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14. ABSTRACT
This report details a research project investigating the acquisition and transfer of strategic stimulus processing skills. Previous research suggests that humans initially acquire processing strategies that reduce the number of redundant comparisons required for accurate visual discriminations. Further, strategies acquired during exposure to one set of visual stimuli can be transferred to a novel stimulus set. Strategies are transferred regardless of their effectiveness, and once acquired, they are difficult to modify. The reported research investigates how strategies can be optimized through controlling the difficulty of initial training. Strategies acquired were shown to transfer not only to novel visual stimuli, but also to auditory stimuli. This suggests that the acquisition and transfer of strategic skills are controlled by a central cognitive mechanism, and that initial training has a significant impact on processing skills necessary for a wide range of operational tasks.

15. SUBJECT TERMS
Training optimization; visual / auditory processing, skill acquisition

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FINAL TECHNICAL REPORT

ONR Grant #: N00014-03-1-0088

PRINCIPAL INVESTIGATOR: Dr. Stephanie Doane

INSTITUTION: Mississippi State University

GRANT TITLE: Augmenting Cognition: Optimizing Strategic Visual Processing

AWARD PERIOD: October 2002 to December 2006

OBJECTIVE:

Many Navy tasks require warriors to discriminate among visual objects represented by technology systems. For example, radar operators must discriminate between familiar and new or unclassified contacts displayed on screen. This research experimentally examined the contextual factors influencing optimal acquisition, transfer, and modification of strategic visual discrimination skills. Performance measures included discrimination accuracy, reaction time, and eye movements. Eye movements were measured using digital eye-tracking equipment obtained from an ONR DURIP award. The main objective of this research was to examine whether eye movements serve as a sensitive measure of visual discrimination strategies, where strategies are designed to reduce the number of redundant comparisons. A second objective was to examine multimodal transfer of discrimination skills. The theoretical goal of this research is to further our understanding of the role of strategic versus stimulus-specific processes in learning to visually discriminate between objects in the environment. The research has direct relevance to warrior performance optimization in the many Navy operational environments that require visual discriminations.

APPROACH:

Discrimination Skills Reflected in Eye Movements

A cognitive theory-driven approach was used to examine the role of strategic processes in attending to relevant features while visually discriminating between displayed objects. Previous research suggests that with practice, visual processing strategies becomes more efficient by elimination of redundant and unnecessary comparisons (e.g., Haider & Frensch, 1999). Further studies suggest that initially acquired strategies can be transferred to novel stimuli (e.g., Doane et al., 1999; Brou et al., 2005). Such findings support the hypothesis that initially acquired strategies are born from processing specific stimuli but are not tied to these stimuli per se, and as such can be transferred to processing novel stimuli (e.g., Doane et al., 1999; Cross & Doane, 2002). Previous research has indirectly inferred the nature of the strategies from accuracy, reaction time, and memory data. This research used digital eye-tracking technology as an additional index of direct evidence of the nature of the visual processing strategies acquired and transferred by participants receiving differential types of initial training.

Strategic processes were examined using a visual discrimination task that required comparison of two objects and a judgment of whether they were the same or different. In this task, two polygons are presented on a computer screen, and participants are asked to determine if the polygons were the same or different. Figure 1 provides an example of a single trial.

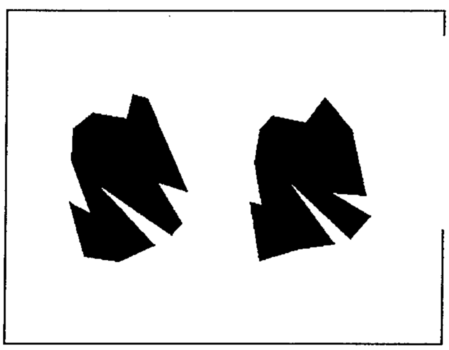


Figure 1. Sample "easy" visual discrimination trial.

The difficulty of initial training was used to influence development of discrimination strategy. Because the manipulation is central to this research, the structure of the stimulus set is described in detail. Each set of polygons includes a standard polygon on the left, paired either with itself or with one of three other polygons of varying similarity to the standard on the right.

Figure 2 depicts the structure of the stimulus sets used for the eye movement study. As shown in the Figure, each stimulus set contained 35 polygons, and they are structured to include five complexity levels (6, 8, 12, 16, 20-sided). Each set contains five "standard" stimuli, one at each level of complexity. At each level of complexity, there are six distractor stimuli that differ psychologically-rated similarity to their respective "standard." D1 is perceived to be the most similar and D6 is perceived to be the least similar. At each trial, a "standard" stimulus is presented on the left side of the screen, and either the standard or one of the distractors from the same level of complexity as the standard is presented on the right side of the screen. When a standard is paired with itself, the correct discrimination is "same." When a standard is paired with a distractor, the correct discrimination judgment is "different." For example, a 6-sided "standard" could be paired with a 6-sided D1, and the correct response would be "different." These polygons were then grouped into sets containing 20 each to create Difficult and Easy training sets. Both difficulty sets included the five standards. The Difficult stimulus set included the D1-D3 stimuli, and the Easy stimulus set included the D4-D6 stimuli. More detailed information about the polygon stimuli can be found in Doane et al., (1999).

