategies in natural environments appear to be very different from those found in static laboratory settings. Recent work in naturalistic decision-making focuses on identifying the sources of uncertainty and how people cope with, or manage, uncertainty (Klein, Schmitt, McCloskey, Heaton, Klinger, and Wolf, 1996; Cohen, Freeman, and Wolf, 1996; Lipshitz and Strauss, 1997; Yaniv and Foster, 1995; Zsambok and Klein, 1997). Zsambok (1997, p. 4) defines naturalistic decision-making as "... the way people use their experience to make decisions in the field." The NDM method tends to rely on simulations to elicit information from experts in a particular domain and highlights the differences in decision-making between experts and novices. For example, Stokes, Kemper, and Kite (1997) used a computer-displayed instrument panel to study in-flight decision-making of expert and novice pilots. The pilots responded to emergencies by indicating their actions and rationale. Expert pilots responded more quickly, generated more alternative actions, and identified more relevant cues than did novice pilots. Novices, on the other hand, tended to be biased toward their first (and usually only) option.

A bias toward the first-derived solution is a strategy that is often seen in uncertain situations (Klein, Schmitt, McCloskey, Heaton, and Wolf, 1996). Other common strategies for coping with uncertainty include an over-reliance on past experience and positive outcomes (Cohen and Wallsten, 1992), minimization of negative evidence (Reece and Matthews, 1993), reasoning based upon the subjective weighing of pros and cons (Lipshitz and Strauss, 1996), and delaying or deferring decisions (Arai, 1997; Dhar, 1996, 1997). For example, Dhar (1997) evaluated consumer preferences for competing alternatives and found that uncertainty (created when no single alternative had an advantage over other alternatives) led research subjects to defer a choice.

Military studies have reported that the ADM procedures called for in doctrine and training are rarely practiced in the field. The doctrinal process of generating and evaluating three courses of action leads to tactical inefficiencies when uncertainty is high and when time is short (Bergstrand, 1997). Bergstrand has identified a list of features (table 1) describing a naturalistic decision-making environment. The resemblance between the features of an NDM environment and a military decision-making environment is extraordinary.

Table 1. Features of naturalistic decision-making.

- Ill-structured problems
- Uncertain, dynamic environments
- Shifting, ill-defined or competing goals
- Action-feedback loops
- Time stress
- High stakes
- Experienced decision-makers
- Multiple players
- Organizational goals and norms

Several models of decision-making in the natural environment have been suggested (Klein, 1993). The model that has been specifically identified by Klein as the most applicable for the military is Recognition-Primed Decision-Making (RPD). This model highlights the importance of intuitive situation assessment as the basis for effective decision-making. The general premise of this model is that, in an operational environment, people rarely weigh alternatives and compare them in terms of expected value or utility (Lehto, 1997). Rather, experienced decision-makers try to recognize familiar patterns, features, or prototypes. Potential solutions are generated sequentially and evaluated mentally to determine if the solution is workable. If the solution is not workable, it is modified or eliminated. The process continues until a workable solution is generated and selected.

Table 2 lists the key features of the Recognition-Primed Decision-Making model as outlined by Bergstrand (1997). The key to this model is level of expertise, in the specific content area, of the individual making the decision. As Lehto (1997) points out, "the most general conclusion that can be drawn from this area of research is that people use different decision strategies depending upon their experience, the task, and the decision context" (p. 1235).

Table 2. Key features of Recognition-Primed Decision-Making model.

• First option usually workable, **NOT** random generation and selective retention options
• Serial generation and evaluation of options, **NOT** concurrent evaluation
• Satisfying, **NOT** optimizing
• Evaluation through mental simulation, **NOT** multi-attribute utility analysis, decision analysis, or Bayesian analysis
• Focus on elaborating and improving options, **NOT** choosing between options
• Focus on situation assessment, **NOT** decision events
• Decision-maker primed to act, **NOT** wait for complete analysis

Table 1 indicates that uncertainty is one of the prime attributes of the NDM model. There is little question that decision-making under conditions of uncertainty is a regular feature of military decision-making. Commanders are typically required to make decisions and develop battle plans without the benefit of knowing the intent of the adversary, how large or well-equipped he is, or where he may be at any given point in time. The literature is rich with reports investigating decision-making under uncertainty (e.g., Rowe, 1994; Lipshitz and Strauss, 1997) and studies investigating situation assessment and awareness in a variety of environments (Gaba, Howard, and Small, 1995; Endsley, 1995; O'Hare, 1992; Salas, Prince, Baker, and Shrestha, 1995). These studies and others suggest not only an assortment of decision-making strategies, but also highlight the vital role that human factors engineers can play by designing display interfaces that better support dynamic decision-making (Lehto, 1997).

In 1998, a workshop was hosted by SSC San Diego and Pacific Science and Engineering Group with the goal of bringing together a number of human factors researchers to speculate on new ideas for improving command-post situation awareness and the portrayal and handling of uncertain information. The workshop specifically addressed how to portray uncertain information, such as the intent and positions of enemy forces, and how to improve situation awareness and decision-making under uncertainty.

Human factors researchers have also investigated how best to design displays to *optimally* present relevant information and enhance situation awareness and decision-making under uncertainty. St John, Callan, Proctor, and Holste (2000) examined how different representations of uncertainty (graphic vs. text based, discreet vs. continuous) concerning enemy intent, composition, and position in a ground war battlefield situation affected situation awareness in terms of situation assessment and time needed to make a decision. They found that Marines with relatively little command-post experience were more likely to "wait-and-see" prior to deciding on a battle plan than were Marines with more experience when confronted with an uncertain tactical scenario. This finding is in concert with the results of Dhar (1997), indicating that the likelihood of delaying a choice is contingent upon the ease of making the decision. Individuals with little experience find the required task more difficult than an individual who has "*been there—done that.*" However, the tactical scenario used in the study by St. John et al. was static; participants were provided with a narrative of the current situation along with a map depicting the scenario and forced to choose whether they would make a decision to "act" or to "wait for additional information." Choosing to wait is, of course, contrary to Marine Corps doctrine, which is to act as quickly as possible.

Decision-making under static and dynamic conditions requires different decision-making processes, and the differences in processing strategies noted between static and dynamic environments raise several questions. Does the tactical decision-making strategy used by expert and novice Marines differ between static and dynamic settings? What model can be used to best describe how U.S. Marines make tactical decisions in a dynamic environment? Would the time-stress imposed by the dynamic nature of the task spur the participants toward action and force them to rely on their experience and intuition to determine a response, thereby accelerating decision cycles?

This study investigated decision response times in a dynamic tactical scenario in which participants were immersed in a virtual command post and were asked to formulate a battle plan as soon as possible pertaining to the developing tactical situation. Two scenarios, differing in the level of certainty in the information provided, were presented to determine if the time required for making a tactical decision was related to the level of information certainty. In addition, the effect of experience was evaluated to determine how expertise affects the decision-making process in a dynamic environment.

