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Submarine Information Organization and Prioritization and Submarine Officer of the Deck Experience

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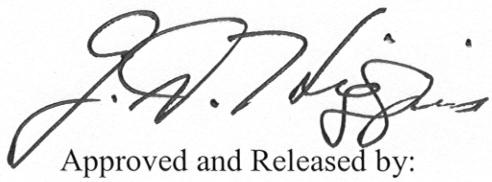

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SUMMARY PAGE

Objective: To determine how sonar and other information is organized and prioritized by the Submarine Officer of the Deck (OOD), for the purposes of augmenting our understanding of submarine "expertise," for making recommendations for information displays of submarine systems, and for training submarine officers.

Method: Eighty-three Naval Officers performed information sorting and ranking tasks to indicate similarity and relative importance among 20 categories of information available on submarines. These 20 submarine concepts were primary elements of information the submarine OOD would encounter while on watch, with the exception of tactics information. Each of the 20 concepts was printed on an index card. Research participants made similarity judgments by sorting the 20 cards into discrete groups, according to the participant's own definition of similarity. The number of piles and the concepts in each pile were recorded. Then, participants placed the 20 cards into a single pile, ranked or ordered according to relative importance. Participants repeated the ranking task four times for four differing operational scenarios. Research participants were Submarine Officer Basic Course students (both pre and post course), Submarine Officer Advanced Course students, and Post Department Head submariners.

Findings: With regard to information similarity, submarine OODs organize information in two basic dimensions, one defined by the source of information (context/noise v. contact/signal), and the other defined by the destination (or primary user) of the information (sonar v. CONN). In addition to the two-dimensional structure in the organization of all 20 information items, there was also a more finely grained grouping or "clustering" of information. The expert group organized information into four clusters and the groups with less expertise organized information into five clusters. Further, the information in these five clusters varied as a function of experience. With regard to information prioritization, the information regarded as the most important varied as a function of operational scenario (i.e., littoral v. pelagic water environment; neutral v. hostile contact). This change in prioritization between scenarios was most evident for the most experienced submariner participants; little change was observed for the least experienced.

Application: The trend towards fusion displays and the importance of presenting "knowledge" v. "information" gives special relevance to these findings. The cognitive model developed from these data and the converging evidence in the literature serve as a guideline in designing submarine displays that not only present the most appropriate information, but present it in a manner that is consistent with the operators' organization of information. This alignment is important in creating "user-friendly" equipment.

ADMINISTRATIVE INFORMATION

This work was conducted under Work Unit 51001 entitled: "Information Requirements and Information Organizations in Submarine Combat Systems." The opinions or assertions contained herein are the private ones of the authors and are not to be construed as official or reflecting the views of the Department of the Navy, Department of Defense, of the United States Government. This research has been conducted in compliance with all applicable Federal Regulations governing the Protection of Human Subjects in Research. This Technical Report was approved for publication on 12 July 2004, and designated as NSMRL Technical Report TR #1234.

ABSTRACT

The submarine environment is alien to typical human experience. In a world without direct visual information, the submarine Officer of the Deck (OOD) receives a variety of diverse information as inputs and makes operational decisions based on his understanding. Although there have been efforts to describe this understanding, organization, and prioritization (Kirschenbaum, 1992; 2001; Laxar, Moeller, & Rogers, 1983; 1989), a validated model has yet to be described. The description of a submarine OOD's cognitive organization of information is the objective of this research. Using analyses of submariner knowledge for concepts related to responsibilities for the OOD task, this research examined how submarine officers cognitively organize this information and how experience may alter knowledge representation and conceptual importance.

Eighty-three Naval Officers, some qualified and some not qualified as OOD, performed information sorting and ranking tasks to indicate similarity and relative importance among 20 categories of information available on submarines. These 20 submarine concepts were primary elements of information the submarine OOD would encounter while on watch, with the exception of tactics information. Each of the 20 concepts was printed on an index card. Research participants made similarity judgments by sorting the 20 cards into discrete groups, according to the participant's own definition of similarity. The number of piles and the concepts in each pile were recorded. Then, participants placed the 20 cards into a single pile, ranked or ordered according to relative importance. Participants repeated the ranking task four times for four differing operational scenarios. Research participants were Submarine Officer Basic Course students (both pre and post course), Submarine Officer Advanced Course students, and Post Department Head submariners.

The results show that more experienced personnel possess different mental models than less experienced personnel. With regard to information similarity, submarine OODs organize information in two basic dimensions, one defined by the source of information (context/noise v. contact/signal), and the other defined by the destination (or primary user) of the information (sonar v. CONN). In addition to the two-dimensional structure in the organization of all 20 information items, there was also a more finely grained grouping or "clustering" of information. The expert group organized information into four clusters and the groups with less expertise organized information into five clusters. Further, the information in these five clusters varied as a function of experience. With regard to information prioritization, the information regarded as the most important varied as a function of operational scenario (i.e., littoral v. pelagic water environment; neutral v. hostile contact). This change in prioritization between scenarios was most evident for the most experienced submariner participants; little change was observed for the least experienced.

This knowledge allows system designers to develop command and control displays that use this cognitive organization to the user's advantage by developing systems that are intuitive to the user. Additionally, the knowledge of these mental models of experts could be used as targets for training less experienced personnel.

INTRODUCTION

The submarine presents an extreme and alien environment to its human crew. In addition to life support challenges, this environment presents significant psychological and cognitive challenges. Humans are adapted for direct path visual and auditory information in an air-filled medium; therefore, they are poorly suited for the fluid-filled underwater medium with limited or no visual information and indirect path auditory information that is presented visually. Our mental representation or cognition of the world is derived from our perception of the world, so the difficulties the submarine presents to perception can be expected to extend to cognition. Compounding the lack of *typical* perceptual information, submarine technology presents a wealth of *atypical* information, information not available in everyday experience [e.g., ESM (electronic surveillance mast)]. Such information is valuable to submarine operations so operators need to adapt their cognition to incorporate this new perceptual ability. Despite these cognitive challenges, people successfully operate submarines all over the world. This research is an exploration of the mental model(s) submarine officers use to execute their mission.

The manner in which submariners cognitively organize available information is expected to be as unique as the submarine environment. The difficulty and vagaries of submarining have been compared to weather prediction and medical diagnosis (Gray & Kirschenbaum, 2000; Kirschenbaum, 1992). For situational awareness (Endsley, 1995), the submariner needs a wide variety of information available at his watch station to build his mental model (Johnson-Laird, 1993). A variety of visual displays that afford data fusion are available, especially given recent technological advances, but the Officer of the Deck (OOD) remains the most effective integrator of information available in the control room (Ferren, 2000; Holland, 1999). This determination is made based on the person's ability to resolve ambiguities better and execute with best knowledge from incomplete information. Given the uniqueness and limited size of the submarine population, there is a scarcity of human-based research in submariner cognition and his organization of submarine information has not been specified. Accurate models of submariner cognition are still in development.

Accurate models of submariner cognition are important in designing displays on submarines for optimal use and for guarding against information overload (Shobe, 2001, 2002; Shobe & Severinghaus, 2004). Organizational systems for information can be inherent in the data, in the person, or in both the system and the person. When there is disconnection between organizational systems and people are required to actively re-organize information into appropriate structures, they have difficulty preserving the relations among items (Durding, Becker, & Gould, 1977). As an example of this phenomenon in submarine display development, when there was a transition from analog to digital systems, one advance was to no longer use the line of sight display. However, brief experience on board without this cognitively compatible display resulted in negative feedback from operators and resulted in the return of the line of sight display. This cognitive phenomenon is related to an activation model of cognition in that when primed with a particular information item, people also think of (or "activate") similar information. There is a finite range of activation around a central concept and the activation burden (i.e., non-conscious retrieval) is eased when similar information is presented together (Schmitter-Edgecombe, 1999). Managing the level of cognitive activation is important because there is a limit to human processing capacities. Many information processing theorists consider too much information a key source of performance degradation (Janis & Mann, 1977). Current and proposed equipment makes it possible to display any information at CONN, from raw auditory data to refined visual displays of ships' predicted positions. In this environment of powerful display capability, an important consideration of the human as part of the system may dictate that less information be provided than is technologically possible (e.g., Human Systems Integration). An accurate cognitive model would serve as an expert system to present or emphasize the most relevant information.

The process of identifying the most relevant information for submarining and effective organization of that information must involve active duty submariners, the experts. This involvement of experts could be through empirical assessment during real or simulated operations, but such approaches are expensive and time-consuming, especially when involving many subjects. Alternately, interviews and other consultation with submariners provide insight into their cognitive approach (Kirschenbaum, 1992; Soldow 1998), but often, people do not have conscious access to their own underlying mental organization and cannot articulate rules for their behavior (Ashby & Maddox, 1992, 1993), particularly as seen in a submarine navigation, (Sun, Merrill, & Peterson, 2001). Talk-aloud protocols (i.e., verbalizing while going through actions) can be more revealing than direct interview, but they have limitations as well, especially in combining data across many subjects. Another research alternative, the one used in this report, is an unconstrained sorting task (aka, Q-sort) and nonmetric multidimensional scaling and clustering analyses (Kruskal, 1964; Shepard, 1962). Other investigators have used these methods exploring Naval antisubmarine warfare (ASW) (Laxar, Moeller, & Rogers, 1983; Laxar, Rogers, & Moeller, 1988; Zachary, 1980). In this report, sorting and ranking tasks are used to elicit judgments from Naval Officers about submarine information, to determine how such information is organized and assigned priorities by the submarine OOD according to level of experience. These methods accommodate active duty submariners' limited time and afford aggregation across many subjects.

The operational community has called for consideration of the operator in systems design (Armbruster, 2003), and the Naval Sea Systems Command is addressing this concern by the recently instantiated Human Systems Integration directorate (e.g., NAVSEA 03). The objective of this research is to model the submarine OOD's approach to information they use on board to execute their mission. This model can be employed in systems design and operations to serve as an expert decision aid, and to present the operator with "intuitive" information (i.e., knowledge). An intuitive display can be achieved by presenting information in an organization that is consistent with the operator's own cognitive organization and consequent expectations.

Without an appreciation of the user's approach (as derived from the human-based cognitive model), the presentation of information is left to the discretion of the system designer (Kallmeier, et al., 2001). A computer system may handle vast amounts of information, but such systems usually fall short when determining what information is important and relevant in a particular situation, especially as the situation changes. As a now commonplace example, World Wide Web search engines can process thousands of web pages in milliseconds, but they often present an overwhelming return to the human operator, rather than the specific item(s) the person desires. As an alternative to burdening the operator by requiring additional complex inputs to retrieve relevant information, an understanding of the operator's approach can facilitate the retrieval of information important for the task at hand.

OBJECTIVES

A central theme of command and control is the power of information. In discussions related to "information superiority", situational awareness is a major element. Situational awareness refers to the ability of an operator to perceive the relevant informational elements in the environment, comprehend and integrate these various pieces of information in support of an operator's goals, and predict future events and system states based on this understanding (Endsley, 1995). However, one of the greatest challenges facing operators and technology providers is to match our increasing capability to gather, process, and display information useful for situation awareness with a corresponding increase in our ability to use that information. Information overload is a valid concern and may be an unintended consequence of the quest for information superiority.

More information does not always mean better situational awareness, unless we gather, integrate, and present information in a way that supports the decision maker's cognitive processes. Sometimes the addition of more information may be counterproductive because it brings with it the potential for additional ambiguities and the need for users to cognitively process greater numbers and types of information inputs. Without the tools to handle the increased size and complexity of the situational awareness picture, operators will be faced with the problem of information overload. This project's goal is to increase situational awareness in a way that helps interpret the increased knowledge base so that it helps rather than hinders the decision making process.

This research defines the information required by the submarine OOD to perform his duties and specifies how this information should be organized for optimal accessibility by the decision maker, as in a computer-based retrieval and display system. These results will serve as a basis on which to design or refine a human system interface for information retrieval and display systems in the submarine Command and Control Center.