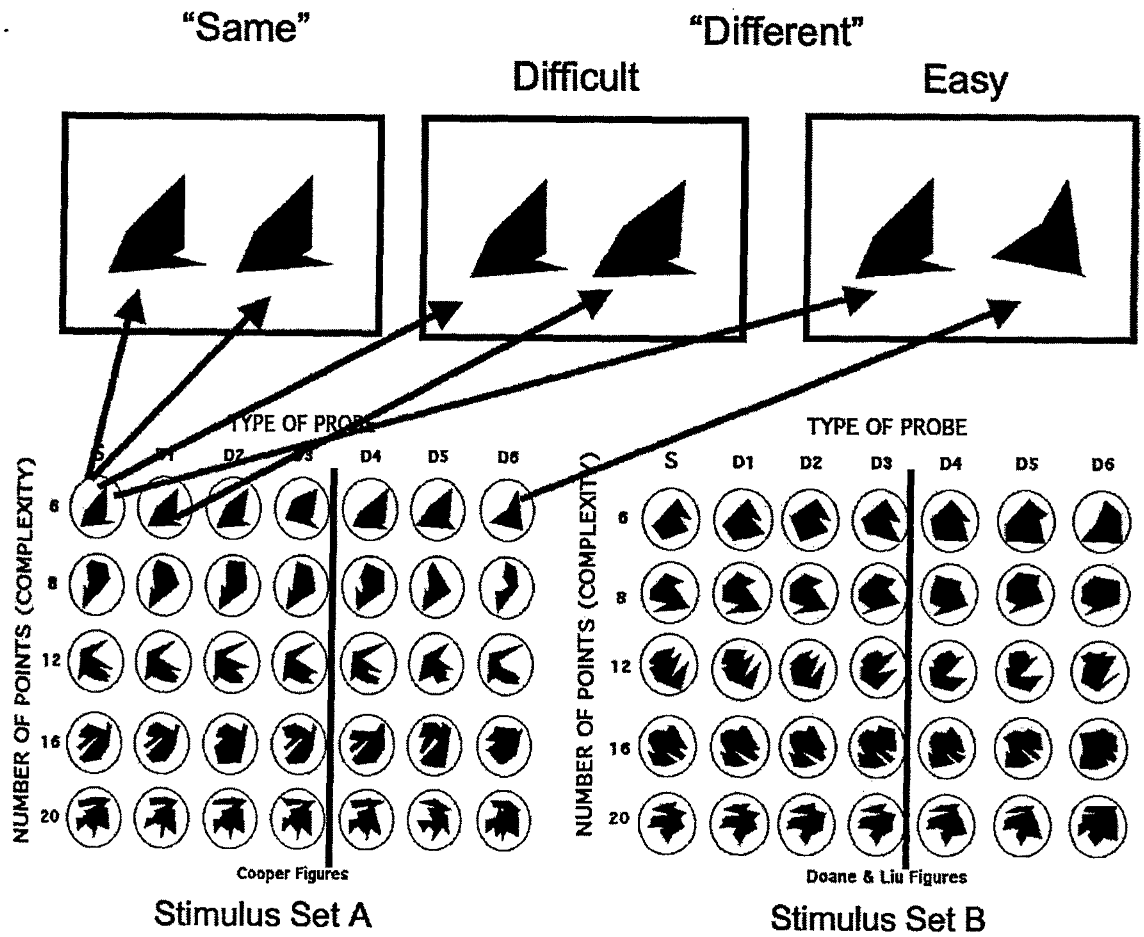


Figure 2. Polygon stimulus sets adapted from Cooper & Podgorny (1976) and Doane et al. (1996). Same judgments (top left) consist of a standard polygon compared to itself. Different judgments (top center and top right) consist of a standard polygon on the left side of the screen compared with a D1-D6 stimulus on the right

As previously mentioned, the difficulty of discrimination training was manipulated to influence strategic discrimination strategies such that subjects randomly assigned to the "Easy" condition viewed same pairings from each complexity level, and D4-D6 stimuli from each complexity level for different pairings with the appropriate standard stimulus (see Table 1). In contrast, participants assigned to the "Difficult" condition viewed the identical same pairings as the easy group, but viewed the D1-D3 stimuli paired with the appropriate standard for different pairings. In summary, the Easy condition viewed very dissimilar stimuli in different trials during training, and the difficult group viewed very similar pairings in different trials during training.

Table 1. Experimental design for visual discrimination eye-tracking experiment

Eye Movement Within-Modality Transfer Study Design

Group	Session 1	Session 2
Difficult Training (N = 30)	Difficult A (D1-D3)	Difficult B (D1-D3)
Easy Training (N = 34)	Easy A (D4-D6)	Difficult B (D1-D3)

At transfer, both groups viewed difficult different pairings and standard same pairings from a novel stimulus set (order of stimulus set exposure was counterbalanced). Participants completed two discrimination sessions (training and transfer). There were eight blocks per session, 120 trials in each block (960 trials per session, 1,920 trials overall). Each block contained four presentations of each of the five standard polygons paired with the appropriate (D1-D3 or D4-D6) different polygons (4 x 5 x 3 =60) and 12 presentations of the standard polygon paired with itself (5 x 12 =60). Response times, discrimination accuracy, and eye movements were measured and time synched for analysis.

