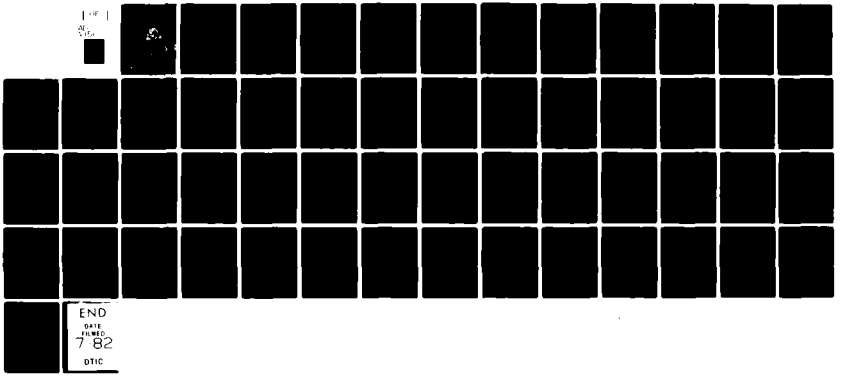
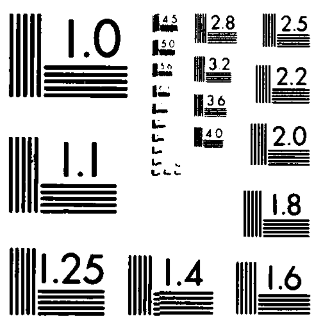
AD-A115 111 ILLINOIS UNIV CHAMPAIGN HUMAN ATTENTION RESEARCH LAB F/G 5/10
AUTOMATIC/CONTROL PROCESSING CONCEPTS AND THEIR IMPLICATIONS FO--ETC(U)
APR 82 W SCHNEIDER N00014-78-C-0012
UNCLASSIFIED HARL-ONR-8101 NL



END
DATE FILMED
7-82
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

AUTOMATIC/CONTROL PROCESSING CONCEPTS AND THEIR IMPLICATIONS FOR THE TRAINING OF SKILLS

(12)

Final Report

Walter Schneider

REPORT HARL-ONR-8101

HUMAN ATTENTION RESEARCH LABORATORY
Psychology Department
603 E. Daniel
University of Illinois
Champaign, Illinois 61820

This research was sponsored by the Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research, under Contract No. N000014-78-C-0012, Contract Authority Identification No. NR150-409.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 8101	2. GOVT ACCESSION NO. AD-A115 111	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Automatic/Control Processing Concepts and Their Implications for the Training of Skills - Final Report		5. TYPE OF REPORT & PERIOD COVERED Technical Report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Walter Schneider		8. CONTRACT OR GRANT NUMBER(s) N000014-78-C-0012
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Psychology University of Illinois Champaign, Illinois 61820		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 150-409
11. CONTROLLING OFFICE NAME AND ADDRESS Personnel and Training Research Programs Office of Naval Research Code (458) Arlington, VA 22217		12. REPORT DATE April, 1982 13. NUMBER OF PAGES 48
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Training, skilled performance, air traffic control, workload, dual task, attention.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Recent research on automatic and controlled processing is reviewed with emphasis on the implications to applied training programs and personnel selection. The research assumes that humans perform mental operations through the interaction between slow, effortful, easy to modify controlled processing and comparatively fast, difficult to train automatic processing. Major conclusions from the work include: performance improves as a function of consistent correct executions; automatic processes can develop with few

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

Unclassified

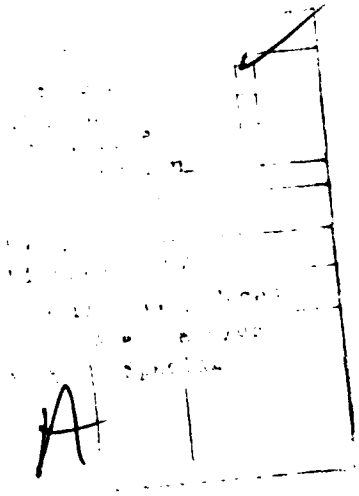
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. abstract.

training trials; massing or distributing practice has little effect; reducing control processing resources slows learning; automatic processes can become context dependent; training operators to respond to classes of events promotes generalization of automatic processing; dual task measures are important assessment tools in assessing skill competency; and motivational characteristics of training programs greatly influence training success rates. Automatic processes influence performance in complex category search tasks, inconsistent tasks with consistent components, tasks which are consistent within a context, visual spatial temporal pattern tasks, and conjunction of features tasks. Automatic processing is very reliable and can perform complex functions, such as category search, with no measurable increase in workload.

The insensitivity of automatic processing to the effects of motivation, vigilance, and drugs, and the stability over long periods without practice, suggest the need to train automatic component skills to obtain high performance skill levels. Individual differences in terms of amount of control processing resources, speed of automatic process development, ability to deal with frustrations inherent in practicing a skill, ability to incorporate context control, and the ability to "let go" of an automatic process may influence training program success. Eleven guidelines are presented for speeding automatic process development in training programs. These guidelines can be incorporated into microprocessor based skill trainers and may substantially imrpove training effectiveness. An application of the guidelines to the training of air traffic control for inflight refueling is presented. The proposed program presents a number of novel approaches to training radar control tasks. The analysis of the air traffic control task illustrates how automatic and controlled processes interact to perform complex operations.

Table of Contents



Automatic/Controlled Processing Concepts and Their Implications for the Training of Skills

Final Report

Walter Schneider

Abstract

Recent research on automatic and controlled processing is reviewed with emphasis on the implications for applied training programs and personnel selection. The research assumes that humans perform mental operations through the interaction between slow, effortful, easy to modify controlled processing and comparatively fast, parallel, difficult to train automatic processing. Major conclusions from the work include: performance improves as a function of consistent correct executions; automatic processes can develop with few training trials; massing or distributing practice has little effect; reducing control processing resources slows learning; automatic processes can become context dependent; training operators to respond to classes of events promotes generalization of automatic processing; dual task measures are important assessment tools in assessing skill competency; and motivational characteristics of training programs may greatly influence training success rates. Automatic processes influence performance in complex category search tasks, inconsistent tasks with consistent components, tasks which are consistent within a context, visual spatial temporal pattern tasks, and conjunction of features tasks. Automatic processing is very reliable and can perform complex functions, such as category search, with no measurable increase in workload. The insensitivity of automatic processing to the effects of motivation, vigilance, and drugs, and the stability over long periods without practice, suggest the need to train automatic component skills to obtain high performance levels. Individual differences in terms of amount of control processing resources, speed of automatic process development, ability to deal with frustrations inherent in practicing a skill, ability to incorporate context control, and the ability to "let go" of an automatic process may influence training program success. Eleven guidelines are presented for speeding automatic process development in training programs. These guidelines can be incorporated into microprocessor based skill trainers and may substantially improve training effectiveness. An application of the guidelines to the training of air-traffic control for inflight refueling is presented. The proposed program presents a number of novel approaches to training radar control tasks. The analysis of the air-traffic control tasks illustrates how automatic and controlled processes interact to perform complex operations.

Automatic/Controlled Processing Concepts and Their Implications for the Training of Skills

Final Report

This report summarizes the research carried out on Contract N000014-78-C-0012. This research examines human information processing in skilled performance. The research interprets human information processing to be the result of two qualitatively different processes: controlled and automatic information processing. Controlled processing requires little training to initiate, is easy to modify, but slow, serial in nature, and highly dependent on load. Automatic processing is a very fast, parallel processing mode which occurs after subjects are extensively trained at treating information in a consistent manner. The objectives of the research program are to determine how to quickly develop skilled behaviors, determine the limits of automatic processing capabilities, improve the theory of individual difference testing and assessment, and suggest guidelines for equipment and training programs to optimize automatic processing performance.

The present report is a summary of the research project results and some speculations about their implications for applied settings. Detailed information about the research is provided in technical reports and working papers listed on pages 31-32 of this document. During this project we have trained subjects for a total of over 10,000 hours. In this report we will discuss both the empirical evidence and our subjective impressions of this training experience. At the end of this report we will illustrate how the principles derived from this research might be utilized in applied training programs. In particular we will discuss how one would develop automatic performance skills for air-traffic control of inflight refueling operations. There is a wide variety of material presented in this report. Readers are encouraged to skim sections attending to underlined comments if pressed for time.

Background

Human performance in almost any cognitive or motor skill shows profound changes with practice. Consider the changes that occur while learning to fly an aircraft, type, play a musical instrument, read, or play tennis. At first, effort and attention must be devoted to every movement or minor decision, thus performance is slow and error prone. Eventually long sequences of movements or cognitive acts can be carried out with little attention, and performance is quite rapid and accurate. For example, the beginning reader may need a few seconds to encode each new letter, and still may be error prone, whereas the expert can accurately encode 25 letters per second and still have sufficient capacity available to encode the material semantically as well. In aircraft control, the novice may have difficulty just keeping his aircraft on the proper heading. However the expert can fly complex aircraft formation maneuvers while performing a simultaneous digit cancelling task (Colle & DeMaio, 1978).

The striking changes that occur with practice have led many researchers to propose that there are two qualitatively different forms of human processing (e.g., James, 1890; LaBerge, 1973; Posner & Snyder, 1975; Shiffrin & Schneider, 1977). I shall refer to these two processes as automatic and controlled

processing. Automatic processing is a fast parallel process, not limited by short-term memory, requires little subject effort, requires extensive and consistent training to develop, and provides little direct subject control. Manipulating a fork at dinner or driving a car are examples of automatic processes. Controlled processing is comparatively slow, serial, limited by short-term memory, and requires subject effort, exhibits a large degree of subject control, and requires little or no training to develop. In addition, control processing appears to be instrumental in causing substantial changes in long-term memory. Trying to remember a telephone number long enough to dial it is an example of a control process.