Specifically, the current research is exploratory and descriptive in nature, and addresses the issue of how submariners cognitively organize and prioritize information in different operational scenarios, and whether these mental models change as a result of experience. These data will be compared with precursor research of submarine operators' cognitive approach to submarine sonar information by OODs (Laxar, Moeller, & Rogers, 1983) and by sonar technicians (Laxar, Moeller, & Rogers, 1989). The earlier research used the same methodology as the present research, but the information considered was limited to sonar information. In those investigations, information was found to be organized in two dimensions, sonar information source (contact v. environment) and sonar information destination (sonar v. CONN). It is expected that the inclusion of non-sonar information and new technology (e.g., relatively new sensor capability) may reflect a different categorization of information by OODs.

METHODS

Participants

Data were collected from 83 Naval Officers. Seventy-nine of these participants were students at Naval Submarine School, Submarine Base New London, and four were instructors at the Naval War College, Newport, RI. These 83 participants comprised four groups in this research, listed here in ascending order of submarine expertise. Submarine Officer Basic Course (SOBC) students served as two groups of 'novice' participants (N = 39). The SOBC students are not OOD-qualified, but in SOBC they do receive all the relevant lectures and simulator experience in initial OOD training. Data were collected from the SOBC students during the first week of class (SOBCpre) and the last week of class (SOBCpst). Submarine Officer Advanced Course (SOAC) students served as 'experienced' participants (N = 40). SOAC students are OOD-qualified. Finally, post Department Head submarine officers currently filling a shore tour billet served as 'expert' participants (N = 4; Post DH). Descriptive information for the 83 participants is presented in Tables 1 and 2. The career path of submarine officers displayed in Figure 1 provides a schematic for the level of experience of the three subject groups used in this study.

Table 1. Subjects' Demographic Information

Characteristic	N	Mean	SD
Age			
SOBC	39	25.2	2.4
SOAC	40	31.2	2.4
Post DH	4	40.5	0.6
Years of Service			
SOBC	39	5.1	3.6
SOAC	40	10.6	3.5
Post DH	4	20.4	1.9
Years of Sea Duty			
SOBC	39	1.1	1.3
SOAC	40	3.8	1.2
Post DH	4	6.5	0.6

Table 2. Rank Distribution of Subjects

	Rank				
	O1	O2	O3	O4	O5
Group					
SOBC	37	2	0	0	0
SOAC	0	0	39	1	0
Post DH	0	0	0	4	0

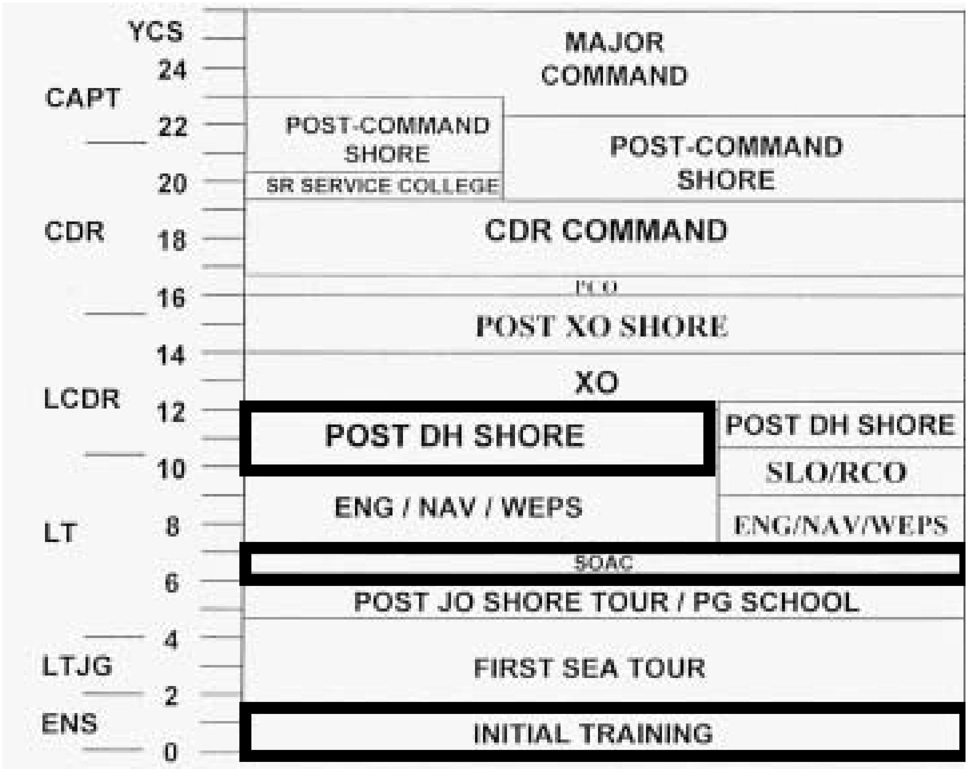

Figure 1. Submarine Officer career path. Participant groups used in the study are outlined with bold lines.

Materials

Various types of information from current and proposed submarine systems were classified into 20 categories by the investigators at the Naval Submarine Medical Research Laboratory and submarine fire control experts at the Naval Undersea Warfare Center (NUWC). To build upon the earlier research by Laxar et al., (1983, 1989) which described submariners' cognitive organization of 15 categories of sonar information, some of those categories were included within the set of 20 items with minimal change where appropriate. These 20 categories are listed in Appendix A. Descriptions of these categories comprised the 20 stimuli for the tasks to be performed by the subjects. Each of the stimuli was typed on a separate 3" X 5" card and numbered on the reverse side to create the stimulus deck.

Some information available to the OOD at CONN (control of a submarine's movements; e.g., torpedo load out, weapons safeties, countermeasures status, intelligence on contacts in the area) was not included in this investigation because it was more relevant to target prosecution than situational awareness. Several subjects did request such information, which indicates its importance for the OOD, but it was considered outside the scope of the present research.

Procedure

All subjects were given a brief overview of the procedure when consent forms were administered. This research was conducted in compliance with all applicable federal regulations governing the protection of human subjects in research. Next, participants completed a background questionnaire to assess their level of experience (Appendix B). Next, participants judged the similarity between different categories of information available to the OOD at CONN. This judgment of similarity is a reflection of the conceptual organization operators employ. To make these similarity judgments, subjects completed an unconstrained sorting task. The officers received a set of 20 index cards with a short description of submarine information printed on each and then arranged these cards into groups according to similarity. The definition of similarity was left up to the subject. Cards describing similar categories were placed in the same group. Any card describing a unique category was placed by itself. The officers could create as many or as few groups as they felt appropriate.

After the sorting task, the officers ranked the information cards according to relative importance, creating a single pile with the most important card on top and the least important card on bottom. Subjects ranked the items four times, once for each of four different operational scenarios (Appendix C). The factors that varied over the four scenarios were the type of contact (neutral vs. hostile) and the type of environment (deep water vs. shallow water). The first scenario was an AntiSubmarine Warfare (ASW) patrol in a shallow water environment (i.e., littoral sea; "brown water") with a hostile contact. The second scenario was the same as the first, except the contact was neutral. The third scenario was an ASW patrol in a deep water environment (i.e., pelagic ocean; "blue water") with a hostile contact. Finally, the fourth scenario was the same as the third except the contact was neutral. These four scenarios differ greatly in the quality and quantity of information available to the OOD.

After each task, subjects recorded their responses (i.e., card sorting or ordering) on answer sheets according to the code number on the back of each stimulus card.

RESULTS

The card sorting data were submitted to both multidimensional scaling analyses, to identify underlying dimensions or organizing principles, and a cluster analysis, to identify groups of similar items. The revealed organization is indicative of submarine OOD's approach to information. The ranking data were used to examine information prioritization within this organization and how this prioritization changes in conditions of contact type and operational environment.

Multidimensional Scaling Analysis

Multidimensional scaling (MDS) was used to reduce the amount of data for easier interpretation and to provide a visual representation of patterns of similarities among the stimuli. The input to the MDS analysis, the raw data from the unconstrained sorting task, are nominal in nature and are difficult to aggregate and analyze quantitatively. To treat these data quantitatively, each subject's data are systematically transformed into a matrix of similarities among the 20 items. Then, all the subject's matrices are aggregated into a single matrix of similarities. This aggregate matrix is the input for the MDS analyses[1]. The MDS analysis constructs a configuration of the stimuli in k-dimensional space such that the Euclidean distances among the stimuli correspond as closely as possible to the input similarities. This construction is an iterative adjustment process, based on the observed dissimilarity between all pairs of stimuli. The final configuration is then rotated so that the principal components of the points lie along coordinate axes. The coordinate axes are then used to help determine the underlying psychological structure of the stimulus domain.

The appropriate number of dimensions is defined by the degree to which additional dimensions account for the similarities in the data. At some number of dimensions, additional dimensions in the analysis do not provide significant additional explanatory power. This point is determined as the number of dimensions at which the stress (i.e., goodness of fit) of the model is acceptable. Generally, stress greater than 0.15 is unacceptable, meaning another dimension should be added; stress less than 0.10 is excellent, meaning no further dimensions should be added (Kruskal & Wish, 1978). This stress acceptability benchmark is usually coincident with the "elbow" in a scree plot, a plot of stress by dimensions. Both quantitative and visual methods of stress assessment were used here. The dimensions of similarity as revealed by the analysis are not necessarily categorical in nature. These dimensions can be considered as continua with no natural gaps. In the graphical output of the MDS analysis, the larger distances are more accurate.

The dimensions, or axes, resulting from MDS are meaningless and the orientation of the picture is arbitrary. What is important is the relative position among items and clusters of items. The labels associated with the dimensions are determined by the researchers according to what makes the best sense given the subject material.

Solution stress levels

In the MDS analyses of the sorting data, the solution stress level for the SOBCpre subjects was 0.09 after 19 iterations, and the stress level for the SOBCpst subjects was 0.05 after 22 iterations. The solution stress levels for the SOAC and PostDH subjects were 0.08 after 24 iterations and 0.00 after 16 iterations, respectively. All of these stress levels fall within the acceptable range.

Number of dimensions

The scree plots for all subject groups revealed two dimensions for each group's organization of the 20 submarine information items.

Coordinates

[1] This procedure assigns values to the 400 pairs of stimuli according to the number of times subjects placed the items in the same groups. For these analyses (i.e., raw data transformation, matrices aggregation, multidimensional scaling, clustering), Anthropac software was used (Borgatti, 1996a, 1996b).

Figures 2 through 5 show the MDS two-dimensional plots for the SOBCpre, SOBCpst, SOAC, and PostDH subject groups. The coordinates of the information items for all subject groups are listed in Appendix D, while the acronyms used in all the plots are explained in Table 3.

Table 3. Acronyms used in MDS plots

Concept	**Acronym**
Electronic Support Measures contact data	ESM
Own ship data	OS
Performance Monitoring/Fault Location data	PMFL
Ocean environment and navigation data	OE
Counterdetectability data	CD
Propulsion Plant Lineup	PROP
Sonar search plan	SSRCHPLN
Visual contact data	VIS
Potable water status	POT
Active sonar lineup	ACT
Ship's atmosphere	ATM
Sonar tracker/cursor audio	SAUD
Sanitary tank status	SAN
Geosit/ops summary	GEO
Trial own ship	TOS
Non-target fire control solution	NTFCS
Sonar detection displays	SDIS
Sonar lineup	SLINUP
Target fire control solution	TCS
Sonar class displays	SCLASDIS