Centrality of Mechanisms Controlling Strategic Skills

A second set of experiments examined the centrality of the mechanism controlling strategic discrimination skills. If strategic skills are controlled by a peripheral cognitive mechanism, then one might expect them to be modality specific, and as such, not transferable to another modality. However, if a central mechanism controls strategic skill acquisition, then one might expect far transfer of the skill even outside the modality of initial training.

To address this question, cross modal discrimination experiments were performed. Participants were trained on visual discriminations and transferred to making discriminations among auditory stimuli. The training session of these experiments is identical to that for the eye movement studies described above. However, at transfer, the participants in this research began making discriminations among sounds. To execute this research, a set of sound stimuli had to be created with a structure somewhat analogous to that for the visual stimulus sets.

Development of auditory stimuli was accomplished via close collaborations with Dr. Tom Santoro at NSMRL and Dr. Greg Wakefield at the University of Michigan. Drs. Santoro and Wakefield advised the development of auditory analogues to the visual stimulus set, and worked to ensure that the sounds retained features that enabled plausible generalization of the findings to Naval underwater warrior task environments. The resulting cross modal paradigm represents the success of this academic and Naval Laboratory collaboration, as well as cross discipline collaborations among visual and auditory perception researchers.

Recall that the visual stimuli varied in complexity (6, 8, 12, 16, 20 points) and psychologically rated similarity to the appropriate standard (D1-D6 – created by distorting points of the standard). Auditory stimuli were developed that varied in complexity (3, 4, 5, 6, 7 notes) and psychologically rated similarity to the appropriate standard (D1-D6 – created by changing the amplitude of notes in the standard). Psychological similarity ratings followed the procedure used for the visual stimuli (180 candidate sounds created, N=30 raters). As in the eye movement study, participants were transferred to making only difficult different discriminations (D1-D3). Thus, the structure of the stimulus set is identical to that for the visual stimulus set (35 stimuli, 20 used for the Difficult condition, 60 "sames" and 60 "differents" presented at each trial, 120 trials per block, and so on).

There are some aspects of the auditory stimuli that are not entirely mapped to the visual stimuli. Because auditory discriminations took significantly longer to make than the visual discriminations, the transfer session included only 3 blocks (360 trials) rather than 8 blocks. In addition, although the visual discrimination trials allowed for simultaneous presentation of stimuli on the left and right side of the screen, simultaneous presentation of auditory stimuli pairing posed a perceptual problem. For this reason, at each trial, participants viewed two sound icons on the screen that were labeled "sound 1" and "sound 2." They selected these icons with a mouse to hear the appropriate sound for 1 second. Participants were allowed to replay sounds as often as desired. Reaction time and accuracy was measured. See Table 2 for a summary of the experimental design.

Table 2. Experimental design for cross-modal transfer experiment (Note that because D1 auditory stimuli were too difficult for participants to discriminate from the appropriate standard, later subjects heard D2-D4 sounds. These data are combined for the sake of brevity.)

Visual - Auditory Transfer

Group	Session 1 (960 trials)	Session 2 (360 trials)
Difficult Training (N = 12)	Difficult Visual (D1-D3)	Difficult Auditory (D1-D3)*
Easy Training (N = 18)	Easy Visual (D4-D6)	Difficult Auditory (D1-D3)*

ACCOMPLISHMENTS (throughout award period):

Discrimination Skills Reflected in Eye Movements

Summary. The primary goal of this project was to experimentally examine whether eye movements provide insight into the acquisition and transfer of strategic visual discrimination skills. Sixty-four participants completed the eye movement study, and the reaction time, accuracy, and eye movement data are summarized below.

To foreshadow the discrimination performance findings, participants trained on difficult discriminations initially spend more time making discriminations as a function of stimulus complexity than the easy discrimination group. However, this difference attenuates with practice. This finding is consistent with a strategy designed to learn features relevant for discrimination, and then eliminate redundant comparisons. The effectiveness of this strategy is reflected in superior accuracy at transfer when compared to the easy training group. The finding of differential skill transfer to a novel stimulus set as a function of training difficulty suggests that strategic skills, while borne from processing specific stimuli, are not tied to them per se. Rather, the findings suggest that training difficulty influences discrimination strategies that are stimulus general at least within a modality (e.g., visual).