Development of skilled performance is primarily the result of developing appropriate automatic processes (see Report 8002; Schneider & Fisk, in press-b). Control processing resources are limited (e.g., one can only maintain 5 items in memory), and do not improve with practice (see Schneider, Dumais, & Shiffrin, in press). Our research suggests that skilled performance results from building up many component automatic processes which perform consistent processing transformations in complex tasks.

The reader should note, however, that the performance of all skilled tasks involves the interaction of both processes. Even brief consideration of any complex task, such as playing tennis, makes it clear that such tasks are carried out by a mixture of automatic and control processes, possibly organized in a systematic network or hierarchy with many of the automatic processes operating in parallel. The control processes deal with strategy (e.g., seeking for advantage or trying to tire the opponent), maintain temporary information (e.g., current point advantage in the game), and deal with any novel components of the task (e.g., particular wind conditions). Operating within the context of the information maintained by control processes, automatic processes perform the consistent elements of the task (e.g., approaching and hitting the ball). The following discussion will occasionally refer to the processes involved in carrying out a task as if they were wholly automatic or controlled. In all such cases the reader should understand that these statements are designed to simplify the discussion; the intended referent will always be some major component process. We assume as a working hypothesis that essentially all tasks are accomplished by a mixture of both types of processes.

Speeding Development of Automatic Processes

The major effort during this contract period has been to determine how to speed up the development rate of producing new automatic processes. We have been fairly successful and have reduced our training time for a simple detection task from approximately 2,000 trials of training to below 200 trials. If these techniques are employed in developing automatic component skills, training time could be reduced by as much as 90% in a variety of applied settings. We have also shown that automatic performance improvements can occur with as few as 10 practice trials (Report 8004). Hence automatic processing should not be viewed as being important only after hours of practice.

Consistency is a necessary condition for performance improvement and automatic process development (see Report 8005; Schneider & Fisk, 1982). In a detection paradigm, subjects were required to detect specific letters in rapidly (i.e., 110 msec each) presented frames of 4 letters. In a consistently mapped

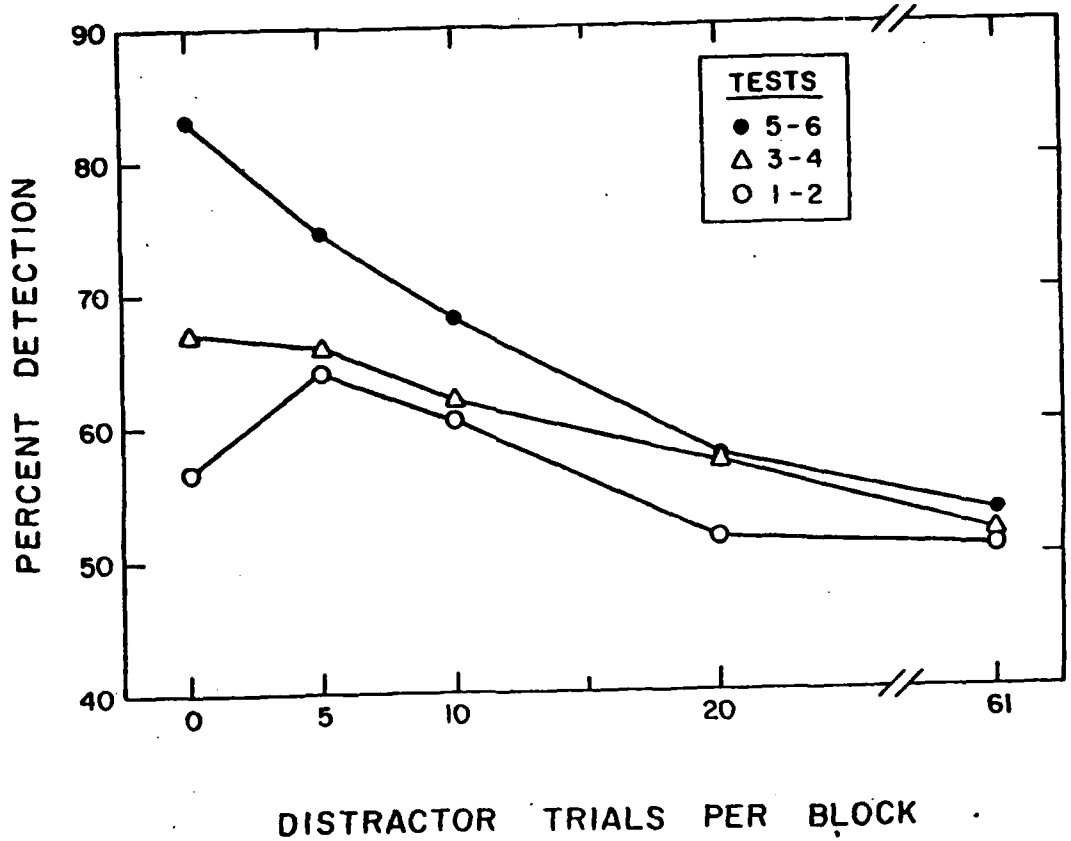


Figure 1. Detection improvement as a function of consistency. The 0, 5, 10, 20, and 61 represent the degree of consistency of 100, 67, 50, 33, and 8% respectively.

(CM) condition, every time a particular letter would occur the subject would respond indicating the position of that letter. In a varied mapping (VM) condition, on some trials the subject would respond to that letter, on other trials the letter would be a distractor and would be ignored. In the VM condition subjects could not consistently respond to the stimulus across trials. In the CM condition subjects' detection performance improved about 35% with practice after 670 detection trials. However, if a stimulus letter appeared as a distractor twice as often as it appeared as a target, there was no significant performance improvement as a function of practice (see Figure 1). As consistency decreased, both the performance improvement rate and the final performance level also decreased. In addition, subjects were tested with the letter detection task treated as a secondary task. Results showed that previous consistent mapping training greatly facilitated the subjects' performance of the detection task as a secondary task. In fact, if the target's previous consistency was less than 1/3 (i.e., a letter appeared as a distractor twice as often as it appeared as a target), subjects could not detect any of the targets if the detection task was treated as a secondary task. These results indicate that performance improves as a multiplicative function of the number of trials and the degree of consistency.

Insert Figure 1 about here

The importance of consistency suggests that training programs should facilitate the identification of consistencies and consistent responding. For example, computer assisted displays might emphasize the consistent events appropriate for a particular task. In our air-traffic control task, we present the consistent control function curves which are representative of the turn characteristics of the aircraft the operators would control (see below). Adaptive training techniques might also promote consistency. Such techniques should not increase the difficulty of the task beyond the point where operators are at least 50% accurate. Otherwise we would predict that responding would not be consistent enough to develop automatic processes to perform the task.

Performance improvement appears to be primarily a function of correct executions of the process. In a search paradigm (Report 8004) we found that detection performance improved as a function of the number of correct detections. Performance did not improve as a function of searching for a letter and not detecting it. In fact, performance decreased with nondetection searches. We speculate that performance improvement is primarily a function of the number of times the proper stimulus to response mapping was executed by control processing. Searching without detecting does not activate the stimulus response mapping and hence would not be expected to improve performance. Our results suggest that when training an observer one should provide many experiences of the critical event relative to searches without the critical event occurring. The effectiveness of "guidance" and "discovery" methods of teaching (see Welford, 1976, Chapter 6) appears to be that they reduce initial errors and result in the learner making few incorrect executions. These methods improve both the consistency of response and the number of correct executions. Hence they would be predicted to speed automatic process development.

Detection performance can improve with as few as 10 consistent training trials. We found (Report 8004) that after an average of 10.1 consistent detections, performance improved 44% over the comparable VM detection rate. In general we find substantial improvements with less than 200 detections of a letter in a consistent mapping search task.

Our results suggest (Report 8011) that there may be some minimal consolidation time for developing an automatic process. When subjects are trained with very rapidly presented stimuli (i.e., at rates faster then 100 msec per stimulus) we often find subjects can consistently detect a target but performance does not improve with practice. However, if the presentation rate is slowed (i.e., from 100 msec per stimulus to 150 msec), not only does detection performance improve but also performance now significantly improves with practice. This suggests that there might be a short (approximately 100 msec) consolidation time required for a correct execution of an automatic process to lead to its development. We are continuing research to determine whether there is such a brief consolidation period.

Our training results suggest that moderate speed stress may improve automatic process development rates. We have observed subjects performing a training task, sometimes for days, with little improvement even though the task is such that most subjects show substantial improvement. We have found that there is little if any performance improvement in some subjects if they are not pushed to perform faster. In some subjects we have found little performance improvement even after 10 sessions of CM training. However, with these subjects we often find that if we push them (e.g., require that they respond under a given deadline reaction time), performance does improve substantially. We have trained subjects in both a single frame and multiple frame procedure. In the single frame procedure the subject is presented a display and required to respond if a target is present on the display. The subject has as much time as he or she wants to process the display. Our second procedure is a multiple frame procedure. In this procedure the subject is presented a rapid series of displays for short duration each (e.g., typically 100 msec). We have found somewhat faster improvement rates when subjects are trained in the multiple frame procedure. We interpret this faster improvement rate as suggestive that mild time pressure improves subject learning rates.

Massing versus distributing practice seems to have little effect on training rate within the ranges tested. In a CM detection paradigm, subjects searched for a given letter at every second trial, fourth trial, or eighth trial. The differences between these levels of distributed training were not significant (Working Paper 80-2).