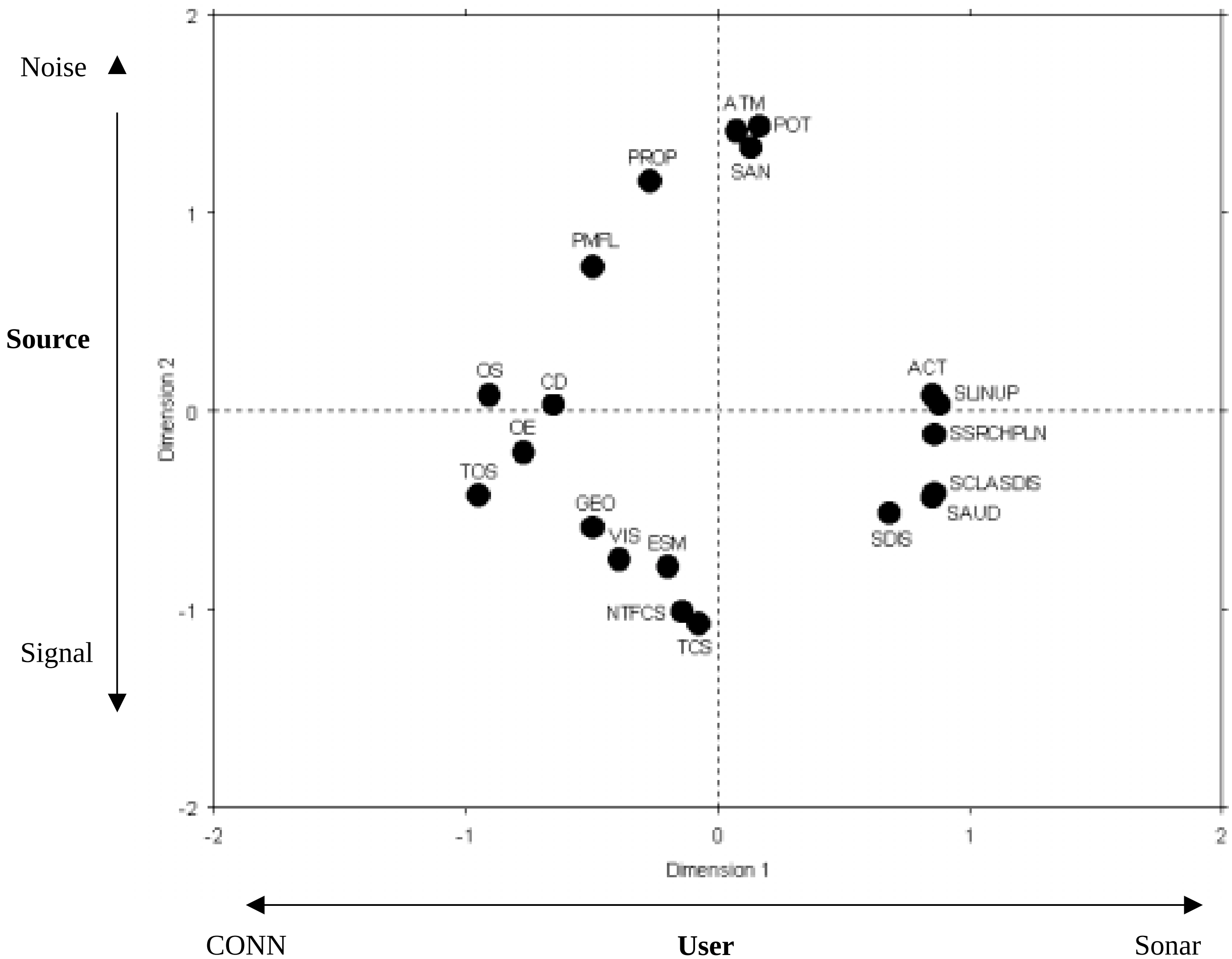

Figure 2. The two-dimensional solution for the multidimensional scaling analysis for information available to the submarine OOD, SOBCpre subjects.

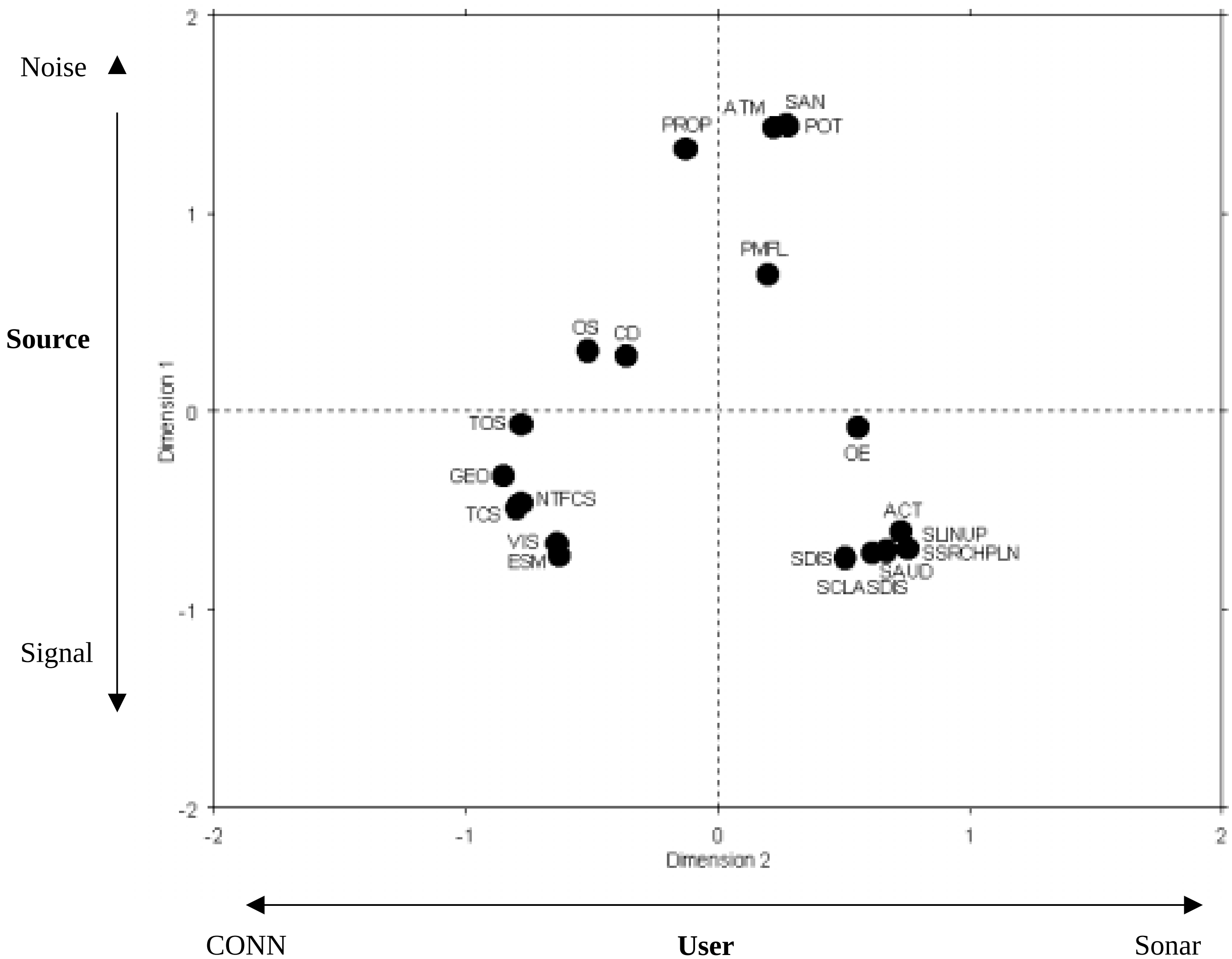

Figure 3. The two-dimensional solution for the multidimensional scaling analysis for information available to the submarine OOD, SOBCpst subjects.

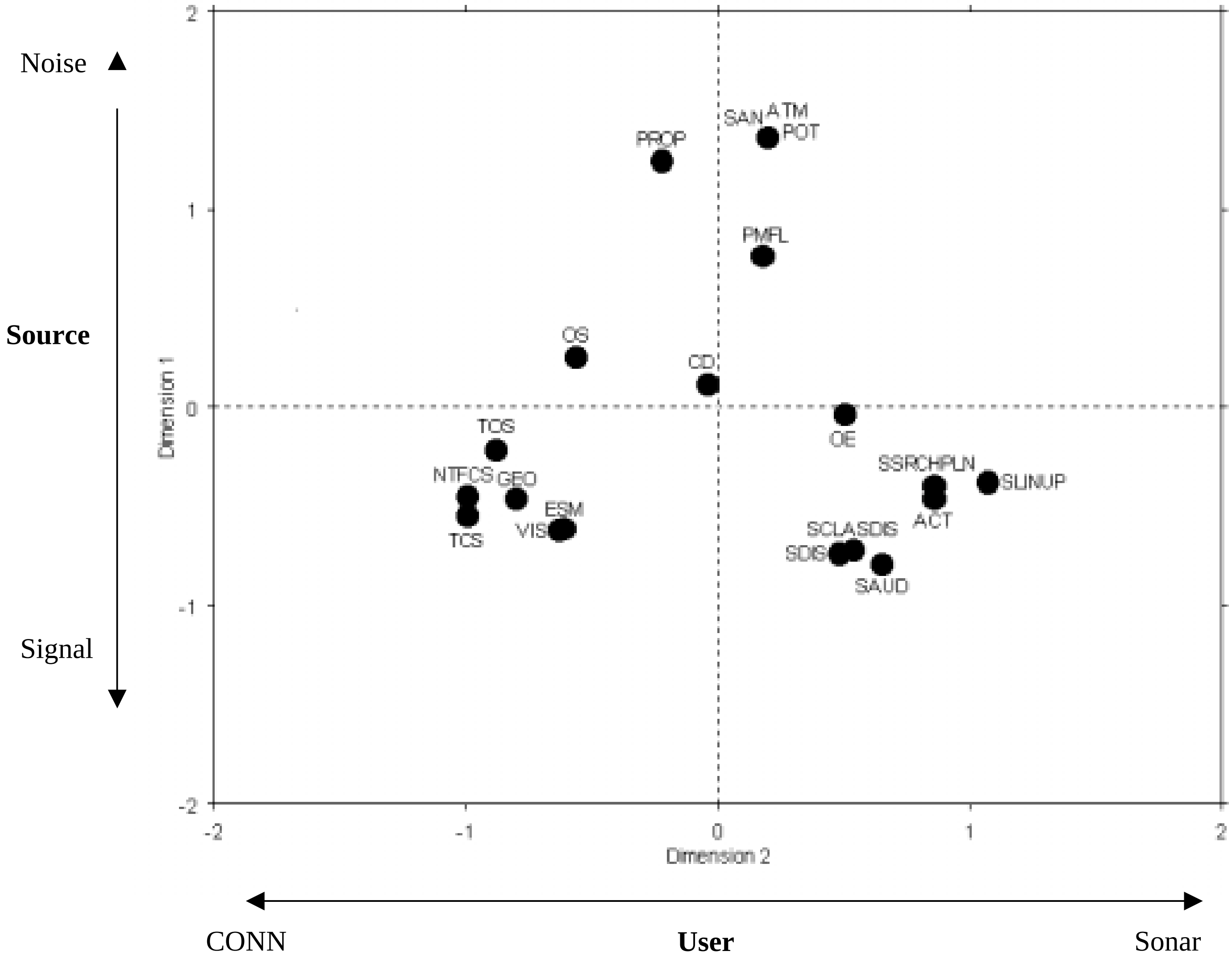

Figure 4. The two-dimensional solution for the multidimensional scaling analysis for information available to the submarine OOD, SOAC subjects.