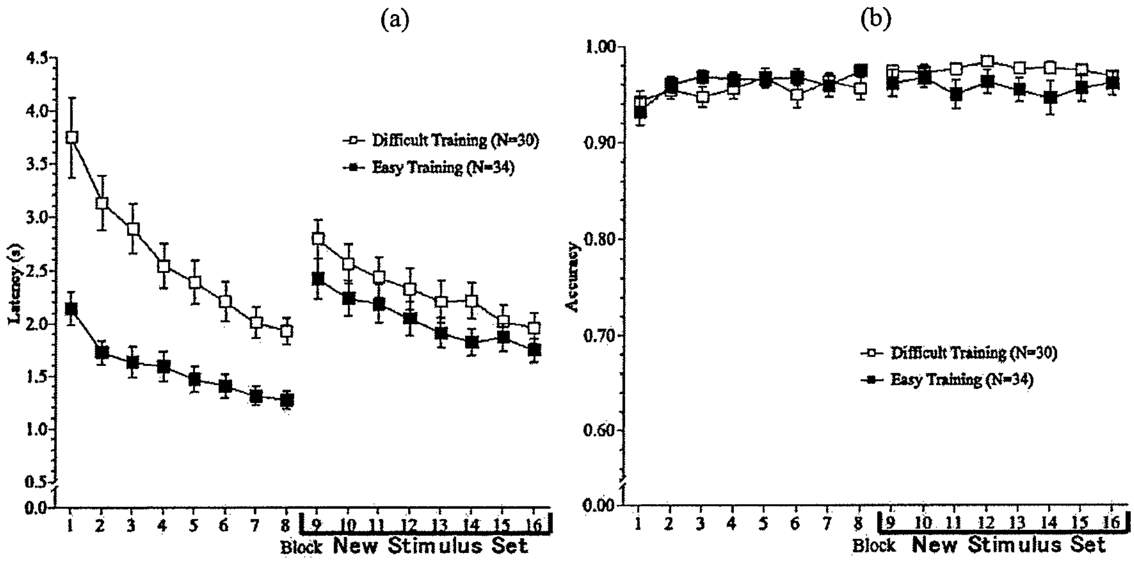
The eye movement findings indicate that participants trained on difficult discriminations spend more time fixating as a function of stimulus complexity than the easy discrimination group, and this difference is particularly salient in the transfer session. This is consistent with a strategy designed to find features relevant for discrimination. Strategic differences are not reflected in dwell times at training, but are reflected in greater dwell times for participants trained in the difficult condition at transfer.

To summarize, the discrimination performance and eye movement results, when considered together, support the information reduction hypothesis (Haider &Frensch, 1999). Eye movements and reaction times reflect a sensitivity to stimulus complexity for participants trained on difficult different discriminations, but not for participants trained on easy discriminations. Thus, the eye movement data provide converging evidence of strategic skill constraints.

Results. Sixty four subjects completed the experiment with a minimum of 80% accuracy in the training session. Technical difficulties with the eye tracker were experienced when running five participants (N=3 difficult condition, N=2 Easy condition), and as a result, they do not have eye movement data

Same Judgments

Latency and Accuracy. Figures 3a and 3b depict mean latency and accuracy for same judgments as a function of difficulty of initial training and practice in the training (1-8) and transfer (9-16) trial blocks. The data suggest that training difficulty has a significant impact on latency for same judgments at training, but not at transfer. Same judgment accuracy is at ceiling level for both groups.



Figures 3a and 3b. Mean latency (a) and accuracy (b) for "same" judgments as a function of block

Latency Slopes. Figure 4 depicts the relationship between latency and stimulus complexity for same judgments. Each data point represents the slope of the line relating latency and stimulus complexity. Participants trained in difficult discriminations show a significantly greater increase in reaction time as a function of stimulus complexity than the easy training group. This difference attenuates with practice, but reappears at transfer. This is consistent with the hypothesis that difficult training dictates a strategy designed to find features relevant for discrimination, and elimination of redundant features with practice.

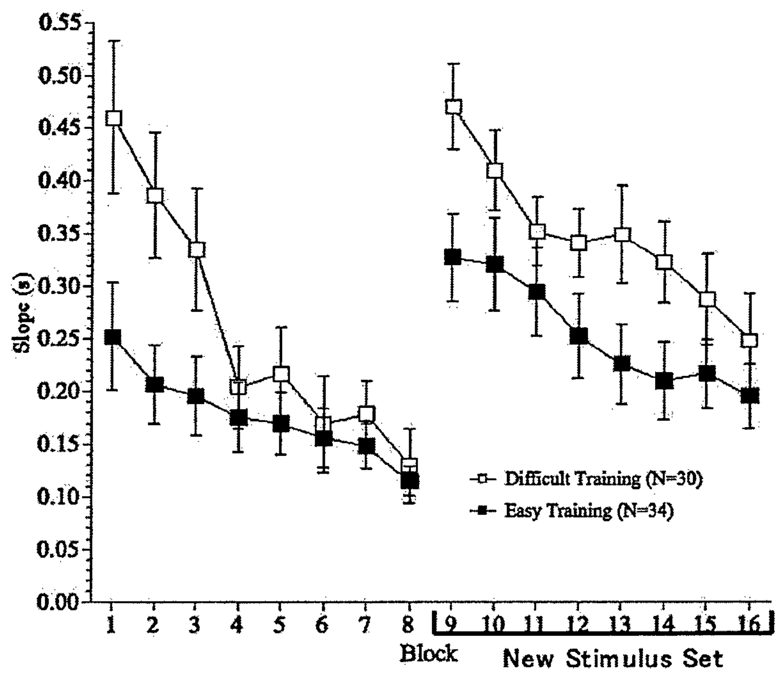


Figure 4. Mean latency slopes relating latency to stimulus complexity for "same" judgments as a function of block.