Reducing control processing resources appears to slow the learning rate. We have carried out many experiments in which subjects learn a detection task while they carry out a secondary task. Our subjective impression is that in these training situations performance improves much more slowly than when subjects do not need to perform the secondary task. The careful examination of Logan's data (1978) also shows that performance does not improve as quickly when subjects are under high secondary task load.

These results suggest the obvious, that operators should not be overloaded while trying to learn a new task. This might stress the importance of part-task

training over full-task training. Although the full-task trainer might more closely approximate performance on the final task, it might also overload the operator. Such overloading might greatly reduce learning rate and hence slow learning in comparison to part-task training. This overloading is usually conceived of in terms of memory limitations. Reed (1924a, 1924b) was the first to speculate that the part method may be superior because it adjusted the material to be learned to the memory span of the subject. Maccoby, Michael, and Levine (1961), Margolius and Sheffield (1961), Michael and Maccoby (1961), and Sheffield (1961) argued that a subject should be presented with only that amount of information which he is capable of "assimilating" at a given moment. They call the capacity of the subject to assimilate a given amount of the material the "demonstration-assimilation span" (D-A span) of the subject. The amount of the given material that subjects are capable of assimilating at a given moment is called the "demonstration-assimilation unit" (D-A unit). They argue that the optimal D-A unit is that amount of material after which the typical subject's responses are 75% correct on a post-test. If the D-A units are larger than this, the authors argue, learning will be impeded; if smaller, learning will be inefficient. In actual practice, the amount of material presented at one time should be a compromise between the logical or natural units of the task (as identified by some form of task analysis) and D-A units.

Automatic process learning may be substantially influenced by context. We carried out a series of 12 experiments (Report 8009) to determine whether subjects could develop automatic processes which were inconsistent across context but would be consistent within a context. In these experiments, the context was manipulated by putting up a set of context symbols (X's in a diamond versus O's in a square formation) around the four visual channels. A particular letter would be consistently mapped as a target in one context (e.g., X's on the display) and would always be a distractor in another context (O's on the display). We found in a number of such context dependent training situations that some of our subjects could clearly develop performance levels typical of automatic processing. Some subjects could detect a given set of stimuli when they were targets on some trials and distractors on the other as well as when they were targets only. For some subjects providing explicit external context improved their ability to develop context dependent automatic processes. Additional research is required. The present results suggest that automatic processes can develop when subjects must consistently respond to stimuli within a given context; however, their responses to the stimuli need not be consistent across all contexts (see Schneider & Fisk, in press-a).

The second set of results suggesting that context is important is our experience in dual task processing conditions. In these tasks subjects are asked to perform two processing tasks at once (e.g., searching for letters while keeping digits in short-term memory). Every time we change the dual task processing conditions even slightly, subjects typically require one to two hours of training before they can perform both tasks well. Logan (1978, 1979) has observed a similar initial training time for dual task conditions. We speculatively interpret this as time in which the automatic processes become active within the particular dual task context.

The military combat environment provides a suggestive example of problems caused by lack of context incorporation. It is generally found that pilots who survive their first ten combat missions have a greatly increased chance of

surviving further missions. We would predict that early missions would incorporate previously learned automatic behaviors such that they would be enabled within combat context. Unfortunately, during the first few missions, many of the automatic behaviors may not transfer to the new context, resulting in very poor performance.

The potential of having automatic processes which are context dependent suggests that training environments should attempt to recreate as much of the final context as possible during training. In training a component task, it would be best to embed that component within the more complex task. For example, in the air-intercept task (see below), while the operator is learning to control one aircraft the computer might also display the performance of the other aircraft for the proper rendezvous. In this way it is hoped that the operator will learn the appropriate visual context under which the various turn characteristics of the aircraft would take place. One must be cautious when adding context not to overload the operator's limited control processing capacities.

If automatic processes do become context dependent, there may be some situations where the context should be varied in training so that the automatic process is context independent. For example, if you cannot train within the actual context (e.g., a life threatening situation), it might be best to train in a variety of situations so that the automatic process would not be context specific. Since our previous research has shown that varied mapping search conditions do not result in automatic process development, we would anticipate that varying the context could result in context independent automatic processes. This is, of course, speculative at present.

To promote proper generalization, training may have to be done at the appropriate level of the task. We have trained subjects to respond to specific letters, words, and categories of words (see *Report* 8102). Results suggest that subjects can automatically respond at any of these three levels of stimulus generalization. When subjects were trained to respond at the category level, they were taught to search for words of a given category but never to search for a given individual word. We speculate that if subjects consistently respond to a single word, automatic processes will develop for that specific word. However, if there is a large set of words that fall into a general category, and subjects are responding to the category, we expect the learning to be at the category level. In an applied training situation, the amount of emphasis given to particular stimulus readouts may be important. For example, in training a nuclear plant operator you may train the operator to respond either to a particular temperature readout, or to a contrast between one gauge and the rest of the gauges. In the former case we would expect less transfer to a variety of similar events than we would in the latter. In the air-traffic control situation (see below) we vary the angle of the incoming planes so the learner does not develop skills specific to one set of incoming planes.

In some situations there is a need to train subjects to let automatic processes operate without resources. A good typist knows the importance of letting automatic process typing behaviors take place without the interference of conscious control processes. If a typist thinks about his/her hand placements, the typing becomes more error prone. We have found in our dual task training experiments that subjects have a strong tendency to waste control

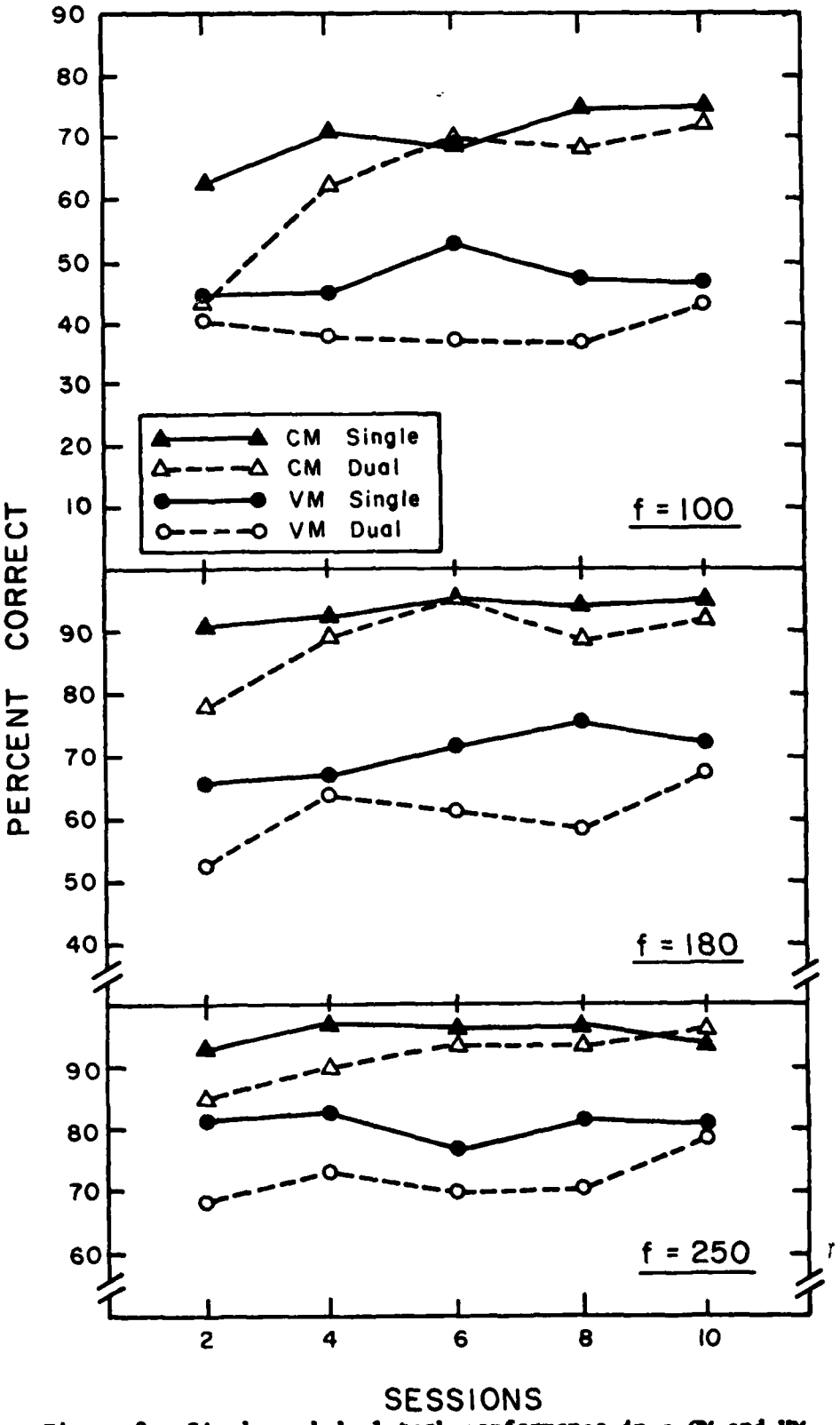


Figure 2. Single and dual task performance in a CM and VM multiple frame search task. The f refers to the duration between displays in milliseconds. The triangles represent CM search conditions, the circles, VM search conditions. Filled symbols show single task performance, open symbols, dual task performance when both CM and VM search are carried out simultaneously. Note the CM single task condition reaches asymptote relatively early compared to the dual task conditions. (See Report 8002 or Schneider & Fisk, in press-a).

processing resources (see Report 8002). After a process was well developed we found that we had to strongly encourage subjects not to expend any resources on that task. Learning to read demonstrates the importance of teaching individuals not to waste resources on an already automatic task. If word encoding is fairly automatic and readers continue to allocate limited control processing resources to the encoding task, they reduce resources available for semantic comprehension. Hence, although the encoding may be slightly more accurate, the total reading performance will be poorer. LaBerge and Samuels (1974) report that teachers who stress accuracy have a tendency to produce poor readers. In development of a complex skill, it may be as important in some situations to stress what not to attend to as well as what to attend to. We have found that some individuals require special training in order to "let go" of an automatic process (see Schneider & Fisk, in press-a). If operators have a tendency to waste resources on task components which are already automatic, they will not have the resources available for performing the potentially more critical strategic memory components of the task.