METHOD

PARTICIPANTS

Fifty-two Marine Corps officers and non-commissioned officers (NCOs) with varying amounts of command-post experience participated in the experiment. The task, a dynamic tactical scenario, was a computer-based simulation of command-post operations during a nighttime land warfare engagement. Participants were selected from the Fifth Marine Regiment, First Marine Division at Camp Pendleton, CA. Table 3 displays the number and ranks of participants. Participants' command-post experience ranged from 0 to 10 years (M = 477 days).

Two groups were formed based on experience in the command-post environment. A median split was effected, based on the experience level of the participants. The Low-Experience group consisted of 29 participants, ranging in experience from 0 to 90 days (M = 35.17 days, SD = 31.62). Fourteen individuals from the Low-Experience group participated in the Low-Certainty condition with the remainder (15 individuals) participating in the High-Certainty condition. The High-Experience group consisted of 23 participants and ranged in experience from 91 to 3650 days (M = 1034.96 days, SD = 991.52). Thirteen individuals from the High-Experience group participated in the Low-Certainty condition with the remainder (10 individuals) participating in the High-Certainty condition.

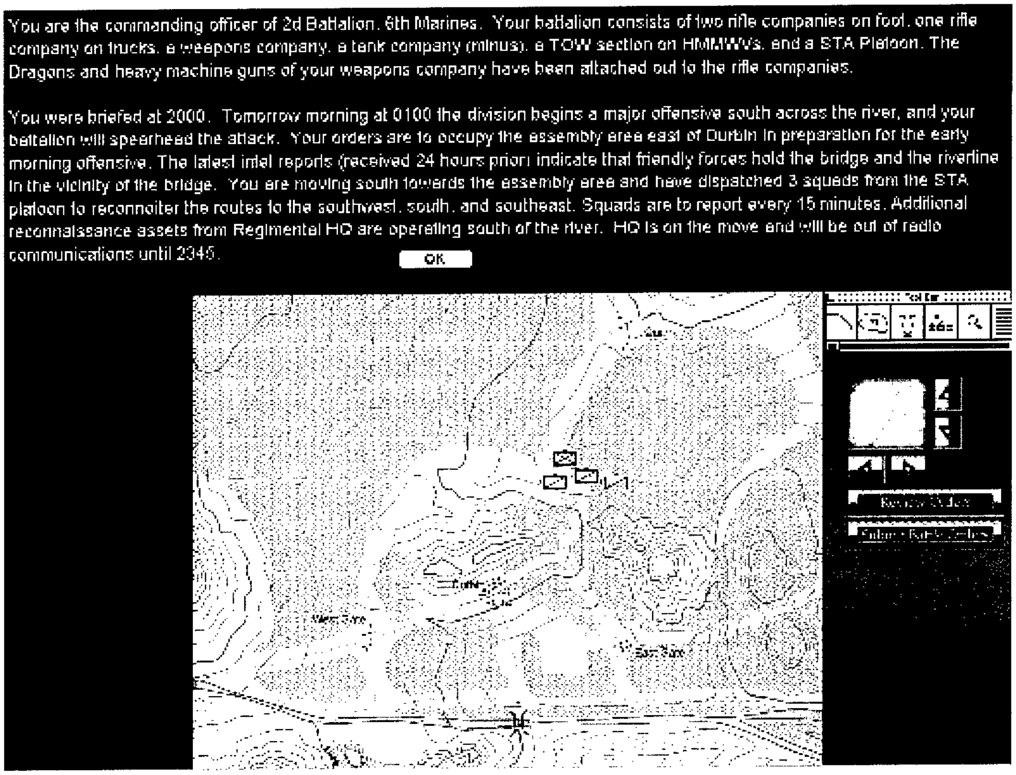
Table 3. Number of participants indicated by rank.

Rank	Number of Participants
• Lieutenant Colonel	2
• Major	6
• Captain	6
• 1st Lieutenant	13
• 2nd Lieutenant	2
• Chief Warrant Officer	4
• Master Gunnery Sergeant	1
• Master Sergeant	2
• Gunnery Sergeant	2
• Staff Sergeant	9
• Sergeant	5

Twenty-seven subjects participated in the Low-Certainty condition, and the remaining 25 subjects participated in the High-Certainty condition.

MATERIALS

The experiment involved a computer-controlled scenario adapted from a tactical decision game published in *Mastering Tactics* (Schmitt, 1994), written in Macromedia Director (version 7.0) and executed on a PC laptop. The scenario was a simulation of a command post in which all information was presented on the laptop screen and over headphones. The computer display was a composite of information available within a field command post, provided on a single display. The interface was iteratively designed after conducting interviews with a large number of Marines with varied backgrounds to determine the type of information required and the optimal way to display that information. Figure 1 depicts the display at the onset of the task.



You are the commanding officer of 2d Battalion, 6th Marines. Your battalion consists of two rifle companies on foot, one rifle company on trucks, a weapons company, a tank company (minus), a TOW section on HMMWVs, and a STA Platoon. The Dragons and heavy machine guns of your weapons company have been attached out to the rifle companies.

You were briefed at 2000. Tomorrow morning at 0100 the division begins a major offensive south across the river, and your battalion will spearhead the attack. Your orders are to occupy the assembly area east of Durbin in preparation for the early morning offensive. The latest intel reports (received 24 hours prior) indicate that friendly forces hold the bridge and the riverline in the vicinity of the bridge. You are moving south towards the assembly area and have dispatched 3 squads from the STA platoon to reconnoiter the routes to the southwest, south, and southeast. Squads are to report every 15 minutes. Additional reconnaissance assets from Regimental HQ are operating south of the river. HQ is on the move and will be out of radio communications until 2345.

Figure 1. The dynamic display at the onset of the scenario.

The display consisted of a color topographic map depicting a tactical situation with associated map manipulation and information tools. Tools and functions available to the participants are shown in table 4.

In addition, the audio channel consisted of radio traffic, together with background verbalizations and ambient background noise, to simulate the command-post environment. Participants used a mouse and keyboard to interact with the scenario.

Table 4. Display tools and functions accompanying the computerized map.