Fixation Dwell Times. Figure 5 depicts the mean fixation dwell times for stimuli shown on the left side of the screen at each trial (always the "standard"), and stimuli shown at the right side of each trial ("standard" or D1-D3 for difficult, D4-D6 for easy training in the first session, and "standard" or D1-D3 for both groups at transfer). The data suggest that participants in the initial difficult training group spend slightly more time fixating on stimuli shown on the right side of the screen at transfer than the easy group.

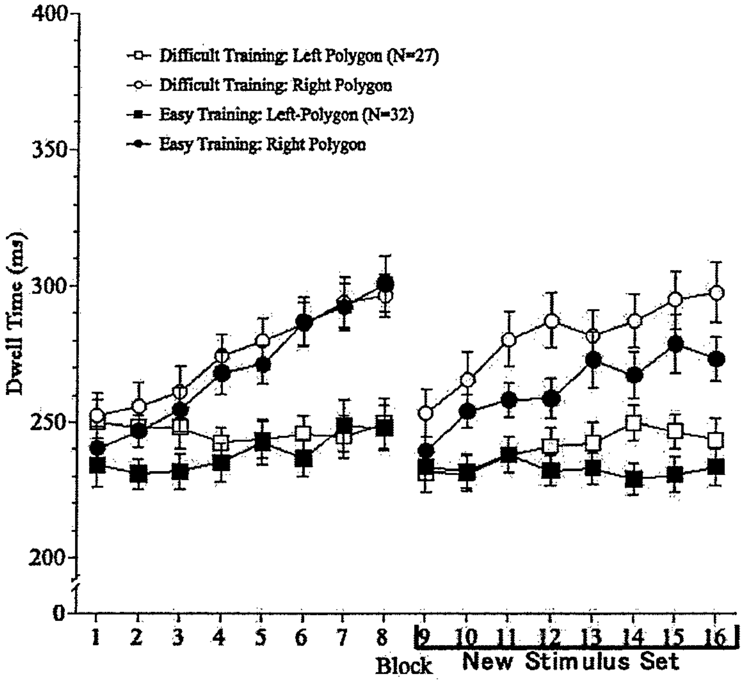
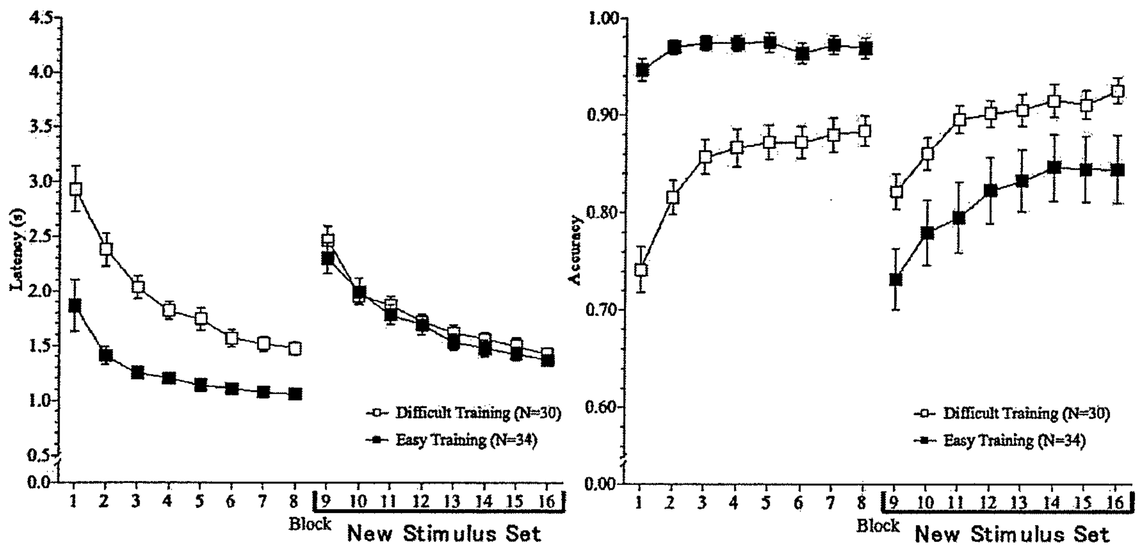


Figure 5. Mean fixation dwell times on left-side and right-side polygons for "same" judgments as a function of block.

Different Judgments

Latency and Accuracy. Figures 6a and 6b depict mean latency and accuracy for different judgments as a function of block in training and transfer sessions. The data show the difficult training group takes longer to make discriminations during training, but not at transfer. In addition, this group is more accurate at making discriminations at transfer than the easy group. The results are consistent with the acquisition of differing strategies as a function of initial training difficulty, and with the hypothesis that what is being learned is a skill designed to attend to only those features relevant for comparisons, and that this skill is transferred beyond specific stimuli.



Figures 6a and 6b. Mean latency (a) and accuracy (b) for "different" judgments as a function of block

Latency Slopes. Figure 7 depicts the relationship between latency and stimulus complexity for different judgments across all similarity levels. Each data point represents the slope of the line relating latency and stimulus complexity. Significant differences in the slope relating reaction time and stimulus complexity exist at transfer. This coupled with the superior accuracy of the difficult discrimination group at transfer suggests a positive strategy transfer for this group.