Dual task performance measures may be important assessment tools for assessing skill competency. We often find little difference between performance in CM and VM conditions when subjects are fully attending to the processing. In many conditions the difference between well practiced CM performance and poorly practiced VM performance is quite small (e.g., only 5% differences in detection or only a 15 msec slowing in reaction time when subjects must search for only one particular stimulus (see Report 8002)). LaBerge (1973) has shown that when subjects compare well learned letter stimuli versus novel stimuli, there are few differences after the second session if subjects are attending to the comparison process. However, if subjects cannot prepare for a particular novel stimulus, differences persist for greater than 10 sessions.

We have found that performance on a task which is fully attended reaches asymptote long before performance on that task when the condition is treated as a secondary task. When subjects were attending to a CM digit detection task we found accuracy seemed to have asymptoted after about the second session (see filled triangles, Figure 2). However, when the digit detection task was treated as a secondary task (open triangles, Figure 2) performance continued to improve for eight sessions.

Insert Figure 2 about here

In many applied situations it is important to assess competency level when the operator is not fully concentrating on the task. For example, one cannot consider a pilot a safe pilot when he can only land his aircraft on an aircraft carrier when fully attending to the task. If something unexpected happens near a critical maneuver (e.g., a warning light comes on), a reduction in resources available to the landing task may result in failure to perform the landing properly. By training operators to the point where they can perform the task with perhaps half of the available resources, there would be a substantially greater margin for error in the performance of critical maneuvers. The inflight refueling training task (see below) illustrates such assessment measures.

Motivational Factors

Our experience of training 10,000 hours of automatic process development has convinced us that motivation is often more important than many other manipulations in the development of new automatic processes. Motivation is much more important in the development of automatic processes than it is in the development of declarative knowledge. The first problem is that automatic process development is very slow and may take hundreds of trials. The second problem is the task may be so difficult initially that the operators will doubt that they can ever perform the task well (e.g., most people who try to learn to play a musical instrument quit before learning to play well). Third, because so much practice may be needed, practicing may become very boring. This is particularly a problem since very early in practice performance may be accurate, but not automatic (see above discussion of dual task performance assessment). Fourth, sometimes operators get into a passive practice mode where they continue to practice but do not improve in performance. We have had subjects plateau and not improve performance even after 10 hours of practice in a simple perceptual letter detection task.

We have learned to motivate our subjects by a variety of methods. The experimenter/subject interaction is often very important. We must train our experimenters to motivate subjects by providing encouraging feedback and working with the subjects. The importance of this is illustrated by the fact that data from new subject runners is often much more noisy than that of more experienced subject runners. Our procedures also encourage subjects to compete with themselves and others. Subjects are typically given feedback in terms of their performance from day to day and their relative performance to other subjects in the task.

Our most effective method of maintaining concentrated performance has been to make tasks intrinsically motivating by making them like arcade games. By providing simple interesting active feedback, we can greatly improve subject learning. For example, in a simple target detection task, once a subject correctly detects a target it appears to spin off the screen. Adding sound effects (explosions on detections) can make subjects want to participate even after of thousands of trials of training.

We have found that providing accuracy feedback with discrete cutoffs substantially improves subject motivation. We provide subjects both percent correct ratings and a rating of whether they are "ace, good, average, or novice" performers. These discrete rating values are provided such that the subject is basically always near one of the breakpoints between one category or the other. As in academic grading scales (i.e., A - F), the learner seems always to be near a salient cutpoint for one category or the other. This seems to maintain motivation much more than does a simple continuous percent feedback measure.

We have also found that subjects improve substantially faster when their initial training leads them to expect substantial improvement. We found that when subjects received massed CM training before later CM and VM training, performance improved much more than if they had received initial VM training (see Working Paper 80-2). We speculate that this improvement is due to motivational factors. In the condition where subjects first experienced the CM

training, they did see substantial improvement during the first hour. We feel this resulted in their spending more effort in the second hour to learn to do the task. Subjects who initially experience VM training perform substantially worse in later tasks. These effects were quite reliable ($p < .002$).

The development of automatic skills might be more appropriately viewed from the perspective of coaching than teaching. In order to properly perform the task once, the learner must be given sufficient knowledge to execute the task. However, to become automatic, hundreds of consistent correct executions may be necessary. A critical role of the instructor is to provide a motivational environment to maintain practice long enough to develop automatic behaviors.

On the basis of our training experience, we recommend that training programs should explicitly attempt to maximize motivation wherever possible. Note: the need for motivation is often considered a truism in training programs. Or worse yet, the need for motivation is stated as a fact but not implemented into the training program. If special sound effects improve performance and do not substantially alter the performance context, they should be built into the training devices. Probably the most cost effective component in our laboratory is a fifteen dollar electronic sound chip which provides noises that substantially improve subject motivation (and hence performance) over the thousands of trials that we must train them.

What Can Become Automatic

Since automatic processes are fast and effortless compared with controlled processes, it is important to know what activities can become automatic. We define automatic processes operationally in terms of those situations where there is substantial improvement in CM conditions relative to VM conditions, and there is a lack of secondary task deficit after extended training (for detailed discussion of operational definitions, see Shiffrin, Dumais, and Schneider, 1981). During this contract period we have carried out a number of experiments to assess the range of activities which would satisfy the above operational definitions of automatic processes. This research has tried to determine the generality of the automatic processing concepts to a variety of experimental paradigms.

Automatic processes appear to develop only when subjects consistently process information. However, it is difficult to operationally define "consistent processing of information". We have already discussed results showing that when stimuli have a varied mapping across trials subjects' detection performance does not improve with training (Report 8005; Schneider & Fisk, 1982). However, processing need not be consistent from stimulus to response. We have trained subjects to consistently attend to stimulus while the responses to stimuli were varied across trials. Results show (Report 8103) that inconsistent responding slowed the development rate, but did not affect detection performance on tests in which the inconsistent responding was eliminated. Hence, we feel that automatic performance improvement will occur when components of a task are consistent even if the entire task is not consistent (see also Schneider & Fisk, in press-a).

Experiments which manipulated context (Report 8009) suggest that subjects can develop context specific automatic processes. A context specific automatic

process will develop when subjects make a consistent response to a given stimulus in a given context, but inconsistent responses across contexts. An example of this context specific consistency is illustrated by driving. A driver often automatically responds to red traffic signals by stopping. This response is viewed as automatic because it generally does not reduce undifferentiated resources (e.g., resources utilized in conversation). However in the context of walking, the same external stimulus of a red traffic light may initiate a completely different set of behaviors in crossing an intersection. Responses to many stimuli are consistent within a given context, but inconsistent across contexts. The evidence suggestive of context specific automatic processes (Report 8009) indicates that automatic processing concepts may determine performance in situations where responses are at least consistent within a given context.

The presence of context specific automatic processes greatly increases the difficulty of defining 'consistency'. The context may be either internal or external. In our experiments (Report 8009), some subjects initially required an external stimulus (X's or O's on the screen) to develop context specific automatic processes. But after sufficient practice (several hours), subjects could perform either task without the use of an explicit external context. In my own case of working with different computer text-editors on the same terminal, I find I must maintain actively in memory which editor I am working with in order to keep from making responses appropriate to the other editor. When there are no external context cues, processes must be cued on the basis of internal context. If the internal context is not maintained, behaviors will slip into those of the more developed automatic processes (see Norman, 1981).

To review, our results on examining automatic processes suggest that: consistency is a necessary condition for automatic process development; however, consistency need only be maintained for a component process in a given context.

Consistent motor output sequences appear to become automatic with practice. We trained subjects to perform sequences of eight button pushes. We found that, when the sequence of buttons was varied from trial to trial, the rhythm of pushes was basically unaffected by training (see Schneider & Fisk, in press-b). There were always pauses and errors at multiples of two responses. In a consistent mapping condition, subjects were required to push the same sequence of buttons across trials. In the consistently mapped button push sequences, the pauses and errors between responses decreased with training. If there was a variably mapped segment within a string of consistently mapped digits, there was always a pause and an increase in error rate at the point at which the variably mapped segment began.

Sequential motor output data seem very similar to the perceptual experimental data. The CM sequences were fast (no large pauses), required little effort, and were of high accuracy compared to the performance in the variably mapped sequence conditions. We expect that motor output sequences will show results very analogous to the past perceptual experiments we have done. We are continuing research to determine whether the training principles derived from perceptual experiments generalize to sequential motor output conditions.

Results from visual spatial temporal pattern detection experiments show substantial improvements with practice and potentially the existence of

automatic temporal pattern detectors. Experiments (Report 7901, 8003) required subjects to detect a sequence of three discrete movements of a line segment. In the CM conditions, subjects always responded to a particular sequence. In the VM conditions, a sequence which was a target on one trial could be a distractor on the others. In general the CM sequences were better identified, less affected by processing load, and less affected by temporal characteristics of the pattern. The CM sequence however, showed no advantage over the VM sequence when both patterns were spatially rotated. Results are not as clearly qualitatively different as we have seen in the past. Processing of discrete sequential information may require controlled processes to maintain the state of the previous stimulus.