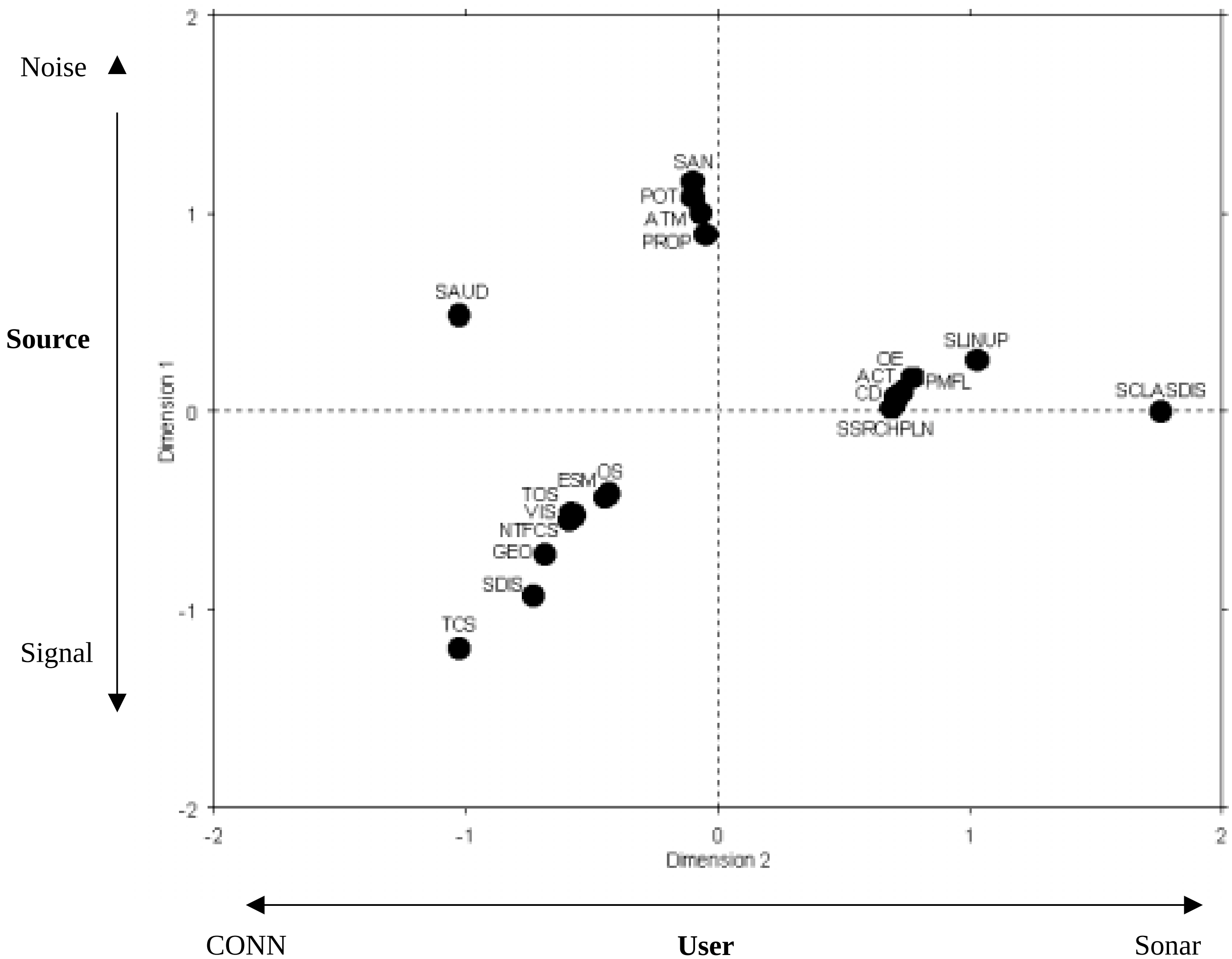

Figure 5. The two-dimensional solution for the multidimensional scaling analysis for information available to the submarine OOD, Post DH.

Interpretation of the MDS Results

For the four subject groups, the horizontal dimension in the figures is interpreted to be the destination (or primary user) of the information: CONN v. sonar (e.g., Geo plot v. sonar lineup). Trial own ship (left side of figures) is an aggregation of sonar information taken from successive maneuvers by own ship. The sonar gram (right side of figures) is the visual representation of the acoustic environment and is the primary source of raw data for the submarine. These types of information are delimiters for the ends of the horizontal axis in the graph above. Both CONN and sonar benefit from knowing the environmental conditions – that is why it falls halfway between. This dimension is consistent with Laxar et al. (1983; 1989). Those earlier findings, however, included only sonar information, so there is an additional quality to the interpretation of this dimension in that it also captures single source information (or raw data; e.g., sonar) v. fused information from multiple sources (e.g., Geo plot). The information fusion quality of the interpretation was not as apparent in the previous investigation that only dealt with sonar information, but it is consistent with the type of information that would be needed at CONN.

The vertical dimension in the figures is interpreted to be the source of information: context/noise v. contact/signal (e.g., information about the ocean environment v. intercept of active sonar pulse). The ocean environment and the operation of the sonar system (i.e., PMFL) are noise that must be factored out in sensor operation to enhance signal detection. Contact classification from an intercepted active sonar signal from the contact and visual image of the contact from the photonics mast are clear signals from the contact of interest. These types of information are delimiters for the ends of the vertical axis in the MDS analysis. The Geo plot (i.e., fusion display) contains both noise and signal, and thus should fall between the ends of the horizontal axis. As with the first dimension, this dimension is consistent with findings in Laxar et al. (1983, 1989).

Sorting data of all four subject groups revealed two dimensions for the organization of the 20 submarine information items. The number of dimensions with which subjects mentally organized the information items did not differ between levels of experience. The initial cognitive organization that SOBC students use to classify the information does not appear to be significantly different from the more experienced subjects in the SOAC and Post DH groups, with respect to general organizing principles.

The primary task onboard submarines is localization of sensed contacts (Kirschenbaum, 1992). In this alien environment in which visual creatures are deprived of visual information from a natural scene, the OOD cannot simply scan the horizon to get an understanding of where objects are in the environment. Instead, data are collected from the surrounding external environment by different sensors (e.g., sonar) and the OOD builds a mental representation of the submarine's situation. This mental construction can be difficult in an everyday environment (Carr & Roskos-Ewoldsen, 1999); it is extraordinarily difficult in the submarine environment in which everything must be imagined (as opposed to being seen) and most everything is in motion. Due to the simultaneous use of different sensors, after initial data collection, the subsequent task is resolution of the contacts that have been localized by different sensors. This resolution helps the OOD's mental model (Johnson-Laird, 1993) and situational awareness (i.e., localization). This situational awareness or mental model allows the OOD to make decisions regarding the operation of the ship. The two dimensions revealed in these data make sense given the submarine problem. One dimension corresponds to sensing and localizing the contacts in the environment. The other dimension corresponds to integrating information from different sources – for the same purpose as the OOD's mental model, to achieve situational awareness and to facilitate decision making regarding the operation of the ship (i.e., targeting, tracking, maneuvering).

Cluster Analysis

MDS analyses reveal general organizing principles at a gross level of detail. The grouping of items within organizing dimensions is a finer-grained approach to understanding cognitive organization and may reveal a more subtle effect of experience. For this finer-grained examination of the data, a cluster analysis was conducted to reveal natural groupings in the data. Johnson's (1967) average method which begins with many small clusters and gradually merges them into bigger, fewer clusters was used. The clusters are determined by Euclidean distance between items and each cluster iteration groups the two items that are most proximal. When the distance determination involves multiple items that have already been grouped into a cluster, the distance between a cluster and an item or another cluster can be determined by using the smallest distance, the largest distance, or the average or median of distances. In this analysis, a computation based on the average of the distances between clusters, as opposed to the minimum or maximum distance, was used. The data input into the analysis are the card sorting data produced by the subjects – the same input as used in the MDS analysis. The results of the cluster analysis only provide the number of clusters needed to best capture the data, not the labels of the clusters. The researchers give the categories labels post hoc to best explain the data.

Cluster analysis results for SOBCpre and SOBCpst subjects

For all subject groups, the level of .50 was used as the criterion in determining clusters. This means that the average distance among items within the clusters is .50 or less (maximum is 1.00). Tables 3 and 4 list the categories that emerged from the cluster analysis for the SOBCpre and SOBCpst subjects. This group of subjects used five groups to organize the information, and we labeled the categories as indicated in Tables 3 and 4. Even though the number of clusters needed to organize the information did not change as a result of the 10 week SOBC course, the placement of three of the information items did change. The "trial own ship" item moved from the Own Ship Parameters cluster to the Fire Control Data cluster, the "geosit/ops summary" item moved from the Contact Management cluster to the Fire Control Data cluster, and finally, the "ocean environment and navigation data" item moved from the Contact Management cluster to the Sonar cluster. It appears that the Fire Control Data cluster gained two new items and lost one item, suggesting some cognitive reorganization of the information items at the local (vice global) level.

Table 3. Cluster analysis results for SOBCpre subjects.

Category	Item
Own Ship Parameters	Own ship data
	Trial own ship
	Counterdetectability data
Ship System Status	PMFL data
	Propulsion Plant Lineup
	Ship's atmosphere
	Potable water status
	Sanitary tank status
Contact Management	ESM contact data
	Visual contact data
	Geosit/ops summary
	Ocean environment and navigation data
Fire Control Data/Target Analysis	Non-target fire control solution
	Target fire control solution
Sonar	Sonar search plan
	Active sonar lineup
	Sonar lineup
	Sonar tracker/cursor audio
	Sonar detection displays
	Sonar class displays

Table 4. Cluster analysis results for SOBCpst subjects.

Category	Item
Own Ship Parameters	Own ship data
	Counterdetectability data
Ship System Status	PMFL data
	Propulsion Plant Lineup
	Ship's atmosphere
	Potable water status
	Sanitary tank status
Contact Management	ESM contact data
	Visual contact data
Fire Control Data	Geosit/ops summary
	Trial own ship
	Non-target fire control solution
	Target fire control solution
Sonar	Ocean environment and navigation data
	Sonar search plan
	Active sonar lineup
	Sonar lineup
	Sonar tracker/cursor audio
	Sonar detection displays
	Sonar class displays

Cluster analysis results for SOAC subjects

The cluster analysis results for the SOAC subjects are displayed in Table 5. An interesting change occurred between the SOBC subjects and the SOAC subjects, suggesting that experience plays an important role in this cognitive organization. Even though SOAC subjects are similar to SOBC subjects in that they organized the information items along two dimensions (as revealed by the MDS results) and categorized the items into five groups, the specific groupings changed. The "ocean environment and navigation data" item changed groups again, but more interesting, the SOAC subjects broke apart one group into two groups, and merged two other groups into one group. The Sonar group splintered into the Equipment Lineup/Search Data group and the Sonar Tactical Displays group, indicating some reorganization of the sonar information. Additionally, the Contact Management group and the Fire Control Data group merged into one group for the SOAC subjects. In one case, experience has taught the subjects that items thought to be dissimilar are in fact similar, and other items that were thought to be similar require a different classification. This change suggests a reorganization of the mental model they use to interpret the data as they encounter while acting as OOD.

Table 5. Cluster analysis results for SOAC subjects.

Category	Item
Own Ship Parameters	Own ship data
	Ocean environment and navigation data
	Counterdetectability data
Ship System Status	PMFL data
	Propulsion Plant Lineup
	Ship's atmosphere
	Potable water status
	Sanitary tank status
Contact Management	ESM contact data
	Visual contact data
	Geosit/ops summary
	Trial own ship
	Non-target fire control solution
	Target fire control solution
Equipment Lineup/Search Data	Sonar search plan
	Active sonar lineup
	Sonar lineup
Sonar Tactical Displays	Sonar tracker/cursor audio
	Sonar detection displays
	Sonar class displays

Cluster analysis results for Post Department Head subjects

Table 6 provides the cluster analysis results for the most experienced subjects, the Post Department Head subjects. A new cognitive organization emerges from this analysis, even though these subjects also required two dimensions to globally organize the information (revealed by the MDS results). First, they only used four groups to organize the 20 information items, whereas the other three subject groups used five groups. Second, items changed groups from the SOAC classification to the Post DH classification. Specifically, the Own Ship Parameters group and the Contact Management group merged into one category for the Post DH subjects (even though two items moved to the Equipment Lineup/Search Data group). The "PMFL" item moved from the Ship System Status group to the Sonar Tactical Displays group.

Table 6. Cluster analysis results for Post DH subjects.

Category	Item
Own Ship Parameters/Contact Management	Own ship data
	ESM contact data
	Visual contact data
	Geosit/ops summary
	Trial own ship
	Non-target fire control solution
	Target fire control solution
Ship System Status	Propulsion Plant Lineup
	Ship's atmosphere
	Potable water status
	Sanitary tank status
Equipment Lineup/Search Data	Counterdetectability data
	Sonar search plan
	Active sonar lineup
	Sonar lineup
	Ocean environment and navigation data
Sonar Tactical Displays	PMFL data
	Sonar tracker/cursor audio
	Sonar detection displays
	Sonar class displays

Summary of cluster analysis results

The results from the cluster analyses garner support from the literature on expertise. Several studies have found that as experience increases, the underlying cognitive organization changes in a way that increases semantic connections between subject matter content (Fiore, Fowlkes, Martin-Milham, & Oser, 2000). In the current study, it was found that the most experienced participants (PostDH) utilized four clusters to categorize the information items, while the other groups required five clusters. Even though the other three subject groups used five clusters, the specific placement of the items within the clusters varied as a function of experience. Because some of these items (e.g., ocean environment and navigation data, PMFL, etc.) changed groups across different levels of experience, we would expect that these items would also move along the two dimensions of context/noise v. contact/signal and CONN v. sonar - the destination (or primary user) of the information.

The MDS and cluster analyses provide insight into how submarine Officers cognitively organize information in a mental model in a generic context. The priority ranking task, on the other hand, provides us with situation-specific mental models.