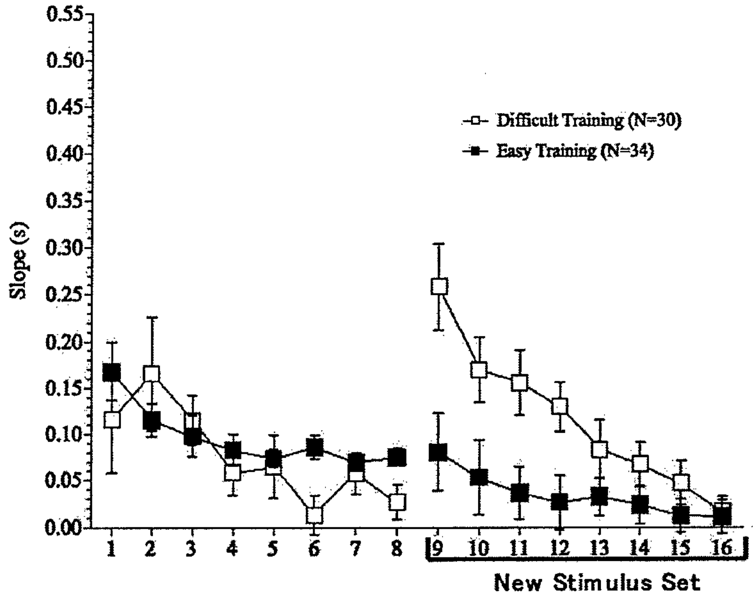


Figure 7. Mean latency slopes relating latency to stimulus complexity for "different" judgments as a function of block.

Fixation Slopes. Figure 8 depicts the relationship between number of fixations and stimulus complexity for different judgments across all similarity levels. Each data point represents the slope of the line relating number of fixations and stimulus complexity. Overall, participants trained in the difficult discrimination condition fixate more as a function of stimulus complexity than the easy group. These data are consistent with the hypothesis that difficult training requires a more comprehensive search for features required for discrimination, and the reduction of redundant features with practice.

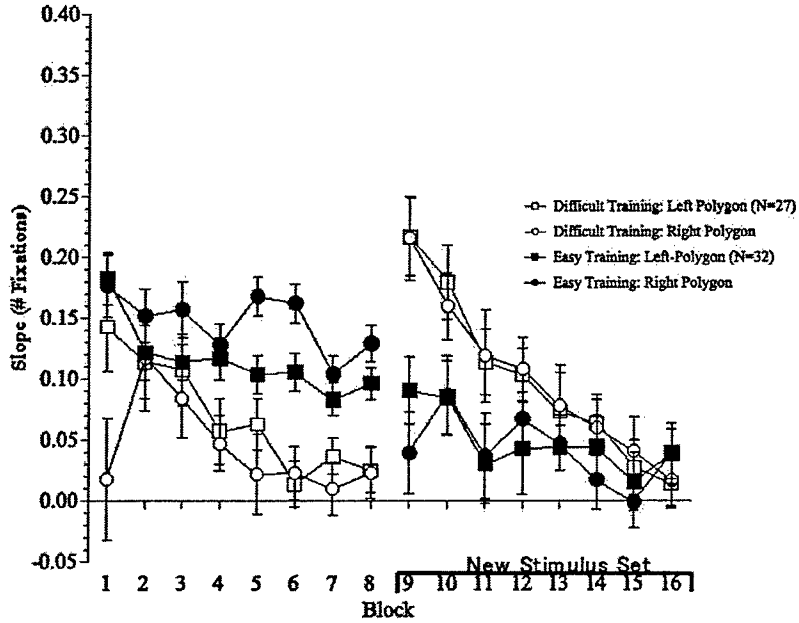


Figure 8. Mean fixation slopes relating number of fixations to stimulus complexity for "different" judgments as a function of block.

Fixation Dwell Times. Figure 9 depicts the time spent fixating on the left and right hand side of the screen during different judgments as a function of discrimination group difficulty and practice at training and transfer. As for same judgments, both groups spend more time fixating on the polygon shown on the right side of the screen, but the difficult training group spends more time on the right polygon at training and transfer for different judgments.

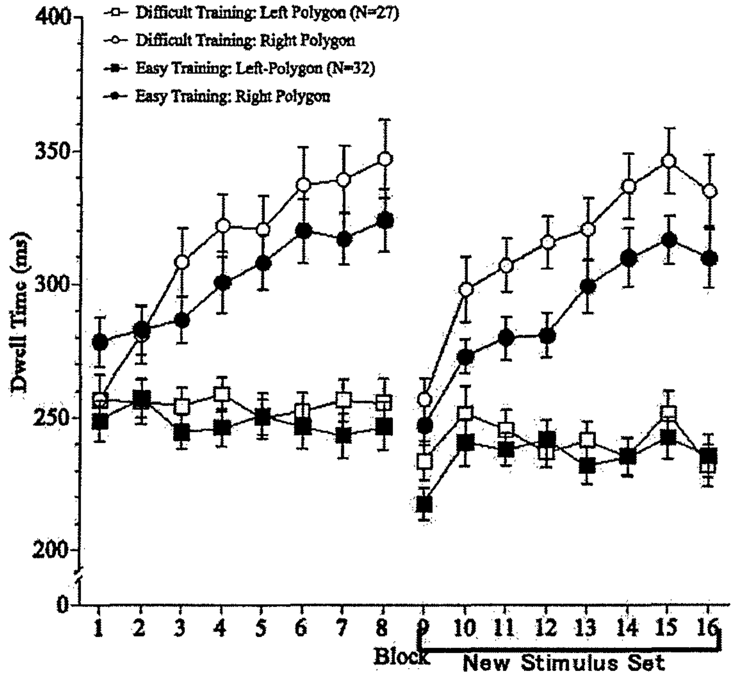


Figure 9. Mean fixation dwell times on left-side and right-side polygons for "different" judgments as a function of block.