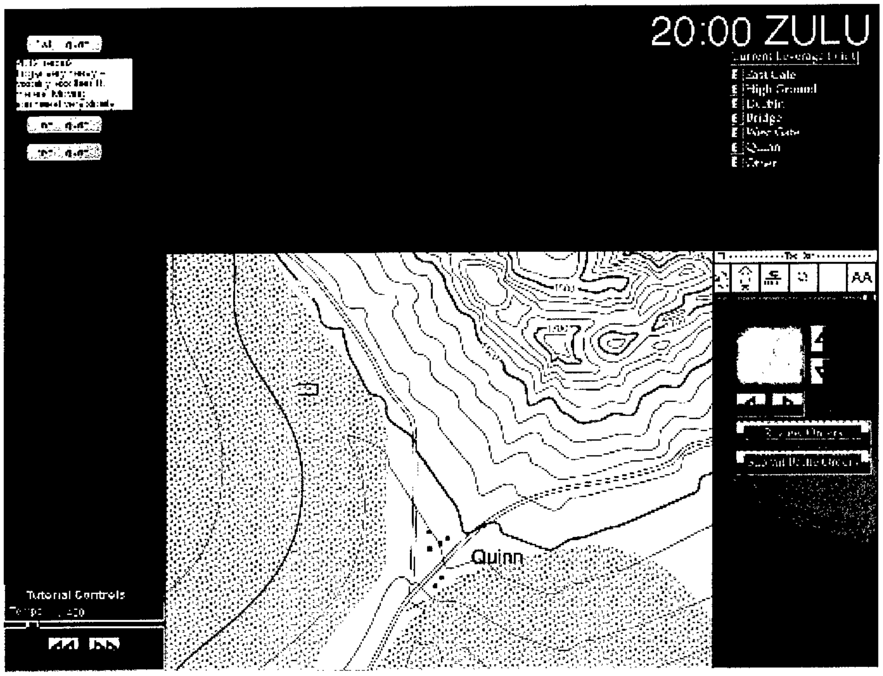
Tool/Function	Capability
Panning	Allows the map to be scrolled in N/S or E/W directions
Zooming	Continuous zoom-in or zoom-out on a selected area of the map
Grid lines	1-km by 1-km grid overlay for the map
Unit movement histories	Map overlay indicating the movement history of friendly units
Axis of advance	Map overlay indicating unit axis of advance
Possible enemy location	Map overlay indicating potential enemy location over time
Clock	Depicts scenario time (faster than real time)
Messages/archive	Text of audio recon reports (including all previous reports)
Review orders	Review of initial brief and mission orders
Submit orders	Opens a text window in which to write and submit orders
Assembly area	Indicates location of assembly area on the map

Tutorial

A tutorial was prepared to provide a brief introduction to display functionality. The tutorial was a noninteractive, computer-based training tour through the functionality and use of the interface and map tools. Participants viewed a portion of the scenario map and received descriptions of each of the interface components and map tools while audio instructions were presented through the headphones.

The tutorial lasted approximately 3 minutes and was followed by a brief question-and-answer (Q&A) period to provide further explanation, if required, of any of the display tools and functions. The testing scenario did not begin until the participant was ready to continue.

Figure 2 shows an example tutorial display screen with text from accompanying audio instructions.



"Periodically, messages will come in. These messages will be listed to the left in the message area. To list current messages, click on the name of the troop you wish to address. Then, click on the time that the message arrived."

Figure 2. The tutorial display screen describing incoming status updates and accompanying audio instructions.

Test Scenario

The test scenario depicted a land warfare engagement and battle in the vicinity of the fictional town of Durbin. The scenario began with friendly forces planning a major assault south across the bridge, scheduled for 0100. Participants played the role of the Commanding Officer of a U.S. Marine Corps battalion whose orders were to occupy an assembly area east of the town of Durbin in preparation for spearheading the major offensive to the south. Their task was to assess the situation as it developed, determine tactical leverage points, develop a course of action, and submit battle orders. Reconnaissance (Recon) teams were sent out and periodically reported back to the command post with updated information.

Approximately half of the participants entered the scenario at time 2000 (i.e., 8:00 p.m.). Intelligence information was somewhat dated, and the recently released recon teams had not yet reported. Initial situation ambiguity was high for this High-Uncertainty scenario. The remainder of the participants began the scenario at time 2130 (i.e., 9:30 p.m.). This Low-Uncertainty condition provided more detailed and recent information regarding intelligence updates and recon reports, and the initial situation ambiguity was significantly lower. Participants who started the scenario at time 2000 had more time to assess the situation and familiarize themselves with the battle theater prior to the onset of unexpected events (i.e., the enemy was detected in a location that was thought to be held by friendly forces). Participants who started the scenario at time 2130 were quickly placed in a situation where the enemy was in unexpected locations, and the original mission orders were rapidly becoming obsolete. In using the different conditions, we hoped to determine whether participants would react differently given the additional uncertainty imposed in the High-Uncertainty scenario.

PROCEDURE

The participants were run individually using a laptop computer with headphones. Figure 3 shows the experimental setup.

The participants were randomly assigned to the Low- or High-Uncertainty condition. Prior to beginning the experiment, participants were shown the tutorial. Once ready, they started the dynamic part of the experiment by clicking on an on-screen start button.

Participants were instructed to select a tactical leverage point from a list of geographical locations as soon as possible. They were allowed to change the leverage point as often as desired, at any time during the scenario. Participants were also instructed to open the "Submit Orders Window" only when they had selected their course of action (COA) committing the entire battalion. They were further instructed to provide battle-plan orders as "Frag" (fragmentary) orders rather than in the conventional five-paragraph format. A "Frag" order includes the commander's orders and task assignments in an abbreviated format.