Ranking Tasks

Participants ranked the 20 information items according to priority for four operational scenarios. For the ranking task data, the data could be presented in many different ways. Given the abundance of the data (4 scenarios for 4 groups = 16 lists), the data were consolidated into some meaningful comparisons. Ranking data for all four subject groups across the four scenarios are presented in Appendix E.

Effect of experience on littoral and pelagic environment rankings

The scenarios varied across operating environment, littoral vs. pelagic, and type of contact, hostile vs. neutral. First, a closer look is taken at the effect of experience on prioritization of the information items across environments and contact situations. The change in judged importance among the 20 submarine information items for the pelagic and littoral operating environments across Post DH, SOAC, and SOBC post participants is shown in Figures 6 and 7. In this analysis SOBCpre subjects were not included because it was determined that the most value would be gained from comparisons among the other groups.

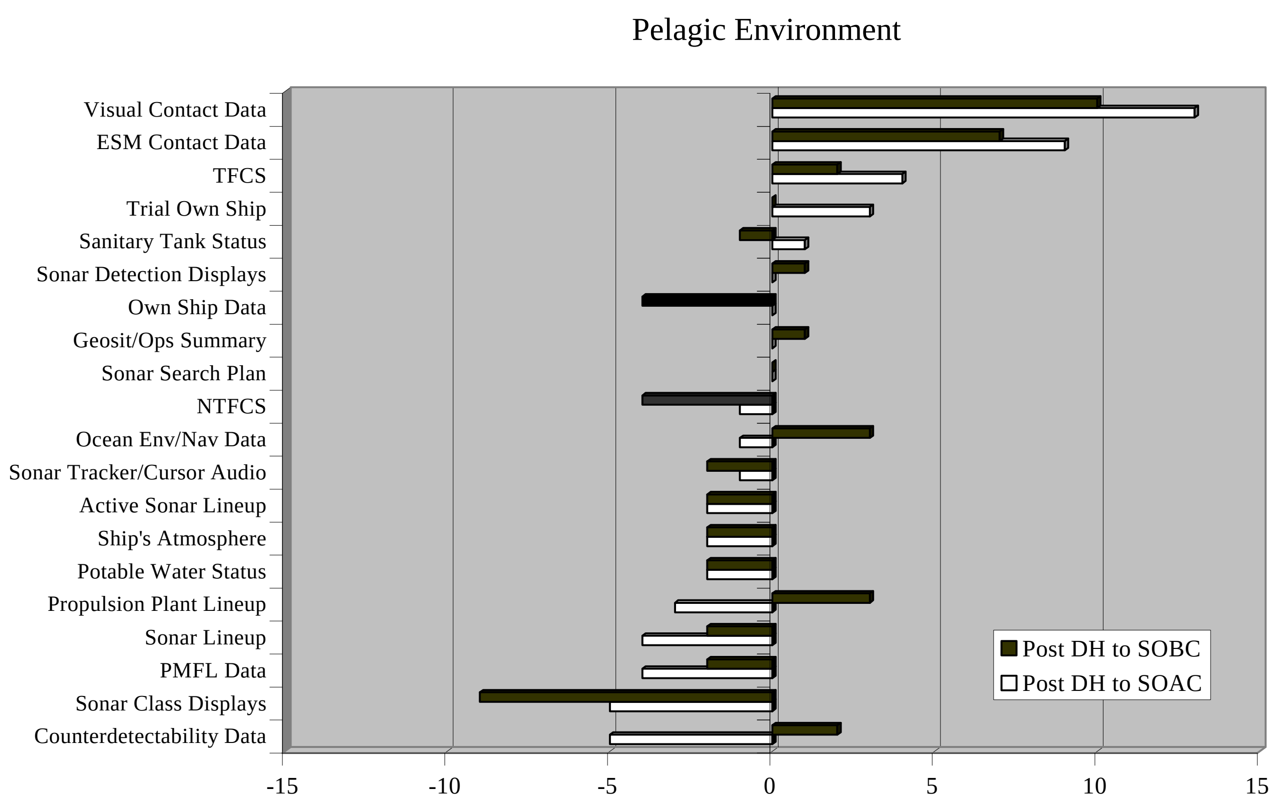

Figure 6. Change in judged importance among the 20 information items between PostDH, SOAC, and SOBCpst participants for the pelagic environment. Note: Negative numbers mean that PostDH subjects rated that item as more important, while positive numbers mean that PostDH subjects rated the item as less important.

For the pelagic, or deep water, operating environment, major differences were found in prioritization for several of the information items. The most experienced subjects judged several items as more important than the other subject groups. These include counterdetectability data, sonar class displays, PMFL data, and sonar lineup. They also judged several items as less important than other subject groups, including visual contact data, ESM contact data, TFCS, and trial own ship.

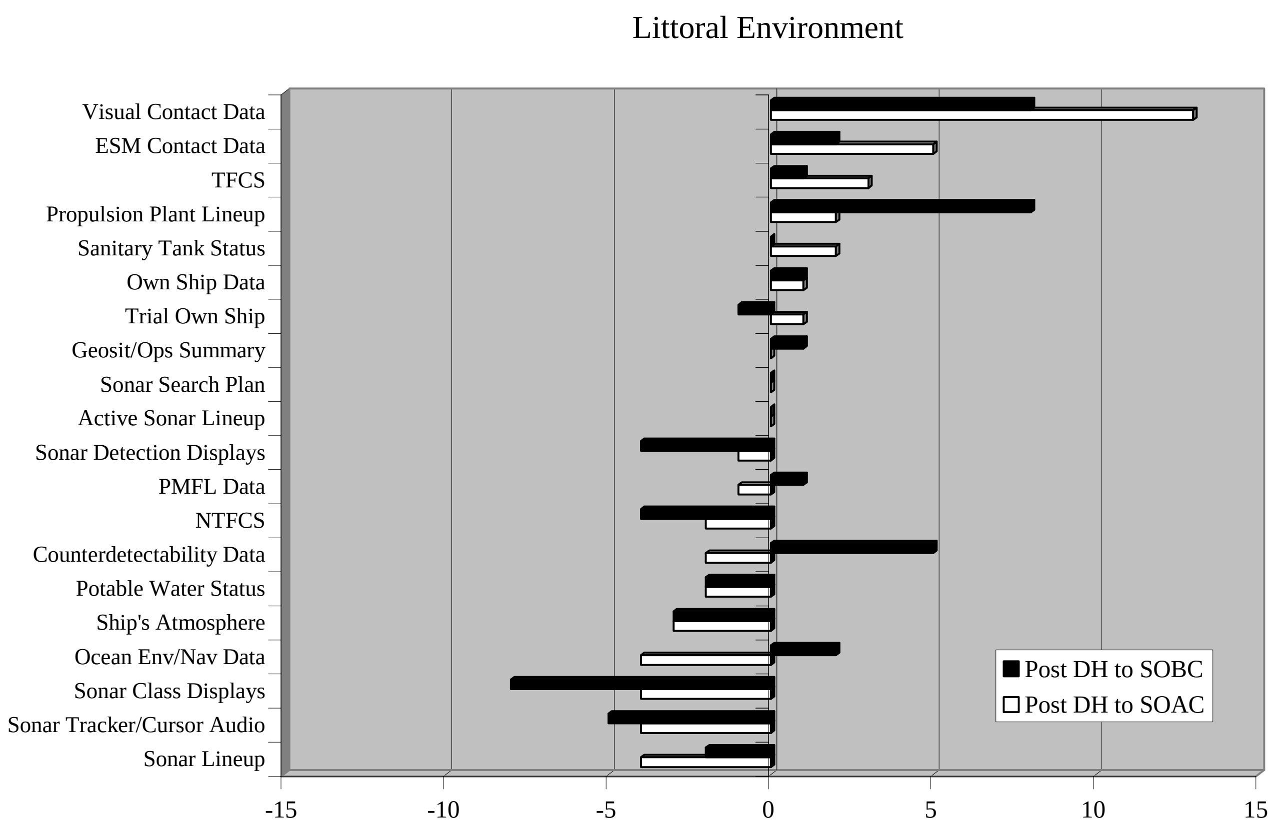

Figure 7. Change in judged importance among the 20 information items between PostDH, SOAC, and SOBCpost participants for the littoral environment. Note: Negative numbers mean that PostDH subjects rated that item as more important, while positive numbers mean that PostDH subjects rated the item as less important.

For the littoral, or shallow water, operating environment, major differences were found in prioritization for several of the information items. Once again, the Post Department Head subjects deemed sonar lineup, sonar tracker/cursor audio, sonar class displays, and ocean environment more important than the other groups. Visual contact data, ESM contact data, and TFCS items were rated as being less important for the littoral than the less experienced subjects ranked them.

Effect of experience on neutral and hostile contact rankings

The change in judged importance among the 20 submarine information items for the neutral and hostile contact scenarios across Post DH, SOAC, and SOBC post participants is shown in Figures 8 and 9.

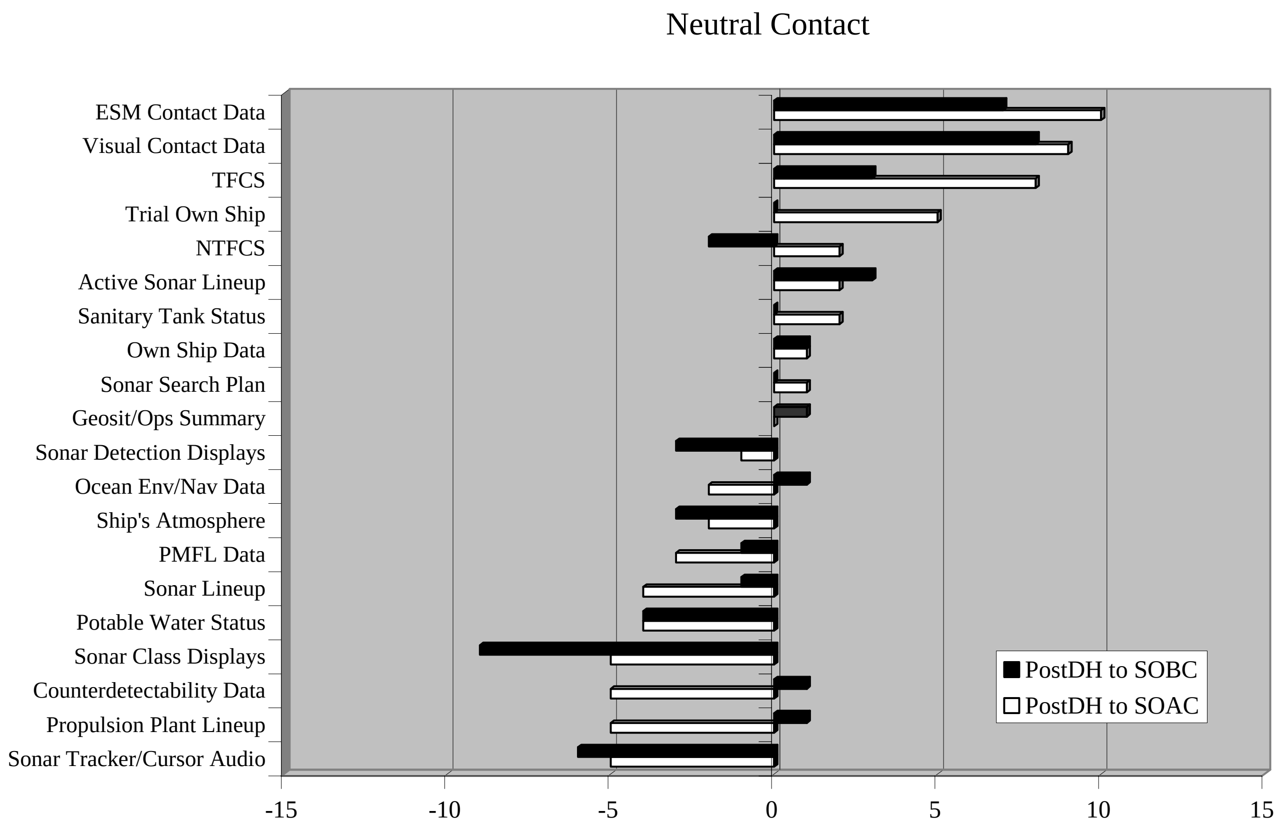

Figure 8. Change in judged importance among the 20 information items between PostDH, SOAC, and SOBCpost participants for the neutral contact scenario. Note: Negative numbers mean that PostDH subjects rated that item as more important, while positive numbers mean that PostDH subjects rated the item as less important.