Searching for conjunctions of color and shape can be greatly speeded with training and may become automatic even if the features are not consistent. Treisman (Treisman & Gelade, 1980) has claimed that subjects cannot do conjunction search without focal attention. In particular, Treisman (Treisman & Gelade, 1980) claims that subjects can, in parallel, find a particular shape feature or a given color feature, but subjects must sequentially search the display with focal attention to detect a given conjunction of color and shape. In a search experiment (Report 8008) we found that the positive slope of reaction time, as a function of the number of characters in the display, decreases in the conjunction search condition from 26 msec per item to 10 msec per item. We also found that there were no qualitative differences between shape and conjunction conditions. Our subjects could learn to rapidly detect texture boundaries of conjunctions of features (e.g., find the row which has green X's and blue T's on one side and blue X's and green T's on the other). Boundary detection for conjunctions dropped from greater than 2 seconds to .76 seconds over about 900 trials of practice.

The conjunction of features search conditions show neither clearly automatic or controlled type search performance. The CM search conditions showed substantial reductions in slope, negative transfer effects, and smaller effects of load. However, in all CM conditions the reaction time was a linear function of the number of comparisons, the slope of the negative responses was twice that of the positive responses, and when memory load was increased, reaction times did increase. Certainly, the processing of these stimuli do not show the parallel type of processing we have seen in the past in automatic processing paradigms. We speculatively interpret the present results as suggesting that outside of focal attention, visual resolution is reduced, and automatic processing has poorer spatial resolution. Hence, illusionary conjunctions (where features in close spatial proximity cause subjects to put them together in inappropriate combinations) are more likely to occur. These illusionary conjunctions will frequently attract attention resulting in subjects inconsistently attending to the real target. This inconsistent attending will slow or inhibit development of automatic processing. We are continuing research on the topic of automatically detecting conjunctions of features.

The apparent difficulty of developing automatic processing for conjunction stimuli may have important implications for instrument panel design. The inability to resolve conjunction stimuli without focusing attention on the location of the stimulus (see Treisman & Gelade, 1980) suggests that instrumentation systems should not allow features which can cause illusionary conjunctions to be within the regions of interaction (e.g., if a critical

warning indicator shows a Red X which is to be responded to automatically, the features of red and X should not be allowed to occur within, for example, two degrees visual angle). We are continuing research on the spatial resolution issue.

We have found that retinal location in the range of one to three degrees has little effect on the type of processing (Report 8001). Subjects participated in a two alternative choice reaction time task, Posner match task, and scanning memory set size one and three task. They also carried out a multiple frame memory set size two CM and VM search task. The main effects of experimental paradigm and retinal locus were significant, but the interactions were not. The results suggest that the automatic letter encoding stage can take the form of a discrete stage of continuous output which cascades at the next stage for search and detection.

Results using the incidental learning paradigm (Report 8007) suggest that automatic processes do not modify memory without the use of control processing. Hasher and Zacks (1979) have suggested that encoding of word frequency and word recency is automatic. Our experiments do not support the Hasher and Zacks position. When subjects were engaged in automatic search the subjects' recall and recognition performance was at chance for the distractors. In a frequency judgment task, subjects were presented a word 40 times for a total of 24 seconds while carrying out a secondary task. Subjects' median estimation for the frequency of occurence of this word which was presented 40 times was zero. We found no evidence that frequency encoding is automatic. We interpret these results as indicating that memory modification requires control processing.

Automatic processing can be developed for word and category detection. We have carried out word and category versions of probe reaction time tasks similar to the letter search experiments we have done previously (Schneider & Shiffrin, 1977). The experimental procedure presented subjects two words and required them to push a button if one of the words was one of either four categories or four words which were held in memory. In the varied mapping conditions reaction time was a linear function of the number of items in memory. The slope in the word search condition was 47 msec per item, in a category condition it was 92 msec per item for positive responses. In the consistently mapped conditions there was no effect of number of comparisons (slope of 2 msec). In another experiment subjects showed that they could carry out joint CM category search and a simultaneous digit task without any deficit in either task. These results suggest that subjects can develop automatic category search capabilities. After subjects consistently attended to some members of a category, any member from a consistently attended category can attract attention. In this way operators can learn to attend and respond to classes of events as well as individual events. We have also shown that if you attend to a subset of elements in a category, there is a very high degree of transfer to the remainder of the category.

Can automatic processing be done without cost of nonspecific resources?

If automatic component processes can be performed without consuming a limited resource pool, then there is no simple identifiable resource limit to human processing capabilities. A major defining characteristic of automatic processing is the proposed costless nature (see Shiffrin, Dumais, and Schneider, 1981); that is, one can perform an automatic process with no decrement in

performance of a concurrent secondary task. The task of reading illustrates the value of having an automatic encoding process. Reading requires the encoding of features, letters, words, phrases, and basic semantic concepts. We suggest that for the skilled reader all of these stages may be automatic for texts the reader frequently reads, hence these encoding processes should not reduce resources available for semantic integration of the material being read. We believe the execution of each of these automatic component processes does not reduce the readers' resources available for semantic comprehension (Schneider and Fisk, in press-b). But this is not to suggest that there are not structural interference problems between automatic processes. For example, if two automatic processes attempt to activate simultaneous responses in working memory, there will be structural interference. Also, if stimuli become highly confusable, control processing may become necessary to resolve feature confusion.

Subjects can perform an automatic detection search while performing a simultaneous control process search task without a sensitivity deficit in either task (Report 8002). Subjects performed a VM search task looking for a particular subset of letters on one diagonal of a display. Simultaneously, subjects also performed a CM detection task (looking for any digit) on a second diagonal of a display. There was no trade off between the two tasks in terms of sensitivity (see Figure 2). Subjects could perform either task in combination as well as they could perform the tasks singly. However, in order for the subjects to perform each task simultaneously, subjects had to be strongly biased to maintain performance on the VM task. This resulted in a severe criterion shift in the CM task.

In a joint category search and serial digit recall task (Report 8103), we also found no cost of combining the category detection task with the digit recall task. In these experiments subjects had to encode and rehearse eight digits while sixteen words were simultaneously presented for categorization. A categorization required pushing a button every time a word from one of four categories (i.e., body parts, animals, furniture, fruits) was presented. If the categorization task was consistently-mapped-detection, the addition of the primary digit recall task dropped detection performance only 2% which was nonsignificant, and memory recall performance was unaffected.

In all our dual task experiments we typically find that subjects generally require some time (e.g., at least two hours) at performing two tasks simultaneously before the two tasks do not interfere. This need for some time sharing experience suggests to us that subjects are developing some sort of enabling condition which allows multiple automatic processes to co-occur. We believe that subjects enable automatic processes by maintaining particular nodes in short-term memory. Whenever that node is active in short-term memory and the particular stimulus appropriate to that automatic process occurs, the process takes place with no additional resource cost. However, when subjects are required to perform two tasks simultaneously, both enabling nodes must be activated. The activation of two versus one node would present some cost to the subject. With dual task timesharing experience, we expect the operator will be able to develop a new node which represents an activating condition for both individual automatic processes. This is similar to the notion of chunking in short-term memory. It takes about as much short-term memory capacity to store a letter, a word, or a well known phrase in memory. This would suggest that the integration time for combining two well-developed automatic processes should be

relatively independent of the complexity of the processes themselves.

The recent results suggest that at least some automatic processes can be performed without any measurable costs of resources. However, the presence of structural competition between automatic component processes, the limitations of activating any information in short-term memory, and the frequent use of control processing for strategic decisions and maintenance of automatic processing enabling nodes clearly imply limits to the extent to which automatic processes can be combined without costs. We feel that productions system modeling techniques (e.g., Hunt, 1981) provide a mechanism for interpreting how automatic and control processes interact to maximize human performance.

Reliability of Automatic Processing for Applied Settings

In general we have found that automatic processes are fairly insensitive to reductions in effort either through manipulations of vigilance, secondary task load, or drug effects. Since many applied settings require operator performance under a variety of stresses, it is important to build processing capabilities which are reliable. In our vigilance experiments (Report 8006; Fisk & Schneider, 1981), we found that automatic processing detection sensitivity performance was not affected by time on task during a 50 minute session. Performance on a controlled process (VM) search task was significantly affected by time on task. In terms of hit rate the automatic processing hit rate dropped about 15% during the session, whereas the control process hit rate dropped about 35%.

In dual task experiments, we have found that when resources are removed from automatic process tasks, there are no decrements in performance (Report 8002, 8103). However, if resources are removed from a control processing task, performance often drops to chance detection level. Hence in situations where there might be multiple task requirements or where operators' attention may drift, it may be particularly important to develop automatic processes.

We have carried out some pilot studies examining the effects of alcohol on automatic and control processing (these were not supported by ONR funds). In these studies we have found little performance decrement in automatic processing conditions and substantial (32% decrement in inconsistent responding condition, 20% decrement in letter detection dual task letter and tone detection) reduction in detection rate in detection tasks which require substantial control processing resources.

Theoretical and empirical results suggest that automatic processes will be much more reliable than control processes. Hence we feel special attention must be given toward developing automatic component skills when operators will be required to perform tasks of long time durations, tasks requiring complex time-sharing, or where the effects of drugs or fatigue are likely to reduce performance levels.