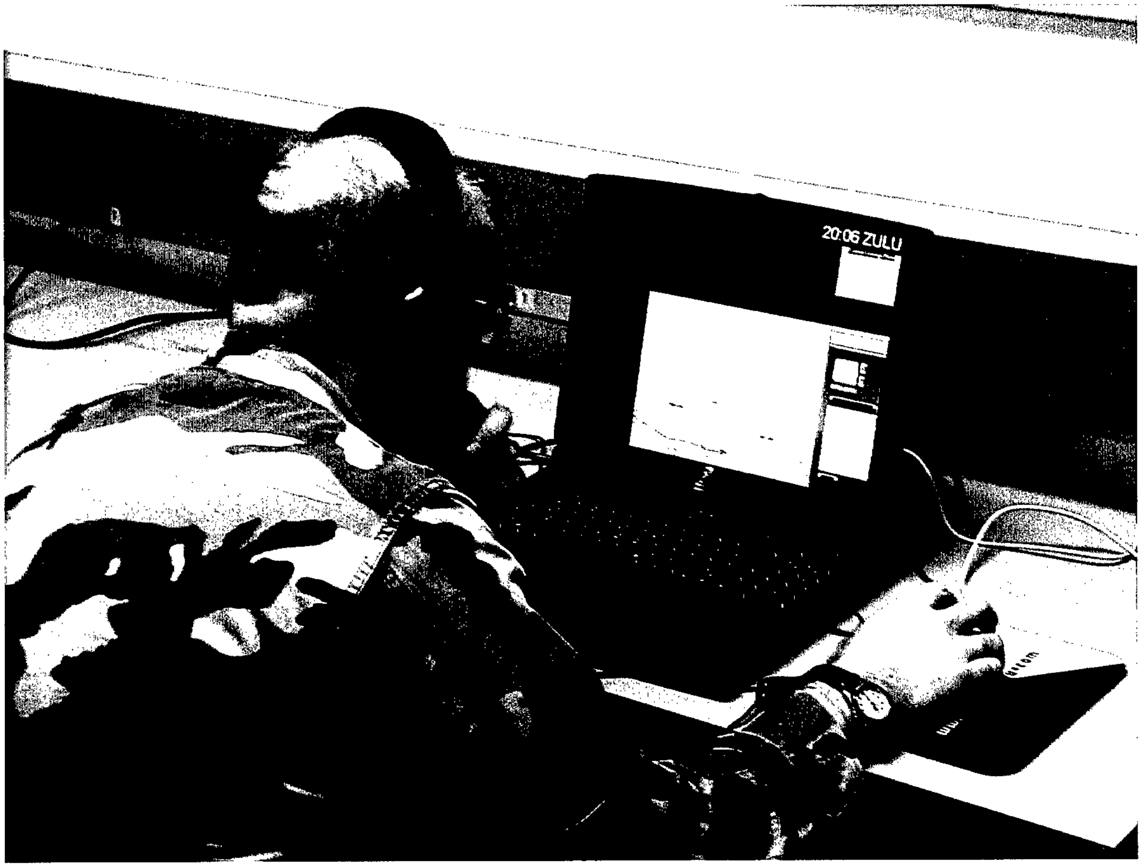


Figure 3. The experimental setup.

All participant interactions with the display using keyboard and mouse were recorded and stored in a database on the computer. Additionally, any notes taken by the participants were collected at the end of the experiment. Participants completed a two-page exit questionnaire after the experiment. Questions centered on subjective assessments of their confidence in their battle plans, the effect that the situation uncertainty had on formulating the battle plans, and the utility of the map manipulation tools for the task. In addition, they described how useful they thought the display and tools would be in an actual command post.

Figure 4 displays a hypothetical time line for a typical participant in the experiment. Each participant followed the same sequence of events. However, the number of leverage points selected and the timing between events differed between subjects. A more detailed description of the task and its relationship with NDM is discussed in the next section.

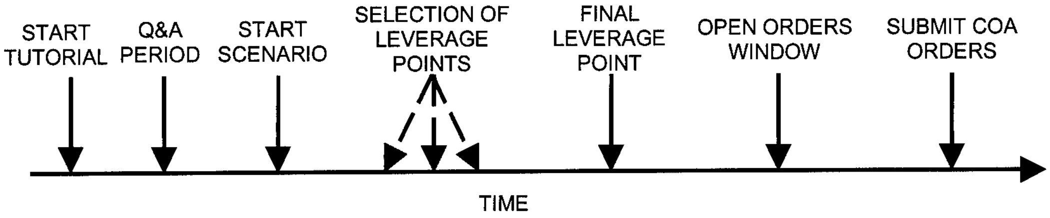


Figure 4. A hypothetical time line for a typical participant.

DATA ANALYSES

In concert with current theory on Naturalistic Decision-Making, the dependent variables collected were used to compute measures related to the model of Recognition-Primed Decision-Making. An additional measure (COA Execution) was also developed and is described in more detail in this section.

Figure 5 depicts an expanded, annotated time line reflecting the actions of a hypothetical participant. The recording of time began at point A for all participants once the scenario was initiated. During the scenario, participants selected the geographical location that they considered to be of key tactical importance. This was referred to as the tactical "leverage point." They were allowed to change their leverage-point selection at any time during the scenario, based on a subjective analysis of the information they were receiving throughout the scenario. The time period between the start of the task and the final leverage point (B) was considered to be the time required by each participant to achieve a reasonable understanding of the tactical situation within the time constraints of the scenario. This time period also reflects a period of recognition priming, leading to achievement of *situation awareness*.

Once the participant decided on a final leverage point, we hypothesized that the decision-making process would proceed to the next stage of processing, which is to decide on a course of action. COA Selection was operationally defined as the time period between the selection of the final leverage point (B) and the selection of the Open Orders Window (C), the first step required to initiate a battle plan.

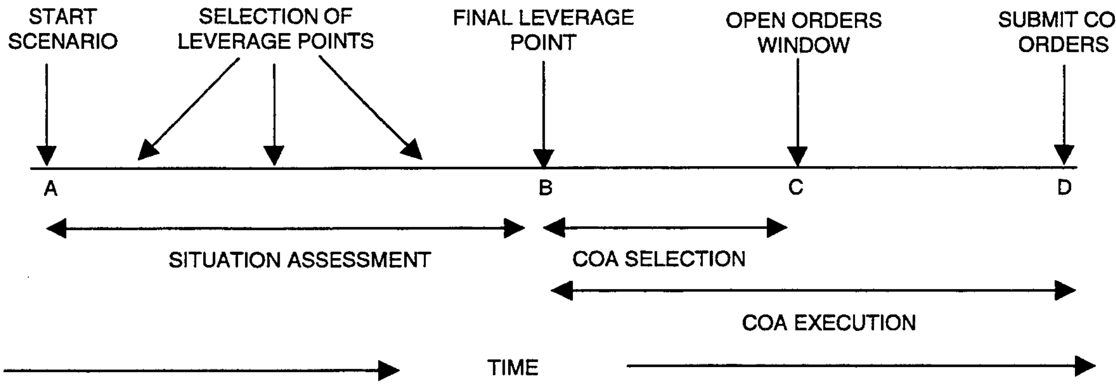


Figure 5. Hypothetical time line for experimental protocol for one participant.

The validity of COA Selection as an accurate measure of the time actually required to select the desired course of action could be questioned due to the dynamic nature of the task. It could be argued that participants may have selected the option to submit orders with one COA in mind, but then altered their plan based on information they received after selecting the Open Orders Window option. Therefore, an additional measure was developed that captures the full time demands of COA Selection but also includes the time needed to execute a response. This time period was referred to as COA Execution and was operationally defined as the time period between the selection of the final leverage point (B) and the submission of orders (D).

RESULTS

Data were collected on seven dependent measures of performance:

1. Time of first leverage point
2. Time of final leverage point
3. Number of leverage points selected
4. Accuracy of final leverage point
5. Time to submit orders
6. Accuracy of course of action selected
7. Total time on task

All times measures were calculated using the initial start of the task as a time of zero. Independent variables of interest were Uncertainty Level (High, Low) and Level of Command-Post Experience (High, Low). Criteria for accuracy were provided in the solution section of *Mastering Tactics* (Schmitt, 1994). In addition, data were collected regarding the subjective rating of confidence in the battle plan selected and the effect that uncertainty had upon participants' decision-making.

Independent two-factor (Certainty X Experience) Analyses of Variance (ANOVAs) were completed for each of the dependent variables.