For the situations in which there is a neutral contact, Post DH subjects prioritized the information items differently than the other subject groups. Sonar tracker/cursor audio, propulsion plant lineup, counterdetectability data, and sonar class displays were given more emphasis for the Post DH subjects. In contrast, ESM data, visual contact data, TFCS, and trial own ship were given higher priority by the less experienced subjects.

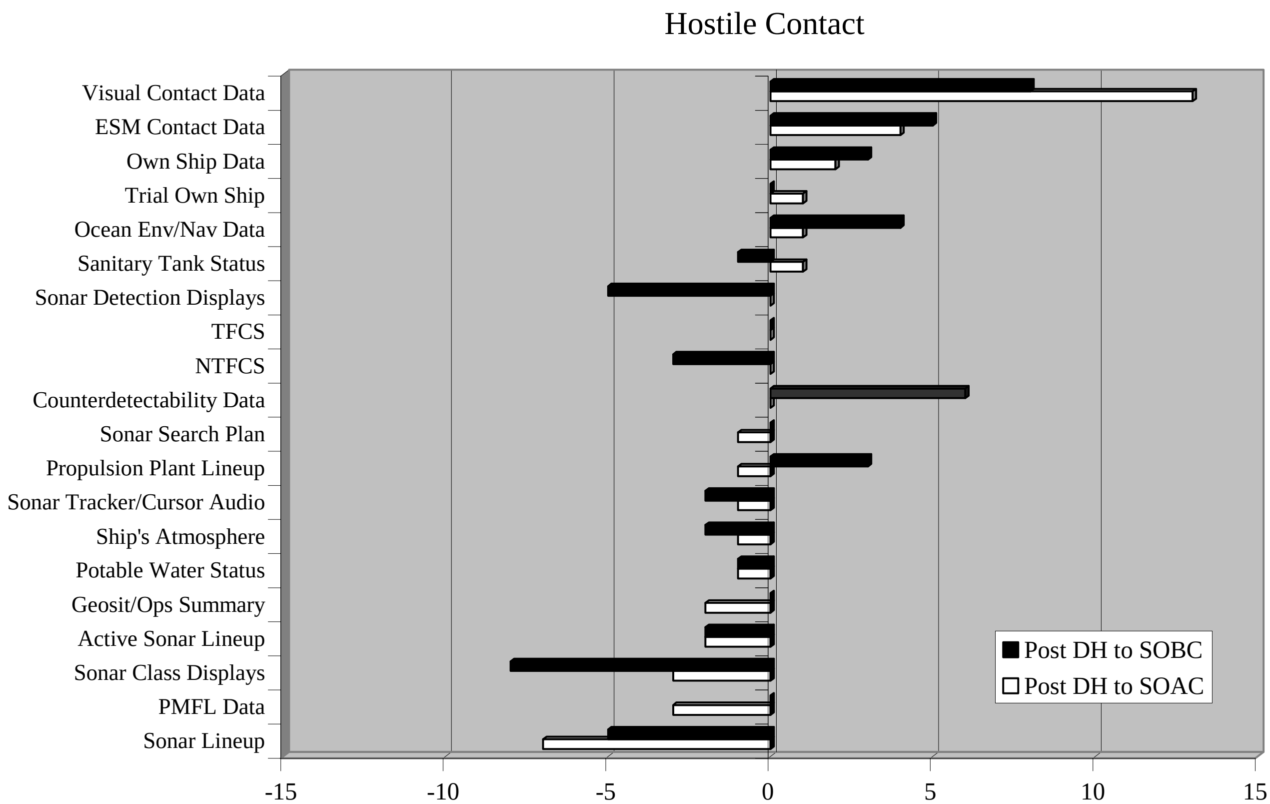

Figure 9. Change in judged importance among the 20 information items between PostDH, SOAC, and SOBCpost participants for the hostile contact scenario. Note: Negative numbers mean that PostDH subjects rated that item as more important, while positive numbers mean that PostDH subjects rated the item as less important.

Figure 9 reveals that for the situations in which a hostile contact is present, the prioritization of items changes with experience, similar to the differences in the neutral contact situation. Post DH subjects ranked sonar lineup, PMFL data, and sonar class displays as more important, while visual contact data, ESM contact data, and own ship data were ranked more important by the less experienced groups.

While the data were analyzed according to the two operating environments and two contact situations, a pattern emerged in comparing the most experienced submariners with the less experienced submariners. Post DH participants placed a greater emphasis on PMFL data, sonar lineup, sonar class displays, and counterdetectability data items in each situation. Compared to the Post DH subjects, the SOAC and SOBC participants consistently prioritized visual contact data, ESM contact data, TFCS, and trial own ship as more important.

Changes between littoral and pelagic environment rankings

Next, a closer look is taken at the effect of operating environment and contact situation for the more experienced participants, SOAC and Post DH subjects. These subject groups were used because they would provide insight into an "expert" mental model that the SOBC subjects have not yet acquired. However, the two groups were not combined given the differences in the way they prioritized the data in the preceding analysis.

Figure 10 displays the changes in prioritization of the information items between the littoral and pelagic operating environments. The figure breaks down this difference for both Post DH and SOAC subjects.

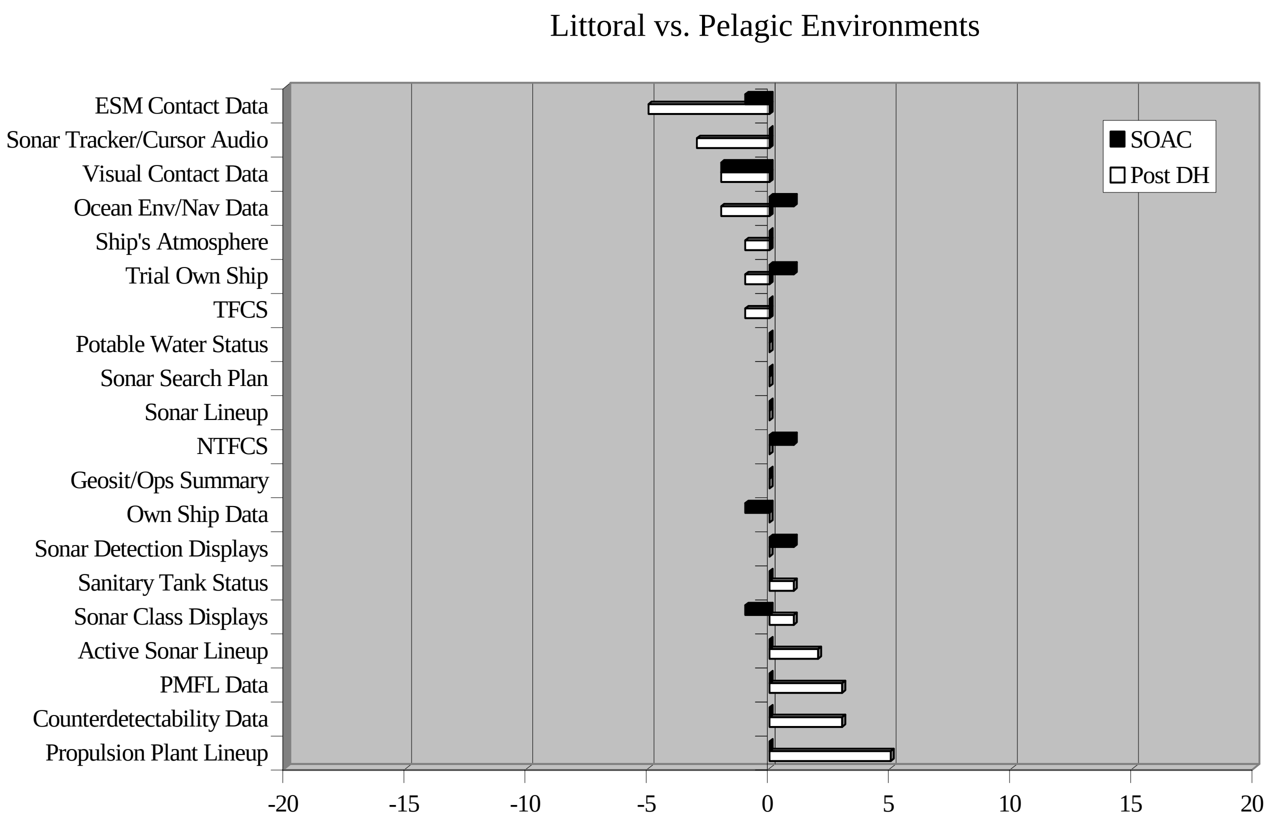

Figure 10. Change in judged importance among the 20 information items between littoral and pelagic operating environments for PostDH and SOAC participants. Note: Positive numbers mean that the item was rated as more important, while negative numbers mean that the item was rated as less important in the pelagic environment.

For the SOAC subjects, there was no noticeable difference in the prioritization of the items for the pelagic and littoral operating environments. However, for the Post DH subjects, major differences did emerge. For the pelagic environment, Post DH subjects rated propulsion plant lineup, counterdetectability data, and PMFL data as more important than for the littoral environment. Items deemed less important include ESM contact data, sonar tracker/cursor audio and visual contact data. These results suggest that serving as a department head onboard a submarine provides a unique experience that alters the manner in which the OOD prioritizes data for different situations.

Changes between hostile and neutral contact rankings

Figure 11 shows the changes in prioritization of the information items between the hostile and neutral contact situation. As before, the data are broken down for Post DH and SOAC subjects.

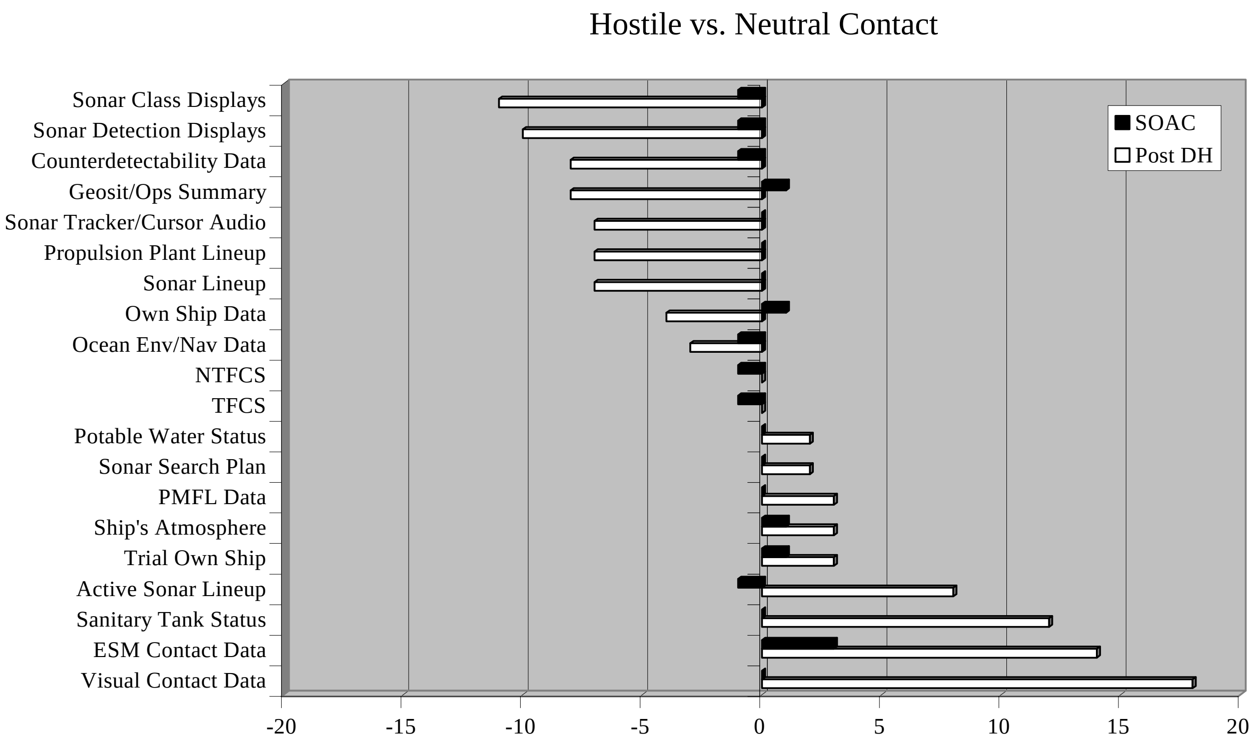

Figure 11. Change in judged importance among the 20 information items between hostile and neutral contact operating environments for PostDH and SOAC participants. Note: Positive numbers mean that the item was rated as more important in the neutral contact environment, while negative numbers mean that the item was rated as less important.