Individual Differences in Automatic/Controlled Processing

Individual differences appear in the rate of controlled processing, subject control of the allocation of controlled processing, how quickly subjects develop automatic processing, and the range of tasks in which subjects show automatic

processing. Since automatic processing is much faster than control processing, most of the between subject variability found in consistent search tasks is determined by differences in the development rate of automatic processes. Some individuals develop an automatic search set in an hour, others show no development after six hours. Subjects who are particularly concerned about doing poorly generally have greater difficulty in performing automatic processes. We have found that about a quarter of our subjects have a great deal of difficulty "letting go" of an automatic process (see 8002, 8201). For example, subjects were required to perform a category word search and digit task either as single task or as a combined dual task. The eight subjects had roughly equivalent single task performance but two of the eight subjects could not effectively perform the dual task. Later research showed that these subjects had difficulty in inhibiting the allocation of control processing resources to the automatic process. In an experiment examining context effects about half the subjects did not appear to develop context specific automatic processes (Report 8009).

In continuing research we are examining a population of high school seniors to determine the range of individual differences. We are assessing differences in ability in automatic/controlled processing and relating these differences to standard psychometric measures. The expectation is that computer task measures of control processing performance (i.e., VM category search) will assess capacity and willingness to perform effortful mental processing during ten hours of training. Computer measures of automatic processing (i.e., CM category search) will assess automatic processing development rate and performance asymptote. We are examining within and between task covariance over ten hours of training.

In addition, our high school students are tested to obtain psychometric measures of "fluid" and "crystallized" abilities (Horne & Cattell, 1966). We hypothesize that measures of fluid ability will relate to controlled processing and measures of crystallized ability will relate to automatic processing. We hope to use our measures to better predict "learning ability". We will later use our measures to predict learning rate and performance in our air-traffic control task (see below).

Recommendations for Skill Development Training Programs

The following is a set of rules for improving training program efficiency. These rules are derived from both our experience in training and our theoretical work. At this point we have trained subjects for some 10,000 hours in developing perceptual skills. From the various experiments (see above), we have found certain techniques considerably speed the rate of learning. In addition, our theoretical work specifies how component skills can become automatic in the process of developing complex performance capabilities. In the next section we will illustrate how these rules might be applied in an air-traffic control task.

Rule 1. Present information to promote consistent processing by the operator. Generally there are many ways to display information to an operator. The emphasis here is that the displayed information should allow the operator to consistently deal with that information. For example, in the air-traffic control task, when two aircraft are brought together for inflight refueling there are typically about one hundred easily distinguishable solutions which will bring the two aircraft together. If training is done at the level of individual solutions, the problem can have one hundred equally valid outcomes. If different solutions are presented on different trials, our work would suggest that the operator would not learn how to consistently deal with the situation. In order to consistently deal with the situation, the operator must be presented the space of possible solutions (see below). By experiencing the problem at the level of solution spaces the operator learns to deal with the problem consistently. We are carrying out research in training operators to perform second order tracking. In this situation we project the control dynamics of the system both forward and backward in time because only when the operator sees the complete control function is it always consistent (see Eberts & Schneider, 1980).

Rule 2. Design tasks to allow many trials of critical skills. Our work would suggest that skill development is a function of the number of correct executions of the component skill. In the air-traffic control task the normal intercept for inflight refueling would take approximately 20 minutes to execute. Hence one would expect to have approximately 24 trials in an eight hour day. If we speed up the task to ten seconds per trial, one could get 2880 trials per day of training. If learning is primarily a function of the number of correct executions of the process (Schneider & Fisk, 8004), then training in the speeded-up fashion could speed up the learning process 120 times.

Rule 3. During training do not overload temporary memory and minimize memory decay. Human short term memory is limited to about five items; human auditory memory decays between one and three seconds; and visual images decay in the range of .1 to 1 second. As displays require the operator to maintain information over periods greater than this, the operator's ability to integrate the information will decline. In the air-traffic control task, a 360 degree turn typically requires about 4 minutes, but the visual display system decays in about 4% of that time. Hence an operator observing such turns will very slowly learn the size of a standard turn. If the turn process is speeded up about 240 times, or the total trajectory is displayed on the scope screen, the operator will not have as much difficulty integrating the visual stimulus and is more likely to learn the perceptual characteristics of the task.

Rule 4. Vary aspects of the task which will vary in the operational situation. In the air-traffic control task, planes can come in at different angles. If the operator is always trained such that one plane is traveling at a zero degree heading, the operator is unlikely to realize the similarity of different intercepts as the angles of the two planes are rotated. For example, the possible intercepts for two planes coming at the headings of 0 and 90 degrees are the same as two planes coming at the angles of 200 and 110 degrees. Hence, if the actual headings are changed and operators are instructed to attend to the actual intercept angle, operators have a better chance of learning a strategy of accomplishing intercepts for given angles independent of the initial rotation of the incoming aircraft.

Rule 5. Maintain active participation minimizing passive observation of the task. A critical distinction between learning declarative knowledge and skill knowledge is that training for declarative knowledge generally requires presenting new information with every informational display. In the standard undergraduate survey course, there is very little direct repetition of the material presented in the course. In contrast, learning to detect even simple letter stimuli may require hundreds of trials of training. If the operator is passively presented displays which he or she is to learn, the marginal return for presenting the display passively after the tenth time is probably very close to zero. In order to actively deal with the stimulus the operator should be required to categorize the stimulus, compare the stimulus, or transform and compare the stimulus. The operator should be frequently tested (e.g., every trial) to verify active participation in the task.

Rule 6. Maintain high motivation throughout the task. In developing a skill it is important to note that the learning rate can be very slow and exhibit apparent asymptotes. If operators lose motivation either because they feel they cannot successfully do the task, or the task is just too boring, practice will either cease or be much more passive. Our research has shown that even after subjects are at asymptote when they attend to the task, substantial additional practice may be necessary to perform the task while under high workload. However, when one is at an apparent asymptote, there is little intrinsic motivation to attempt to do the task any better. For the above reasons, it may be necessary to provide artificial motivation to continue practice at the task. Methods which would be likely to maintain motivation might include: engaging feedback (e.g., in the air-traffic control task, missed intercepts result in crashing aircraft), performance feedback that provides salient cutpoints (e.g., dividing operators into five skill classes based on some continuous measure of performance), and encouraging competition among operators (e.g., it is often beneficial to divide the group into teams to add team competition motivating effects).

Rule 7. Present information in total context if possible as long as such presentation does not result in processing overload. When presenting one component task to the operator, it is often possible to present other components of the task so the operator experiences the to-be-trained component within the context of other components.

Rule 8. Train under mild speed stress. Mild speed stress encourages the operators to develop more efficient automatic processes. In addition, faster operator processing results in more training trials per session.

Rule 9. Train strategies which minimize operator workload. In many skilled tasks there are a number of strategies that may result in equal performance accuracy but lead to differential operator workload. For example, in driving an automobile, one can either drive by lining up the hood ornament on the right road stripe, or anticipate the curves and turn the wheel appropriately for the sharpness of the curve. Both may result in approximately equal performance. However, the former strategy may require operator judgment every half a second, while the latter strategy may require an operator judgment only every ten seconds. Hence, the latter strategy requires considerably less operator workload. It is important in training a complex skill to train strategies that minimize operator workload. In fact, it may be necessary to prohibit operators from using easy to learn but high workload strategies for performing a task.

Rule 10. Use tests under high secondary task workload to assess competence and facilitate automatic process development. We have often found that operators will show an early asymptote in performance when they are attending to the task. For example, we found that subjects' performance on a task reached asymptote after the second hour when they were fully attending the task, but continued to improve for six hours when the task was a secondary task. Testing in high workload environments may also encourage the operators to develop low workload strategies.

Rule 11. Provide consistent stimuli for categories of events which have meaning to the operator. The features of the symbols should consistently identify the operational characteristics of that symbol to the operator. For example, in air-traffic control, it would be useful to identify each class of aircraft (e.g., jumbo jet, small jet, private aircraft) with symbols that identify the type of aircraft. Such identification would minimize the need for the operator to maintain performance information about the aircraft in short-term memory. Reducing short-term memory load will reduce the chances for error.