<u>Analysis Tool Developed.</u> As a means of understanding the voluminous amount of eye movement data, an analysis tool that displayed eye fixations overlayed on stimuli was developed. Figure 10 shows a screen capture of this tool, which is available for other researchers to use as desired.

Centrality of Mechanisms Controlling Strategic Skills

The primary goal of this project was to experimentally test the hypothesis that strategic visual discriminations, though borne from processing specific stimuli, are not tied to them per se, and may in fact be controlled by a central mechanism that is modality independent. Recall that in this study, the training session was identical to that for the eye movement study. But at transfer, participants were presented with difficult auditory discriminations (see Table 2). Thirty participants completed a stimulus rating study designed to obtain the psychological similarity ratings required to prepare an auditory discrimination stimulus set. Thirty additional subjects participated in the cross-modal discrimination study.

For the sake of brevity, the discrimination performance data are represented in two figures. Accuracy data were subjected to signal detection analyses and d', a measure of observer sensitivity, and bias, a measure of observer response criterion, were calculated (correct judgment of a Same stimulus pairing as "same" = hit, incorrectly judging a Different stimulus pairing as "same" = false alarm). If participants acquire a strategy at training that is stimulus general and modality general, then those exposed to difficult visual discriminations should show positive transfer for difficult auditory discriminations. This should be reflected in superior observer sensitivity and not in response criterion. As indicated in Figures 11 and 12, participants trained on difficult visual discriminations show greater observer sensitivity at transfer to difficult auditory discriminations than those trained on easy visual discriminations (Figure 11), and this result is not reflected in response bias (Figure 12). This finding is consistent with the hypothesis that strategic skills acquired during visual training were transferred to the auditory discriminations at transfer, and that the strategic skills are controlled by a central cognitive mechanism.

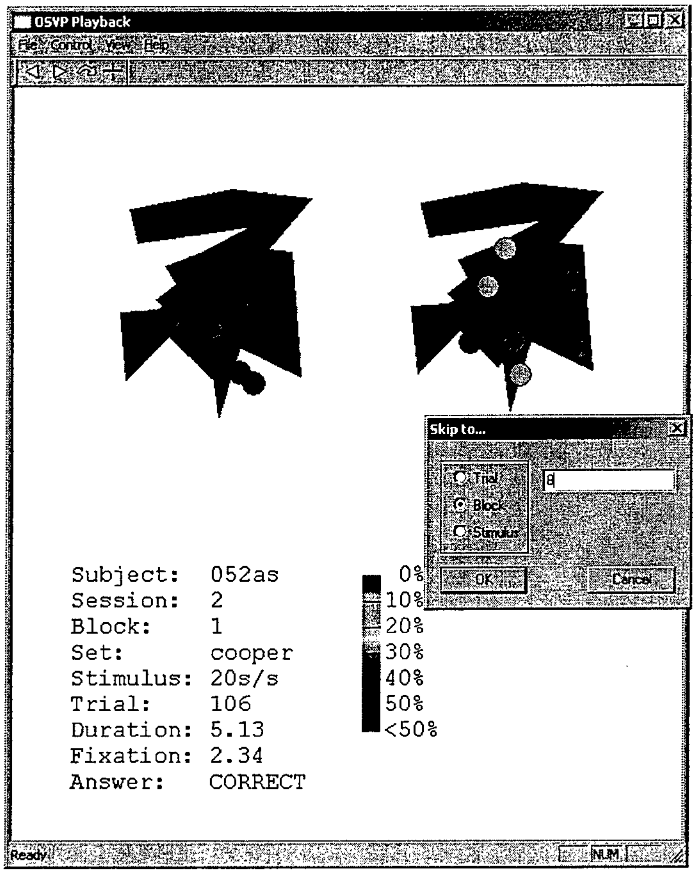


Figure 10. Screenshot of data visualization tool designed to assist with the analysis of the complex eye-movement data.