There were minor differences in prioritization of the data for the SOAC subjects when comparing the hostile and neutral contact situations. However, extreme differences were found for the Post DH subjects. Visual contact data, ESM contact data, sanitary tank status, and active sonar lineup were judged as more important in the neutral contact situation, while sonar class displays, sonar detection displays, and counterdetectability data were judged as more important in the hostile contact situation.

In both comparisons, the different operating environments produced a much larger difference for the Post DH subjects than the SOAC subjects. This suggests that the increase in experience from the SOAC level to the Post DH level provides an opportunity to master the domain, which results in differences in how the subject matter is organized and prioritized.

DISCUSSION

This study was an investigation into the cognitive organization of submarine OOD mental models, and how they may change with experience and with the operational scenario. The multidimensional scaling analysis revealed that the 20 submarine information items are organized along two dimensions, source of the information (signal v. noise) and user of the information (sonar v. CONN). This two-dimensional organization did not change as a result of experience; however, the manner into which the information items were categorized on a finer-grained level did change with experience. The most experienced participants, the Post DH submariners, used four categories to organize the 20 items, while the less experienced subject groups used five categories. Over the course of experience, the placement of some of the information items changed, some groups merged, and some groups split into two groups (e.g., the sonar information).

The prioritization task for the four operational scenarios provided a finer analysis of the mental models the submarine OOD possesses as a function of experience, and as a function of scenario. Interestingly, the difference in prioritization between the SOBC (novice) and SOAC (intermediate) student participants was not as great as expected. The difference between these two groups and the Post DH participants was very noticeable, however. There appears to be a change in the mental models of submarine officers between the time they are SOAC students, and several years later after they have served a department head tour. The Post DH participants had about twice as many years in the Navy, and twice as much time on sea duty, which may explain the big difference.

This analysis investigated *group* differences, and does not address the issue of *individual* differences within the subject groups. A predominant theory of expertise suggests that as people become more experienced in a particular domain, their mental models become more homogenous (Fiore, Fowlkes, Martin-Milham, & Oser, 2000). In other words, how much do the individuals within the group agree with the aggregate group model? This issue is addressed in Shobe, Fiore, & Carr (2004).

CONCLUSIONS

There are several ways in which these results could be used for the operational community. First, the design of decision aids and other electronic combat systems onboard the submarine could be aided with this knowledge of how submariners would intuitively think about and organize the information that is being conveyed to them. Second, concerning the effect of experience on these mental models, training commands could make use of the expert model and teach toward it for the junior officers. One limitation of this study is that we did not correlate the mental models with indices of performance. There is a strong possibility that submariners better at their job would possess a different cognitive organization than average or poor submariners.

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APPENDIX A Information Categories Available to the OOD at CONN

1. ESM contact data	Bearing and classification of radar and communications systems data provided by the Electronic Support Measures system
2. Own ship data	Own ship's course, speed, depth, etc.
3. PMFL data	Data on fault location and performance monitoring of various sonar components, i.e., data required to maintain electrical information systems
4. Ocean environment and navigation data	Sea state; bottom depth; type, and features; background noise; sound velocity profile; propagation loss, i.e., computer generated data used to position own ship to maximize sonar detection range (L_e)
5. Counterdetectability data	Own ship electromagnetic signature, radiated noise, surface visibility/wake, contaminants, etc.
6. Propulsion Plant Lineup	Operating condition of the reactor and propulsion equipment including reactor coolant pump speed (fast, slow, RFO); electric plant lineup (full power, half power, other); any limits on operations due to casualties or maintenance in the engineering spaces
7. Sonar search plan	Physical lineup of sonar system, including operator displays and processing used; search track to be followed by ship to locate target of interest; depth to search at based on ocean bathymetric data
8. Visual contact data (from photonics mast)	Visual information on surface contacts including night vision, infrared, video, laser ranging etc. (Note: only available at PD)
9. Potable water status	Amount of water in potable water tanks and tank on service
10. Active sonar lineup	Power, pulse type, range gate, etc., i.e., parameters indicating active sonar transmission status
11. Ship's atmosphere	Status of atmosphere inside the submarine (oxygen percentage, CO_2 concentration percentage, CO/H_2 concentrations); status of oxygen bleed from O_2 banks; status of oxygen generator or O_2 candle furnace; status of CO_2 scrubbers and CO/H_2 burner
12. Sonar tracker/cursor audio	Auditory presentation of minimally processed sonar signals as picked up by the various arrays
13. Sanitary tank status	Tank levels in ship's sanitary tanks and status of pumping or blowing tanks
14. Geosit/ops summary	Computer generated geographical picture of all contacts and own ship, in either true or relative bearing orientation, with classification information where possible
15. Trial own ship	CPA solutions, trial maneuvers, etc., i.e., data which aid in assessment of the present and future tactical situation
16. Non-target fire control solution	Rapid passive localization by wide aperture array (WAA), KAST ranging, multipath ranging, D/E ranging, hyperbolic ranging; Bearing, range, course, speed, depth if submerged contact, for secondary contacts
17. Sonar detection displays	Visual displays of sonar detections as presented to sonar operators
18. Sonar lineup	Narrow band and broadband detection system lineup, filter and alarm settings, other operator set parameters
19. Target fire control solution	Rapid passive localization by wide aperture array (WAA), KAST ranging, multipath ranging, D/E ranging, hyperbolic ranging; Bearing, range, course, speed, depth if submerged contact, for target of interest
20. Sonar class displays	Sonar signal interpretation aids such as signature assemblies, lofargrams, etc. i.e., data used to aid in the classification of signals

APPENDIX B Background Survey

Please provide responses to the following to help us evaluate the results of this experiment.

1. Present rank ____

2. Years in rank ____

3. Age ____

4. Years in service ____

5. Years Sea Duty ____

6. Sea Billets ____

   ____

   ____

   ____

   ____

7. Present billet ____

8. Training (e.g., SOBC, SOAC, JO courses, PXO, PCO) ____________________________________

APPENDIX C Scenarios Used for Prioritization Task

INSTRUCTIONS FOR RANKING TASK 1

We would now like you to reassemble the cards into a single deck. Then, rank the information on the cards according to importance for display at CONN.

For context, the operational environment should be assumed to be a SSN in the following scenario:

Mission: (littoral, enemy contacts)
The world situation is that a war has broken out between Russia and Ukraine over control of the former Soviet Navy. Both nations are trying to get the U.S. involved and have been attacking U.S. shipping with submarines and then blaming each other. You are patrolling in the eastern Mediterranean Sea. Your mission is to protect U.S. shipping lanes. Your orders are to search and destroy any enemy submarines in the vicinity of U.S. shipping. There are several surface contacts (i.e., merchants, fishing trawlers), and no subsurface contacts. The broad band range of the day for a subsurface contact is 3-6 Kyd. Intelligence has indicated a Kilo-type former Soviet Submarine is patrolling in the area. There are no friendly submarines in your patrol area. The month is April and the sea state is 2.
OS Course: 120 Speed: 5 Operating Depth: 250-400ft

INSTRUCTIONS FOR RANKING TASK 2

Again, we would like you to reassemble the cards into a single deck. Then, rank the information on the cards according to importance for display at CONN.

For context and unlike Ranking Task 1, the operational environment should be assumed to be a SSN in the following scenario:

Mission: (littoral, no enemy contacts)
The world situation is that it is peacetime and there are no conflicts brewing. You are on a training exercise in the eastern Mediterranean Sea. There are several surface contacts (i.e., merchants, fishing trawlers) and there is a friendly submarine in your patrol area, a Trafalgar class British sub. The broad band range of the day for a subsurface contact is 3-6 Kyd. The month is April and the sea state is 2.
OS Course: 120 Speed: 5 Operating Depth: 250-400ft

INSTRUCTIONS FOR RANKING TASK 3

We would now like you to reassemble the cards into a single deck. Then, rank the information on the cards according to importance for display at CONN.

Unlike the previous scenarios, the operational environment should be assumed to be a SSN in the following scenario:

Mission: (deep water, enemy contacts)
The world situation is that a war has broken out between Russia and Ukraine over control of the former Soviet Navy. Both nations are trying to get the U.S. involved and have been attacking U.S. shipping with submarines and then blaming each other. You are underway from the East Coast and are cruising along to the eastern Mediterranean Sea. Once you arrive, your mission is to protect U.S. shipping lanes. Your orders are to search and destroy any enemy submarines in the vicinity of U.S. shipping. While you are underway, in the middle of the Atlantic Ocean, intelligence has indicated a Kilo-type former Soviet Submarine is in the area. The month is April and the sea state is 2.
OS Course: 120 Speed: 20 Operating Depth: 500

INSTRUCTIONS FOR RANKING TASK 4

We would now like you to reassemble the cards into a single deck. Then, rank the information on the cards according to importance for display at CONN.

Unlike the previous scenarios, the operational environment should be assumed to be a SSN in the following scenario:

Mission: (deep water, no enemy contacts)
The world situation is that it is peacetime and there are no conflicts brewing. You are underway in the Atlantic Ocean to a training exercise in the eastern Mediterranean Sea. There are a few commercial surface contacts and there is a friendly submarine in the area, a Trafalgar class British sub. The broad band range of the day for a subsurface contact is 3-6 Kyd. The month is April and the sea state is 2.
OS Course: 120 Speed: 20 Operating Depth: 500

APPENDIX D MDS Coordinates for the 20 Information Items for All Subject Groups

Table 1. Coordinates of Information Items in Two-Dimensional Solution for SOBCpre subjects

Information Item	Dimension 1	Dimension 2
ESM	-0.2	-0.78
OS	-0.91	0.08
PMFL	-0.5	0.73
OE	-0.77	-0.21
CD	-0.65	0.04
PROP	-0.27	1.16
SSRCHPLN	0.86	-0.12
VIS	-0.39	-0.75
POT	0.16	1.44
ACT	0.85	0.08
ATM	0.07	1.41
SAUD	0.85	-0.43
SAN	0.13	1.33
GEO	-0.5	-0.59
TOS	-0.95	-0.42
NTFCS	-0.14	-1.01
SDIS	0.68	-0.51
SLINUP	0.88	0.04
TFCS	-0.08	-1.07
SCLASDIS	0.86	-0.41

Table 2. Coordinates of Information Items in Two-Dimensional Solution for SOBCpst subjects

Information Item	Dimension 1	Dimension 2
ESM	0.73	0.63
OS	-0.31	0.52
PMFL	-0.69	-0.20
OE	0.08	-0.55
CD	-0.28	0.36
PROP	-1.32	0.13
SSRCHPLN	0.60	-0.72
VIS	0.67	0.64
POT	-1.44	-0.28
ACT	0.67	-0.72
ATM	-1.43	-0.22
SAUD	0.70	-0.67
SAN	-1.45	-0.27
GEO	0.32	0.85
TOS	0.06	0.78
NTFCS	0.46	0.78
SDIS	0.74	-0.50
SLINUP	0.69	-0.75
TFCS	0.49	0.80
SCLASDIS	0.71	-0.61

Table 3. Coordinates of Information Items in Two-Dimensional Solution for SOAC subjects

Information Item	Dimension 1	Dimension 2
ESM	0.61	0.61
OS	-0.25	0.56
PMFL	-0.77	-0.18
OE	0.04	-0.50
CD	-0.12	0.04
PROP	-1.24	0.22
SSRCHPLN	0.40	-0.86
VIS	0.62	0.63
POT	-1.36	-0.20
ACT	0.46	-0.86
ATM	-1.36	-0.20
SAUD	0.79	-0.65
SAN	-1.36	-0.20
GEO	0.46	0.80
TOS	0.22	0.88
NTRGTFCS	0.45	0.99
SDIS	0.74	-0.48
SLINUP	0.38	-1.07
TFCS	0.55	0.99
SCLASDIS	0.72	-0.54