TIME TO FIRST LEVERAGE POINT

A two-way ANOVA revealed that neither of the independent variables nor the interaction were statistically significant at the .05 level for time to first leverage point. However, the difference between High- and Low-Experience levels was suggestive and approached statistical significance ($\underline{p} = .067$). The Low-Experience group ($\underline{M} = 3.4$ min) tended to select the first leverage point almost twice as quickly as their more experienced ($\underline{M} = 6.5$ min) counterparts.

TIME TO LAST LEVERAGE POINT

The results indicated a significant effect for Experience and a borderline effect for Certainty, but no significant interaction. Low-Uncertainty participants ($\underline{M} = 7.6$ min) tended to select the last leverage point faster than High-Uncertainty participants ($\underline{M} = 12.3$ min) ($\underline{p} = .055$).

The effect for Experience was statistically significant ($\underline{F}(1,43) = 4.25$, $\underline{p} < .05$), with Low-Experience Marines tending to select the final leverage point faster ($\underline{M} = 7.7$ min) than Marines with more experience in the command post ($\underline{M} = 12.6$ min).

NUMBER OF LEVERAGE POINTS

There were no statistically significant effects for Certainty or Experience in terms of the number of leverage points selected.

TIME TO INITIATE ORDERS

The overall time to make the decision to act (Open Orders Window) was significantly different between the two Certainty groups (F (1,47) = 23.1, $p < .001$). The Low-Uncertainty group (M = 7.84 min) made the decision to submit orders significantly faster than the High-Uncertainty group (M = 18.27 min). There was no statistically significant difference based upon command-post experience and the interaction likewise was not significant.

TOTAL TIME ON TASK

Total time required to finish the task was found to be significantly different between Certainty groups (F (1,48) = 19.14, $p < .001$). The High-Uncertainty group spent significantly more time (M = 25.11 min) completing the task than did the Low-Uncertainty group (M = 15.36 min.). Level of command-post experience had no statistically significant effect upon time to complete the task and no significant interaction was found.

RANK

Post hoc analyses were also conducted involving military rank. Officers selected significantly fewer leverage points (M = 2.93 selections) than enlisted participants (M = 5.47 selections) regardless of the condition in which they participated (F (1,43) = 8.08, $p < .005$). No other result was statistically significant.

SITUATION AWARENESS

Figure 6 displays the mean response time results for situation awareness acquisition between groups (High/Low Experience) during both the High- and Low-Uncertainty conditions. Acquisition of situation awareness was operationally defined as the time elapsed from the beginning of the experiment until the selection of the last (or only) leverage point. Independent analyses of each main effect revealed a statistically significant effect for Experience (F(1,43) = 4.25, $p < .05$). These results indicate that the High-Experience group spent significantly more time (M = 12.6 min) than the Low-Experience group (M = 7.7 min) analyzing the situation in the development of situation awareness. The main effect for task Certainty approached statistical significance ($p = .055$) as the time taken to acquire awareness under High Uncertainty tended to be greater than under Low Uncertainty. The interaction between Certainty and Experience was not significant for situation awareness acquisition.

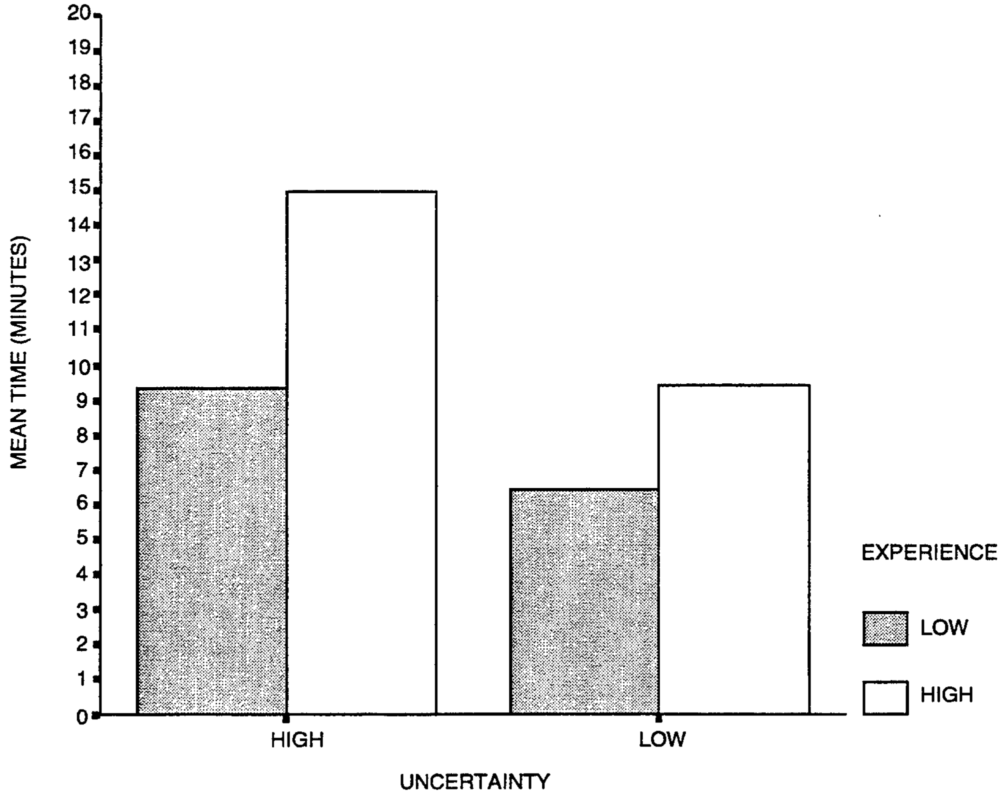


Figure 6. Mean response time (minutes) for situation awareness (recognition priming).

COA SELECTION

Figure 7 displays the mean COA selection time results for each group (High/Low Experience) during both the High- and Low-Uncertainty conditions. Analysis of Variance revealed a significant main effect for command-post experience (F(1,40) = 4.27, p < .05). The High-Experience group took less time (M = 3.1 min) for response selection than the Low-Experience group (M = 6.8 min). In addition, a significant main effect of task certainty was found (F(1,40) = 4.15, p < .05) indicating that response selection under High Uncertainty took longer (M = 6.85 min) than when available information conveyed greater certainty (M = 3.2 min). The interaction was not statistically significant.