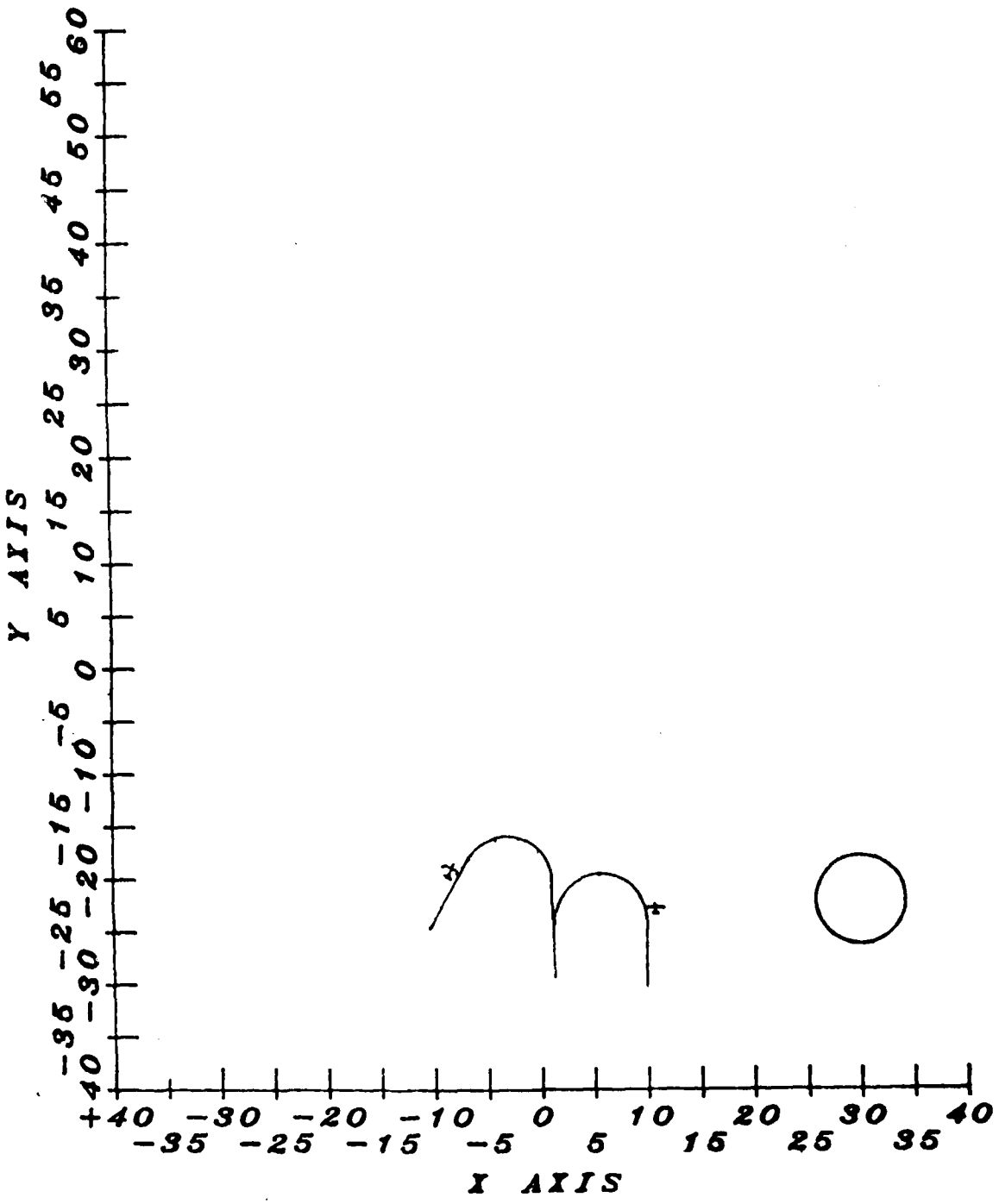


Figure 3. Air traffic control for rendezvous to enable inflight refueling. The lines from the small planes represent the initial positions and headings of the two aircraft. The intercept angle is 30°. The operator must specify the direction of turn and the start of turn of each aircraft plus the final rollout heading. The circle represents the turn radius of the aircraft.

Application of Automatic/Controlled Processing Concepts to Inflight Refueling Air-Traffic Control

The following description serves two purposes. First it provides a concrete interpretation of how automatic and controlled processes might interact in a complex skill. Second, it illustrates the application of the training principles described above to training the task of inflight refueling. Note that this is not yet a specification of how to efficiently train automatic and controlled processing skills. These statements are examples of what we feel should be done. In the coming contract period we will be examining how much the learning efficiency can be improved by applying these principles.

Specification of Inflight Refueling Air-Traffic Control Task

The job of the air-traffic controller, in inflight refueling, is to give turn commands and speed commands to two pilots such that two aircraft will rendezvous heading in a given direction. Figure 3 illustrates a basic rendezvous for inflight refueling. The controller must specify: the turn direction for each aircraft (starboard or port), the time that each aircraft begins its turn, and the final rollout heading of the two aircraft. We will limit our discussions to a slightly more difficult version of the control task in which the operator is allowed only one turn per aircraft and the two aircraft must fly at a fixed speed. We simplify the task slightly by training operators to get the two aircraft to rendezvous at the same point in time as opposed to *rendezvousing one aircraft two nautical miles behind the other as* in the real task (all of the following discussions are essentially equivalent if we consider rendezvous with the delay). Most of the principles discussed in the following presentation relate to other close air-traffic control tasks (landings, takeoffs, intercepts).

Insert Figure 3 about here

Learning to perform a particular standard solution for inflight rendezvous requires a modest amount of training, perhaps two weeks. A standard solution might be a tanker on turn rendezvous where the two aircraft approach at a 180 degree angle at a fixed displacement.

Unfortunately, in operational environments "the standard solution" is often not available. For example, bad weather, other air traffic, aircraft being low on fuel, and the presence of damaged aircraft all may make the "standard solution" unavailable. Major William Derrick (USAF) estimated that he performed approximately two "standard tanker on turn" rendezvous in a year of active duty in Thailand. Most of the other rendezvous could not be performed as the "standard" rendezvous because of various operational constraints.

In operational environments, it is important for the operator to have available many possible solutions for a given problem instead of a single "standard" solution. With multiple solutions available, the operator can choose the particular solution which is best for the given operational constraints. However, training the operator to visualize all the possible solutions can be quite difficult. For a simple 30 degree intercept as illustrated in Figure 3, there are actually 100 possible solutions to the problem (assuming the aircraft

rollout in 10 degree intervals). [To illustrate the difficulty of the task, the reader should examine Figure 3 and find the routes where the two aircraft would first meet if they rendezvous at a 130 degree heading (southeast).] There are three combinations of turns which will result in the two aircraft heading out at the specified angle. Only one of these three solutions is easy to find. It is difficult to intuitively have a feel for where possible solutions might be.

The solution space of the intercept is very complex. It is doubtful that any operator could learn to deal with the full solution space in traditional training programs. Figure 4 illustrates all the possible solutions to the problem specified in Figure 3. There are 100 possible solutions (at 10 degree headings) to the problem for a simple 30 degree intercept. Figure 5 shows the solution space when the two aircraft will not cross each other's path at the same point in time. Note the substantial difference in position of the rendezvous (Figure 4 versus 5) given a rather small change in the displacement of the lower aircraft. The substantial transformation of the solution space caused by small modifications of the intercept illustrates the difficulty of the controller's task.

Training the operator to manipulate the full solution space (e.g., Figure 4) cannot practically be accomplished if the training is done in real time. If an operator were to run all the intercepts represented in Figures 4 & 5 in real time (about 20 minutes/intercept) it would take 35 hours (for 100 intercepts). Since there is no clear relationship between all the solutions, it would be unlikely for an operation to integrate over the 35 hours of training well enough to be able to draw out the total solution spaces as represented in Figures 4 & 5.

Insert Figures 4 & 5 about here

The proposed training program will train operators to perceive and manipulate solution spaces. The operator will be trained to visualize prototypical spaces as illustrated in Figure 4. The operator will then learn to manipulate the prototype to the proper angle and displacement (see below) of the two aircraft.

The goal of the following training program is to teach operators to perceive all the possible solutions to the intercept problem. We want to train operators so they see not a single solution, but rather a set or space of all possible solutions of the problem. If the operator can see this "space" of solutions, the operator can quickly choose among the solutions within the space to get the solution that best fits the appropriate operational conditions.

Assumed Automatic/Controlled Components of ATC Task

Figure 6 provides a flow chart with the basic stages of the air-traffic control task for inflight refueling. We break down the task into four basic stages. The first stage involves identifying the constraints of the problem. The operator must identify the intercept angle of the two aircraft, identify the relative distance of the two aircraft when their paths cross, and identify any other constraints of the solution (e.g., what direction the two aircraft should