Table 4. Coordinates of Information Items in Two-Dimensional Solution for Post DH subjects

Information Item	Dimension 1	Dimension 2
ESM	-0.43	0.45
OS	-0.41	0.43
PMFL	0.17	-0.77
OE	0.1	-0.73
CD	0.05	-0.71
PROP	0.89	0.05
SSRCHPLN	0.02	-0.69
VIS	-0.52	0.57
POT	1.08	0.1
ACT	0.07	-0.7
ATM	1	0.07
SAUD	0.49	1.03
SAN	1.16	0.1
GEO	-0.72	0.69
TOS	-0.51	0.58
NTFCS	-0.55	0.59
SDIS	-0.93	0.73
SLINUP	0.26	-1.03
TFCS	-1.2	1.03
SCLASDIS	0	-1.76

APPENDIX E Ranking Data

Table 1. Ranking data for SOBCpre participants

Rank	Deep/Neutral	Deep/Hostile	Shallow/Neutral	Shallow/Hostile
1	Own Ship Data	Own Ship Data	Own Ship Data	Own Ship Data
2	Geosit/Ops Summary	Geosit/Ops Summary	Target Fire Control Solution	Geosit/Ops Summary
3	Target Fire Control Solution	Ocean Environment	Geosit/Ops Summary	Ocean Environment
4	Counterdetectability	Sonar Detection Displays	Counterdetectability	Sonar Detection Displays
5	Ocean Environment	Counterdetectability	Ocean Environment	Propulsion Plant Lineup
6	Sonar Detection Displays	NonTarget Fire Control Solution	Sonar Detection Displays	Counterdetectability
7	Trial Own Ship	Visual Contact Data	Trial Own Ship	NonTarget Fire Control Solution
8	NonTarget Fire Control Solution	Propulsion Plant Lineup	Propulsion Plant Lineup	Visual Contact Data
9	Propulsion Plant Lineup	Target Fire Control Solution	NonTarget Fire Control Solution	Trial Own Ship
10	ESM Contact Data	ESM Contact Data	Sonar Search Plan	Target Fire Control Solution
11	Sonar Search Plan	Trial Own Ship	ESM Contact Data	ESM Contact Data
12	Visual Contact Data	Sonar Search Plan	Visual Contact Data	Sonar lineup
13	Sonar lineup	Sonar lineup	Sonar lineup	Sonar Search Plan
14	Sonar Class Displays	Sonar Class Displays	Sonar Tracker	Sonar Class Displays
15	Sonar Tracker	Sonar Tracker	Sonar Class Displays	Sonar Tracker
16	Active Sonar Lineup	Active Sonar Lineup	Active Sonar Lineup	Active Sonar Lineup
17	PMFL Data	Ship's Atmosphere	Ship's Atmosphere	Ship's Atmosphere
18	Ship's Atmosphere	PMFL Data	PMFL Data	PMFL Data
19	Potable Water Status	Potable Water Status	Potable Water Status	Potable Water Status
20	Sanitary Tank Status	Sanitary Tank Status	Sanitary Tank Status	Sanitary Tank Status

Table 2. Ranking data for SOBCpst participants

Rank	Deep/Neutral	Deep/Hostile	Shallow/Neutral	Shallow/Hostile
1	Own Ship Data	Own Ship Data	Own Ship Data	Own Ship Data
2	Counterdetectability	Geosit/Ops Summary	Counterdetectability	Geosit/Ops Summary
3	Target Fire Control Solution	Trial Own Ship	Target Fire Control Solution	Counterdetectability
4	Geosit/Ops Summary	Counterdetectability	Geosit/Ops Summary	NonTarget Fire Control Solution
5	Sonar Detection Displays	NonTarget Fire Control Solution	Ocean Environment	Sonar Lineup
6	Ocean Environment	Sonar Detection Displays	Sonar Detection Displays	Trial Own Ship
7	Trial Own Ship	Ocean Environment	Sonar Lineup	Ocean Environment
8	Sonar Lineup	Sonar Search Plan	Trial Own Ship	Sonar Search Plan
9	Propulsion Plant Lineup	Sonar Lineup	NonTarget Fire Control Solution	Propulsion Plant Lineup
10	NonTarget Fire Control Solution	Target Fire Control Solution	Propulsion Plant Lineup	Sanitary Tank Status
11	Sonar Search Plan	Propulsion Plant Lineup	Sonar Search Plan	Sonar Detection Displays
12	ESM Contact Data	ESM Contact Data	ESM Contact Data	ESM Contact Data
13	Sanitary Tank Status	Visual Contact Data	Sanitary Tank Status	Target Fire Control Solution
14	Visual Contact Data	Sanitary Tank Status	Active Sonar Lineup	Sonar Class Displays
15	Active Sonar Lineup	Active Sonar Lineup	Visual Contact Data	PMFL Data
16	PMFL Data	Ship's Atmosphere	Ship's Atmosphere	Active Sonar Lineup
17	Ship's Atmosphere	PMFL Data	PMFL Data	Visual Contact Data
18	Sonar Tracker/Cursor	Sonar Tracker/Cursor	Sonar Tracker/Cursor	Ship's Atmosphere
19	Sonar Class Displays	Sonar Class Displays	Sonar Class Displays	Potable Water Status
20	Potable Water Status	Potable Water Status	Potable Water Status	Sonar Tracker/Cursor

Table 3. Ranking data for SOAC participants

Rank	**Deep/Neutral**	**Deep/Hostile**	**Shallow/Neutral**	**Shallow/Hostile**
1	Sonar Detection Displays	Own Ship Data	Sonar Detection Displays	Sonar Detection Displays
2	Own Ship Data	Sonar Detection Displays	Own Ship Data	Own Ship Data
3	Target Fire Control Solution	Geosit/Ops Summary	Target Fire Control Solution	Geosit/Ops Summary
4	Geosit/Ops Summary	Target Fire Control Solution	Geosit/Ops Summary	Target Fire Control Solution
5	Visual Contact Data	Visual Contact Data	NonTarget Fire Control Solution	Trial Own Ship
6	NonTarget Fire Control Solution	NonTarget Fire Control Solution	Trial Own Ship	NonTarget Fire Control Solution
7	Trial Own Ship	Trial Own Ship	Ocean Environment	Visual Contact Data
8	ESM Contact Data	ESM Contact Data	Visual Contact Data	ESM Contact Data
9	Ocean Environment	Ocean Environment	Sonar Class Displays	Ocean Environment
10	Sonar Class Displays	Sonar Class Displays	Counterdetectability	Sonar Search Plan
11	Counterdetectability	Counterdetectability	ESM Contact Data	Sonar Class Displays
12	Sonar Search Plan	Propulsion Plant Lineup	Sonar Search Plan	Counterdetectability
13	Sonar Tracker/Cursor	Sonar Search Plan	Propulsion Plant Lineup	Propulsion Plant Lineup
14	Propulsion Plant Lineup	Sonar Tracker/Cursor	Sonar Tracker/Cursor	Sonar Tracker/Cursor
15	Sonar Lineup	Sonar Lineup	Sonar Lineup	Sonar Lineup
16	Active Sonar Lineup	Ship's Atmosphere	Active Sonar Lineup	Ship's Atmosphere
17	Ship's Atmosphere	Active Sonar Lineup	Ship's Atmosphere	Active Sonar Lineup
18	Sanitary Tank Status	Sanitary Tank Status	Sanitary Tank Status	Sanitary Tank Status
19	PMFL Data	Potable Water Status	Potable Water Status	Potable Water Status
20	Potable Water Status	PMFL Data	PMFL Data	PMFL Data

Table 4. Ranking data for Post DH participants

Rank	Deep/Neutral	Deep/Hostile	Shallow/Neutral	Shallow/Hostile
1	Sonar Detection Displays	Sonar Detection Displays	Sonar Detection Displays	Sonar Detection Displays
2	Target Fire Control Solution	Own Ship Data	Own Ship Data	Own Ship Data
3	Own Ship Data	Geosit/Ops Summary	Geosit/Ops Summary	Geosit/Ops Summary
4	Geosit/Ops Summary	NonTarget Fire Control Solution	NonTarget Fire Control Solution	Sonar Class Displays
5	NonTarget Fire Control Solution	Sonar Class Displays	Target Fire Control Solution	NonTarget Fire Control Solution
6	Sonar Class Displays	Counterdetectability Data	Counterdetectability Data	Ocean Environment
7	Trial Own Ship	Ocean Environment	Trial Own Ship	Trial Own Ship
8	Ocean Environment	Sonar Tracker/Cursor Audio	Sonar Class Displays	Counterdetectability Data
9	Sonar Search Plan	Trial Own Ship	Ocean Environment	Propulsion Plant Lineup
10	Sonar Lineup	Propulsion Plant Lineup	Propulsion Plant Lineup	Sonar Search Plan
11	Counterdetectability Data	Sonar Lineup	Sonar Lineup	Sonar Lineup
12	ESM Contact Data	Target Fire Control Solution	Sonar Search Plan	Sonar Tracker/Cursor Audio
13	Sonar Tracker/Cursor Audio	Ship's Atmosphere	Sonar Tracker/Cursor Audio	Target Fire Control Solution
14	Active Sonar Lineup	Sonar Search Plan	Active Sonar Lineup	Ship's Atmosphere
15	Propulsion Plant Lineup	Visual Contact Data	PMFL Data	Potable Water Status
16	Ship's Atmosphere	Potable Water Status	Ship's Atmosphere	PMFL Data
17	PMFL Data	Sanitary Tank Status	ESM Contact Data	ESM Contact Data
18	Visual Contact Data	ESM Contact Data	Potable Water Status	Visual Contact Data
19	Potable Water Status	PMFL Data	Visual Contact Data	Active Sonar Lineup
20	Sanitary Tank Status	Active Sonar Lineup	Sanitary Tank Status	Sanitary Tank Status

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14. ABSTRACT

The submarine environment is alien to typical human experience. In a world without direct visual information, the submarine Officer of the Deck (OOD) receives a variety of diverse information as inputs and makes operational decisions based on his understanding. Although there have been efforts to describe this understanding, organization, and prioritization (Kirschenbaum, 1992; 2001; Laxar, Moeller, & Rogers, 1983; 1989), a validated model has yet to be described. The description of a submarine OOD's cognitive organization of information is the objective of this research. Using analyses of submariner knowledge for concepts related to responsibilities for the OOD task, this research examined how submarine officers cognitively organize this information and how experience may alter knowledge representation and conceptual importance.

Continued

15. SUBJECT TERMS

mental models, submarine, cognitive organization, human factors, training, decision displays, card sorting

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14. Abstract (cont)

Eighty-three Naval Officers, some qualified and some not qualified as OOD, performed information sorting and ranking tasks to indicate similarity and relative importance among 20 categories of information available on submarines. These 20 submarine concepts were primary elements of information the submarine OOD would encounter while on watch, with the exception of tactics information. Each of the 20 concepts was printed on an index card. Research participants made similarity judgments by sorting the 20 cards into discrete groups, according to the participant's own definition of similarity. The number of piles and the concepts in each pile were recorded. Then, participants placed the 20 cards into a single pile, ranked or ordered according to relative importance. Participants repeated the ranking task four times for four differing operational scenarios. Research participants were Submarine Officer Basic Course students (both pre and post course), Submarine Officer Advanced Course students, and Post Department Head submariners.

The results show that more experienced personnel possess different mental models than less experienced personnel. With regard to information similarity, submarine OODs organize information in two basic dimensions, one defined by the source of information (context/noise v. contact/signal), and the other defined by the destination (or primary user) of the information (sonar v. CONN). In addition to the two-dimensional structure in the organization of all 20 information items, there was also a more finely grained grouping or "clustering" of information. The expert group organized information into four clusters and the groups with less expertise organized information into five clusters. Further, the information in these five clusters varied as a function of experience. With regard to information prioritization, the information regarded as the most important varied as a function of operational scenario (i.e., littoral v. pelagic water environment; neutral v. hostile contact). This change in prioritization between scenarios was most evident for the most experienced submariner participants; little change was observed for the least experienced.

This knowledge allows system designers to develop command and control displays that use this cognitive organization to the user's advantage by developing systems that are intuitive to the user. Additionally, the knowledge of these mental models of experts could be used as targets for training less experienced personnel.