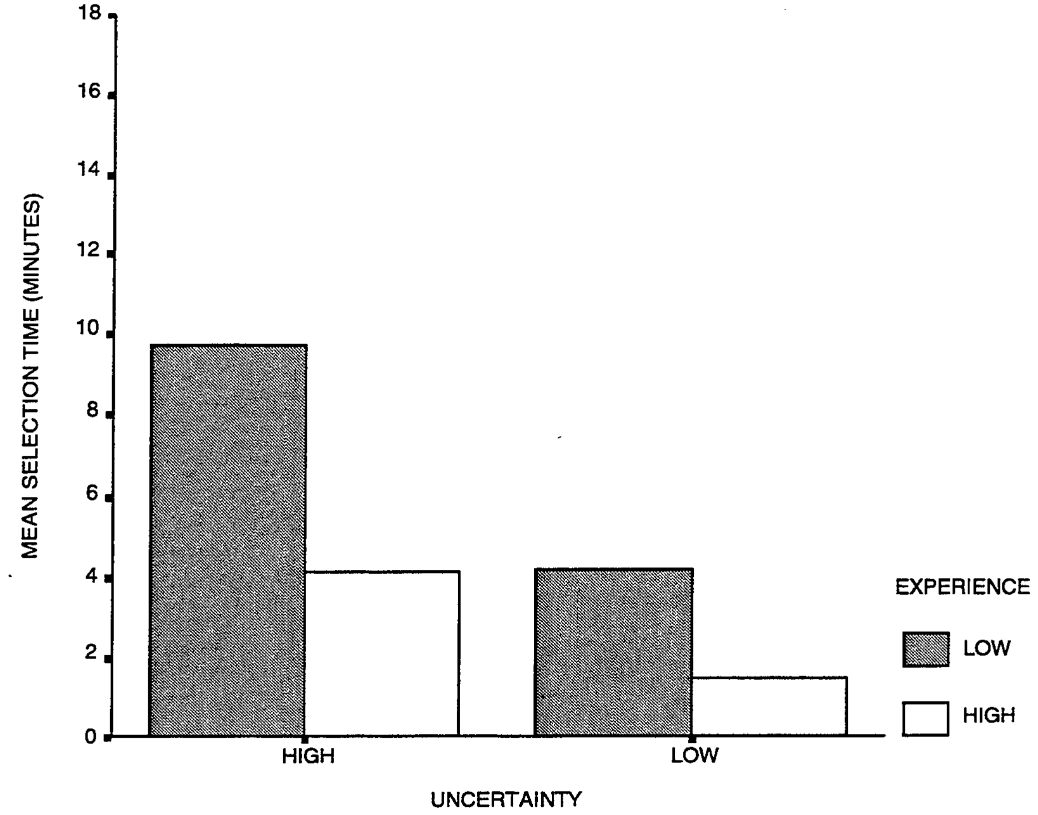


Figure 7. Mean response time (minutes) for COA selection.

COA EXECUTION

Figure 8 displays the response execution results for each group (High/Low Experience) during both High- and Low-Uncertainty conditions. The ANOVA results indicated a significant main effect for command-post experience ($\underline{F}(1,41) = 4.55$, $\underline{p} < .05$). COA execution was significantly faster for the High-Experience group ($\underline{M} = 8.95$ min) than the Low-Experience group ($\underline{M} = 12.94$ min). In addition, task certainty approached statistical significance ($\underline{F}(1,41) = 3.55$, $\underline{p} = .067$) showing that COA execution under High-Uncertainty conditions took longer ($\underline{M} = 12.84$ min) than under Low-Uncertainty conditions ($\underline{M} = 9.0$ min). The interaction between task Certainty and Experience was significant ($\underline{F}(1,41) = 4.84$, $\underline{p} < .05$). This result is clearly displayed in figure 8. The High-Experience Marines were significantly faster ($\underline{M} = 8.4$ min) that the Low-Experience Marines ($\underline{M} = 17.67$ min) to execute a COA under the High-Uncertainty condition. Under the Low-Uncertainty condition, the two groups displayed nearly identical execution times.

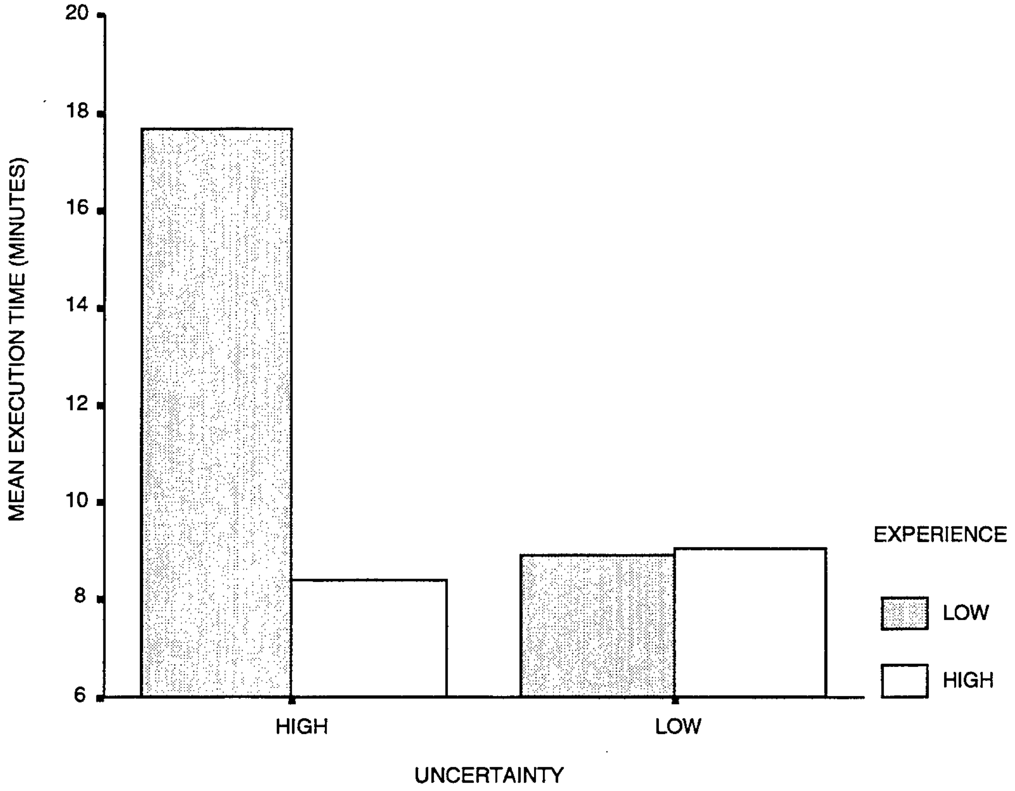


Figure 8. Mean response time (minutes) for response execution.

ACCURACY

Two measures of task accuracy were employed. Analyses were conducted to determine if participants selected (1) the most correct leverage point and (2) the most appropriate course of action according to the outcomes suggested in *Mastering Tactics* (Schmitt, 1994).

Despite a relatively large difference in the expected direction, the leverage point selection performances of the two Experience groups were not significantly different. The High-Experience group ($\underline{N} = 23$) leverage point accuracy was 75%, while the Low-Experience group ($\underline{N} = 29$) achieved an accuracy of 48%.

In terms of COA selection, significantly more participants in the High-Experience group executed responses in agreement with the criterion (87%) than the Low-Experience group (48%), ($\chi^2(1) = 6.52$, $\underline{p} < .05$).