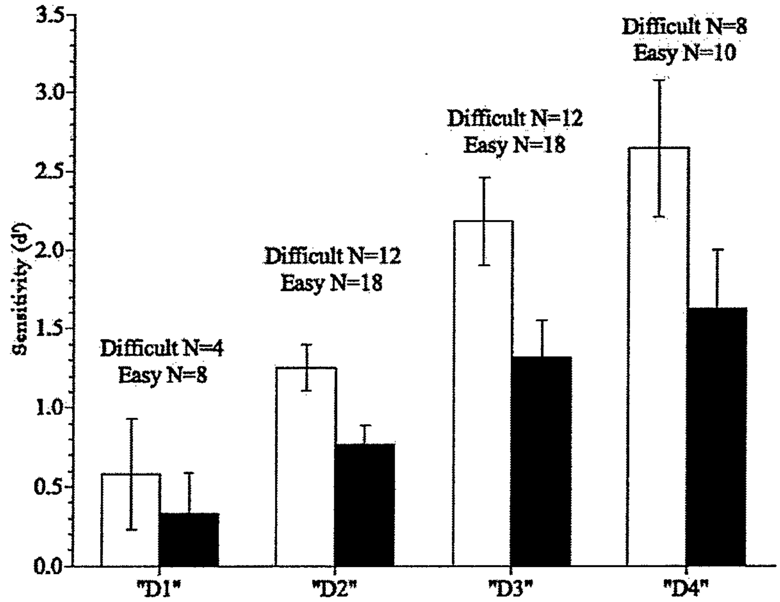


Figure 11. Mean observer sensitivity (d') during the transfer session as a function of auditory stimulus similarity.

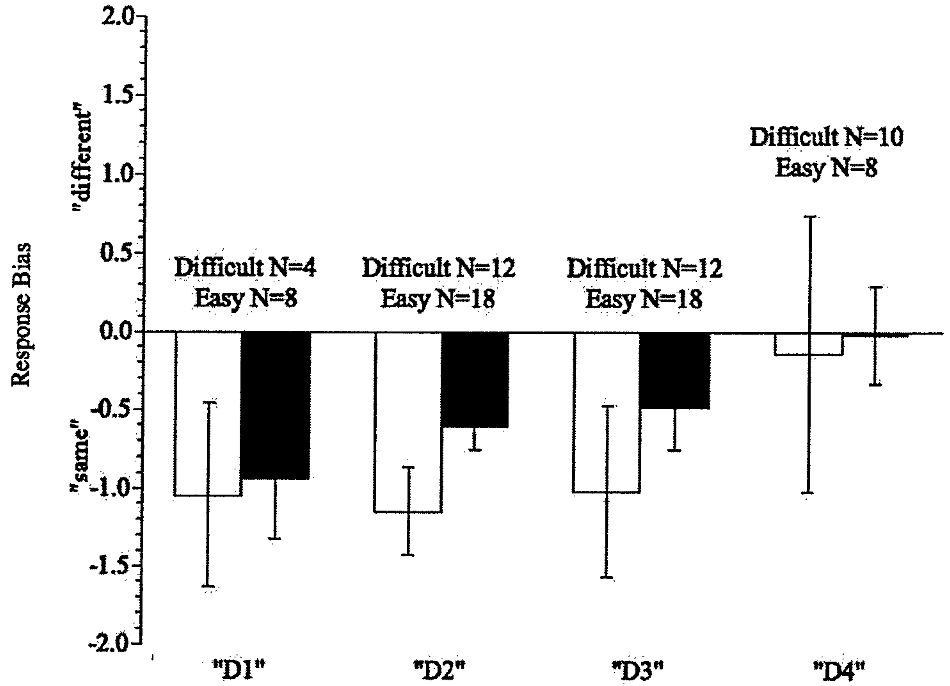


Figure 12. Mean response bias during the transfer session as a function of stimulus similarity.

<u>CONCLUSIONS</u>:

Difficulty of initial discrimination training influences the strategy learned to make discriminations, and has a direct impact on the transfer of discrimination skills to novel stimuli in the same modality and across modalities. This finding has relevance to the design of training methods used to promote optimal warrior performance in discrimination tasks, and to the design of multimodal operator stations, where warriors continually "transfer" their discrimination skills to novel stimuli within and across modalities.

Eye movement data provide converging evidence of strategic differences, but do not provide insights unique from those gleaned from reaction time and accuracy data. This has relevance for the design of technology systems where monitoring eye movements and/or performance might provide assessment of operator performance during a mission.

<u>SIGNIFICANCE</u>:

Many current and future Navy jobs demand that sailors be able to discriminate between objects and sounds presented in information displays. For example, aviation, submarine, and surface sonar operators must discriminate among both visual and auditory stimuli to identify radar contacts. It appears that initial training context is crucial to the development of stimulus discrimination skills. Skills acquired from "easy" training may be suboptimal and not be easily modified to accommodate for "difficult" discrimination demands

Further, the skills acquired for discriminating one set of stimuli will likely be transferred to making discriminations stimuli from other categories and modalities. Thus, optimizing training of discrimination skills and constraining the design of technology to accommodate the centrality of the mechanism that controls strategic skills might have a broad impact on Navy warrior performance. Multimodal operator designers need to consider the strategies that are optimal for the discrimination of objects (sights, sounds) processed by Naval Warriors, and even the order of processing. What these studies suggest is that strategic transfer will occur across objects even if they are represented in different modalities, and that initial training on "easy" discriminations may harm future "difficult" discrimination performance.

Future research needs to explore the limitations of strategic discrimination learning and transfer. Regardless, attention to the constraints on development of optimal strategic skills shows promise for enhancing warrior performance, and perhaps across a wide range of tasks.

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3. Doane, S. M., Garrison, T. M., Alderton, D. L., Sohn, Y. W., & Cross, G. W. (submitted). *Far transfer of strategic skills: Optimizing airframe discriminations.* Manuscript submitted for publication.