RESULTS OF SUBJECTIVE REPORTS

Analyses of self-reported battle-plan confidence or the subjective rating of the effect of uncertainty resulted in no significant differences, either between High- and Low-Uncertainty level or between High- and Low-Experience groups. In both cases, the groups had similar scores that tended to be mid-range on a five-point Likert scale for both confidence and uncertainty.

Finally, the usefulness of each display tool was rated on a 5-point Likert scale (1 = not useful, 5 = highly useful). Table 5 shows the average utility rating for each of the display tools. A

Kolmogorov–Smirnov test was performed on the subjective ratings for each item to determine whether the distribution of scores departed significantly from a uniform or normal distribution. All tools were rated as "useful" ($\underline{p} < .05$) with the exception of the Grid Color tool, which was rated as "not useful" ($\underline{p} < .05$).

Table 5. Average utility rating of the display tools.

Map Tool	Utility in the Command Post	Utility of Map Tools in Task
Battalion Schematic	4.15	3.94
Grid	3.48	3.65
Grid Color Change	2.17	1.69
Message Archiving	4.15	3.96
Message Bulletin Board	4.37	4.20
Message Post-it	4.40	4.33
Movement Histories	4.17	3.80
Movement Indicator	4.46	4.33
Panning	4.61	3.74
Projected Positions	4.23	3.66
Review Orders	4.21	4.08
Zooming	4.33	3.40

DISCUSSION

The Recognition-Primed Decision-Making model of Naturalistic Decision-Making (Klein, 1993) emphasizes the importance of investigating the dynamics of the decision-making process in an applied environment. This experiment provides a unique example of decision-making in such an environment. We measured behavior reflecting time to acquire situation awareness, as well as time required for (and accuracy of) COA selection and execution.

SITUATION AWARENESS

Our results indicated that while experts take longer to achieve situation awareness, compared to novices, they are significantly faster in choosing a course of action and executing a response. Such results are consistent with the expert vs. novice literature (Di Bello, 1997; Stokes, Kemper, and Kite, 1997; and Xiao, Milgram, and Doyle, 1997). Differences in the time required to achieve situation awareness have been explained by suggestions that experts have a larger cognitive database of related experiences to compare with the new situation, thus requiring more time. Furthermore, experts seem to know which information is most important and relevant, whereas novices tend to review all available information in a haphazard manner regardless of its actual relevance (Lehto, 1997). It can be argued that the systematic review of information by the expert takes longer because, in a dynamic situation, the expert is aware of the links and contingencies associated with the data under review and consequently elects to search and/or wait for relevant updates. This result differs from what is found in the static situation in which the expert quickly realizes that no new information will be available and that the decision can be based upon current data (St. John, Callan, Proctor, and Holste, 2000). St. John et al. showed that novices were significantly more likely than experts to adopt a "wait and see" approach in the static situation.

This study also supports research indicating that novices have a tendency to make decisions based upon a limited understanding of the situation, usually developing only a single course of action (Dhar, 1997). However, while one might infer from earlier findings that novices would have a tendency to change leverage points more often than experts (due to being more easily swayed by irrelevant information), this was not the case here. Our results revealed no significant between-group differences in the number of leverage points selected. Other studies have indicated that novices tend to be less capable of developing situation awareness than more experienced individuals due to their inability to distinguish relevant from irrelevant information. Although a much larger proportion of the High-Experience Marines selected the correct tactical leverage point (75% versus 48% for novices), this result was not statistically significant, probably due to sample size. Several cells in the analyses contained fewer than 15 participants, a number often cited as the suggested minimum number of participants required for proper analyses (Myers and Hansen, 1997). A major problem in the conduct of applied research, especially if expertise is required, is the recruitment of a sufficient number of qualified participants to obtain desired statistical power.

COA SELECTION

COA selection was faster in the Low-Uncertainty environment than in the High-Uncertainty environment. This supports previous findings that response selection is faster when information is more reliable and less ambiguous. In addition, the High-Experience group was significantly faster in selecting a course of action than the Low-Experience group, and this difference was apparent regardless of the level of information certainty. The High-Experience group also was significantly more accurate than the Low-Experience group in choosing the correct response. This result is consistent with previous studies reporting that naïve participants are limited in their generation of courses of action and are highly influenced by irrelevant information (e.g., Lehto, 1997).

COA EXECUTION

Because the experimental task was dynamic—and the participants were constantly receiving new information—there is a possibility that they may have modified their orders (i.e., altered COA) subsequent to achieving "situation awareness" (which was deemed to have occurred upon selection of the Open Orders Window). Therefore, we developed the measure of COA Execution, operationally defined as the time between selection of the final leverage point and completion of the order. This measure is inclusive of COA Selection and incorporates the time required for the submission of the final order for execution.

The results for COA Execution were very interesting. Figure 8 displays the differences in response time as a function of Combat Operations Center (COC) experience and degree of information certainty. The High-Experience group was significantly faster in executing the selected course of action than the Low-Experience group, but more interesting was the significant interaction indicating that the differences in response execution between High- and Low-Experience groups occurred only under the High-Uncertainty condition. This suggests that, in a dynamic situation, novices are dramatically affected by ambiguous or uncertain information (in terms of Response Execution) while experts respond as quickly under either level of certainty.

These results support the intuitive premise that decision-making is faster when information used to make the decision is reliable and unambiguous. It might be expected from this result that experts would show a greater confidence in their decisions and indicate that uncertainty has less of an impact upon their decision-making. However, the data indicated that there were no significant differences in battle-plan confidence as a function of either Level of Experience or Task Certainty. Nor were there any differences between the High- and Low-Experience groups regarding the subjective effect of uncertainty upon battle-plan generation. From these data, it cannot be determined whether experts have a tendency to understate confidence and overestimate the effect of uncertainty, or if it is the novices who tend to overstate confidence and underestimate the effect of uncertainty.

The findings of this study clearly expand the novice–expert decision-making distinctions found by St. John et al. (2000) in a static task to differences observed in a dynamic task. The results of the current study contrast with the findings of St. John et al. (2000) in two key areas. The current study found that (1) experience in the command post affected time spent developing situation awareness and (2) High-Experience Marines responded faster once situation awareness was obtained. The current task differed from the previous study in that it used a dynamic instead of static display. Another difference between studies was the overall level of command-post experience. In the current study, the median of command-post experience was much greater than reported by St. John et al. (2000) (90 versus 14 days, respectively).

This study also highlights an important distinction between the ways experts and novices process information. Experts appear to spend the majority of their time assessing the situation to develop situation awareness. Once assessment is complete, they spend relatively little time selecting and developing a course of action (which may be mentally linked to a recognized pattern). On the other hand, novices spend less time assessing the situation, leading to long delays in selecting and developing a course of action—which may be the result of impaired situation awareness.

These results clearly support the claim that improving displays to enhance situation awareness will likewise enhance user performance. Improved command-post displays should enhance the ability of the experienced Marines to provide a more rapid response and, at the same time, strengthen the ability of the novice to acquire improved situation awareness.

Eleven of the display tools used during this task were rated as useful for operational use in the command post. Only one tool (which provided the ability to change the color of the grid) was judged not to be useful. The tools that were rated as useful were incorporated into the prototype Tactical Situation Awareness (TacSAT) display.

FINAL NOTE

This study demonstrates the importance of investigating decision-making in an applied, dynamic environment. The strategy selected by the decision maker (e.g., analytic or intuitive) is highly task-dependent. When an individual is provided ample time to make a decision, an analytic approach (consistent with many current training curricula) is frequently selected. On the other hand, in a dynamic task in which information uncertainty is high and a rapid decision is required, an intuitive decision-making strategy is usually chosen. Therefore, when investigating ways to optimize human performance in an applied setting, consideration must be given to the context of the task. Future displays should be configured to present information in a way that best supports the appropriate strategy (analytic or intuitive) to optimize decision-making. We have incorporated these findings and ideas into the development of the TacSAT, an interface designed to assist Marine Corps COC personnel to more rapidly achieve situation awareness and develop one or more suitable courses of action.

REFERENCES

Arai, D. 1997. "Temporal Resolution of Uncertainty in Risky Choices," *Acta Pyschologia,* vol. 1–2, no. 96, pp. 15–26.

Bergstrand, B. 1997. "Situating the Estimate: Naturalistic Decision-Making as an Alternate to Analytical Decision-Making in the Canadian Forces," in *Ex New Horizons* [online]. Available: http://www.cfcsc.dnd.ca/irc/nh/nh9798/0021.html, accessed 25 September 2000.

Cohen, M. S., J. T. Freeman, and S. Wolf. 1996. "Metacognition in Time-Stressed Decision Making: Recognizing, Critiquing, and Correcting," *Human Factors*, vol. 2, no. 38, pp. 206–219.

Cohen, B. L. and T. S. Wallsten. 1992. "The Effect of Constant Outcome Value on Judgments and Decision Making Given Linguistic Probabilities," *Journal of Behavioral Decision Making*, vol. 1, no. 5, pp. 53–72.

Dhar, R. 1996. "The Effect of Decision Strategy on Deciding to Defer Choice," *Journal of Behavioral Decision Making*, vol. 4, no. 9, pp. 265–281.

Dhar, R. 1997. "Consumer Preference for a No-Choice Option," *Journal of Consumer Research*, vol. 2, no. 24, pp. 215–231.

Di Bello, L. 1997. "Exploring the Relationship Between Activity and Expertise: Paradigm Shifts and Decision Defaults Among Workers Learning Material Requirements Training," *Naturalistic Decision Making,* Lawrence Erlbaum Associates, Mahwah, NJ.

Endsley, M. 1995. "Toward a Theory of Situation Awareness in Dynamic Systems, *Human Factors*, vol. 1, no. 37, pp. 32–64.

Gaba, D. M., S. K. Howard, and S. D. Small. 1995. "Situation Awareness in Anesthesiology," *Human Factors*, vol. 1, no. 37, pp. 20–31.

Jungermann, H. 1997. "Reasons for Uncertainty: From Frequencies to Stories," *Psychologische Beitraege*, vol. 1–2, no. 39, pp. 126–139.

Kahneman, D., P. Slovic, and A. Tversky. 1979. *Judgement Under Uncertainty: Heuristics and Biases*, Cambridge University Press, Cambridge, England.

Klein, G. 1993. "Recognition-Primed Decision (RPD) Model of Rapid Decision Making," *Decision Making in Action: Models and Method,* Ablex, Norwood, NJ, pp. 138–147.

Klein, G., J. Schmitt, M. McCloskey, J. Heaton, D. Klinger, and S. Wolf. 1996. "A Decision-Centered Study of the Regimental Command Post," Summary Report, Klein Associates, Inc., Fairborn, OH.

Lehto, M. R. 1997. "Decision Making," *Handbook of Human Factors and Ergonomics,* John Wiley & Sons, Inc., New York, NY, pp. 1201–1248.

Lipshitz, R. and O. Strauss. 1997. "Coping with Uncertainty: A Naturalistic Decision-Making Analysis," *Organizational Behaviour and Human Decision Processes,* vol. 2, no. 69, pp. 152–154.

Myers, A. and C. Hansen. 1997. *Experimental Psychology, 4th Edition*. Brooks/Cole Publishing Company, Pacific Grove, CA.

O'Hare, D. 1992. "The 'Artful' Decision Maker: A Framework Model for Aeronautical Decision Making," *International Journal of Aviation Psychology*, vol. 3, no. 2, pp. 175–191.

Reece, W. and L. Matthews. 1993. "Evidence and Uncertainty in Subjective Prediction: Influences on Optimistic Judgment," *Psychological Reports*, vol. 2, no. 72, pp. 435–439.

Rowe, W. D. 1994. "Understanding Uncertainty," *Risk Analysis*, vol. 5, no. 14, pp. 743–750.

Salas, E., C. Prince, D. P. Baker, and L. Shrestha. 1995. "Situation Awareness in Team Performance: Implications for Measurement and Training, *Human Factors*, vol. 1, no. 37, pp. 123–136.

Shafir, E. 1994. "Uncertainty and the Difficulty of Thinking Through Disjunctions," *Cognition*, vol. 1–3, no. 50, pp. 403–430.

Schmitt, J. F. 1994. *Mastering Tactics: A Tactical Decision Games Workbook,* Marine Corps Association, Quantico, VA.

St. John, M., J. Callan, S. Proctor, and S. Holste. 2000. "Tactical Decision-Making under Uncertainty: Experiments I and II," TR 1821. Space and Naval Warfare Systems Center, San Diego, CA.

Stokes, A. F., K. Kemper, and K. Kite. 1997. "Aeronautical Decision Making, Cue Recognition, and Expertise under Time Pressure," 1997. *Naturalistic Decision Making*, Lawrence Erlbaum Associates, Mahwah, NJ.

Xiao, Y., P. Milgram, and D. J. Doyle. 1997. "Capturing and Modeling Planning Expertise in Anesthesiology: Results of a Field Study," *Naturalistic Decision Making*. Lawrence Erlbaum Associates, Mahwah, NJ.

Yaniv, I., D. and P. Foster. 1995. "Graininess of Judgment under Uncertainty: An Accuracy-Informativeness Trade-Off," *Journal of Experimental Psychology: General*, vol. 4, no. 124, pp. 424–432.

Zsambok, C. E. and G. Klein (eds.). 1997. *Naturalistic Decision Making*, Lawrence Erlbaum Associates, Mahwah, NJ.

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