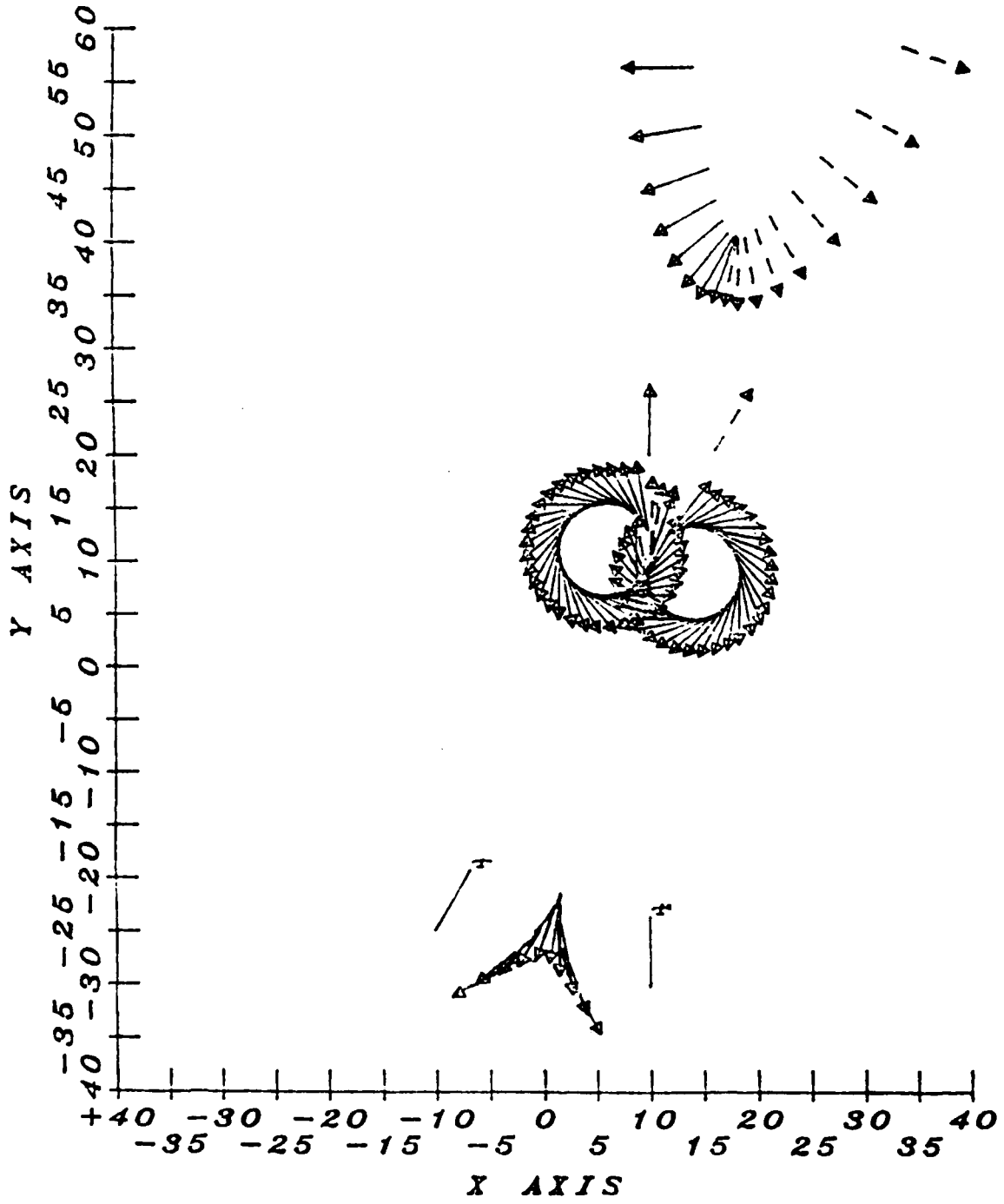


Figure 4. Solution space for a 30 degree intercept where the two aircraft are on a collision course. Each arrow represents a possible rendezvous point beginning at the start of the arrow. This figure represents the solution space assuming both aircraft are traveling at 400 knots and have a turn radius of 4.2 nautical miles. This would be typical of a KC-135.

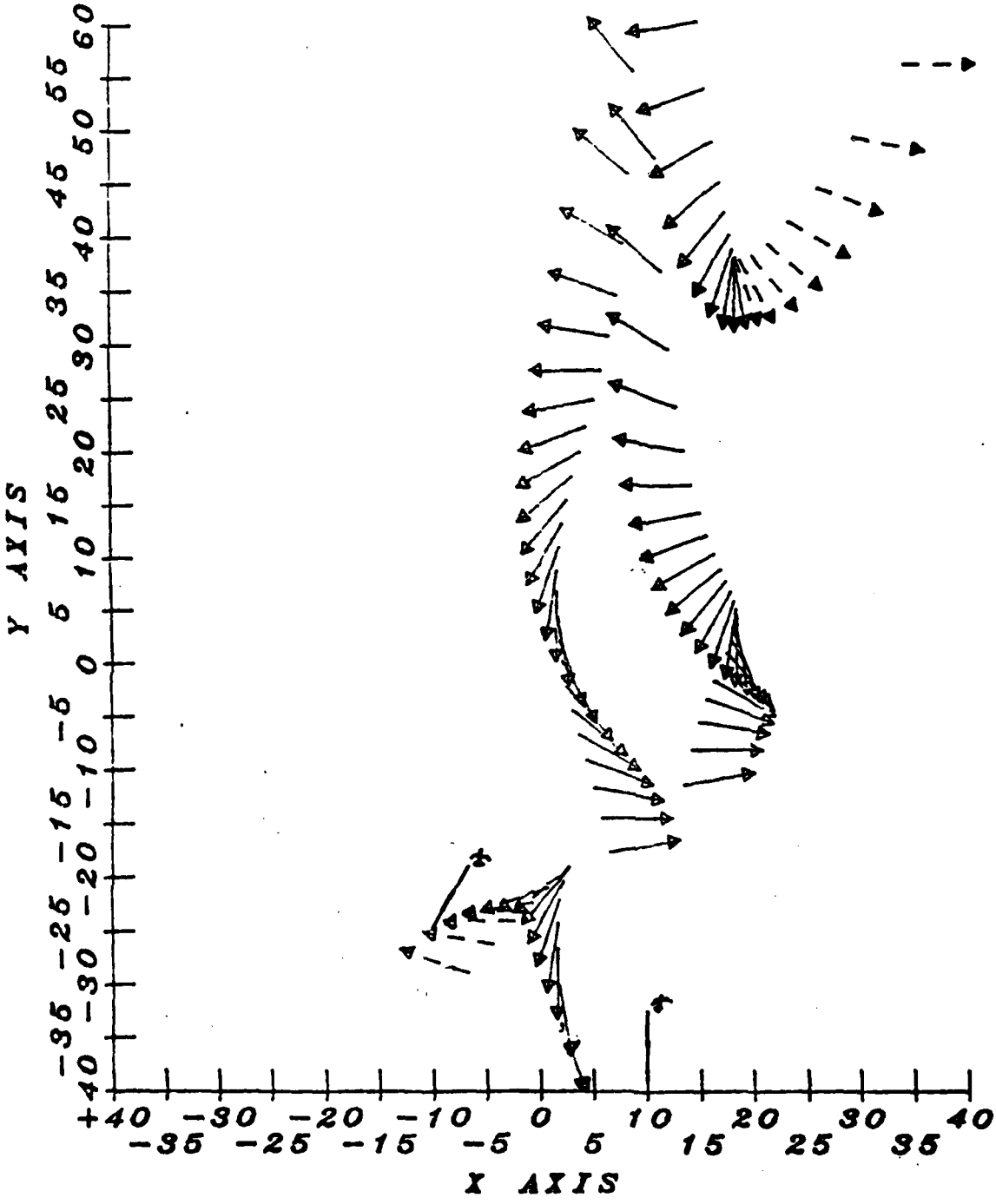


Figure 5. Solution space for a 30 degree intercept with the two aircraft on a non-collision course. This intercept is the same as Figure 4 except the lower aircraft starts from a position 9 nautical miles farther south. Note the large differences between Figures 4 and 5 resulting from a small change in position of the two aircraft.

Table 1
Rendezvous Solution Equations
(assume plane 2 turns onto path of plane 1)

```
T2(1)=(OUTANG - ANGLE(1) * R)/(DIR(1) * V)
T2(2)=(OUTANG - ANGLE(2) * R)/(DIR(2) * V)
T3(2)=0     !strategy assumption

T3(1)= {[V * SIN(ANGLE(2)) * (T2(1) - T2(2)) +
      [X(2) - SIN(ANGLE(2)) * DIR(2) *
      R * (1 - COS(T2(2) * V/R)) +
      SIN(ANGLE(2)) * R * SIN(T2(2) * V/R)] -
      [X(1) - SIN(ANGLE(1)) * DIR(1) *
      R * (1 - COS(T2(1) * V/R)) +
      SIN(ANGLE(1)) * R * SIN(T2(1) * V/R)]] -
      [V * COS(ANGLE(2)) * (T2(1) - T2(2)) +
      [Y(2) - SIN(ANGLE(2)) * DIR(2) *
      R * (1 - COS(T2(2) * V/R)) +
      COS(ANGLE(2)) * R * SIN(T2(2) * V/R)] -
      [Y(1) - SIN(ANGLE(1)) * DIR (1) *
      R * (1 - COS(T2(1) * V/R)) +
      COS(ANGLE(1)) * R * SIN(T2(1) * V/R)]] *
      [V * SIN(ANGLE(1)) - V * SIN(ANGLE(2)) -
      V * COS(ANGLE(1)) - V * COS(ANGLE(2))]} /
      {[V * SIN(ANGLE(1) + DIR(1) * T2(1) * V/R) -
      V * SIN(ANGLE(2))] -
      [V * COS(ANGLE(1) + DIR(1) * T2(1) * V/R) -
      V * COS(ANGLE(2))] *
      [V * SIN(ANGLE(1)) - V * SIN(ANGLE(2)) -
      V * COS(ANGLE(1)) - V * COS(ANGLE(2))]}

T1(1)= {[V * SIN(ANGLE(2)) * (T2(1) - T2(2))] +
      [X(2) - SIN(ANGLE(2)) * DIR(2) *
      R * (1 - COS(T2(2) * V/R)) +
      SIN(ANGLE(2)) * R * SIN(T2(2) * V/R)] -
      [X(1) - SIN(ANGLE(1)) * DIR(1) *
      R * (1 - COS(T2(1) * V/R)) +
      SIN(ANGLE(1)) * R * SIN(T2(1) * V/R)] -
      [V * SIN(ANGLE(1) + DIR(1) * T2(1) * V/R) -
      V * COS(ANGLE(2))] *
      T3(1)} /
      [V * SIN(ANGLE(1)) - V * COS(ANGLE(2))]

T1(2)=T1(1) + T2(1) + T3(1) - T2(2)

Where V = velocity
      R = turn radius
      I = aircraft index 1 or 2
      ANGLE(I) = initial heading of aircraft
      X(I) = initial X position of aircraft
      Y(I) = initial Y position of aircraft
      OUTANG = output angle of potential rendezvous
      DIR(I) = direction of turn -1 port, +1 starboard
      T1(I) = time before turn begins
      T2(I) = time in turn
      T3(I) = time after turn until rendezvous
```

Table 2 Strategies

Strategy	Plane 1	Plane 2	Plane to Intercept
1	Port	Starboard	1
2	Starboard	Port	1
3	Port	Port	1
4	Starboard	Starboard	1
5	Port	Starboard	2
6	Starboard	Port	2
7	Port	Port	2
8	Starboard	Starboard	2

Plane to intercept indicates which plane will rollout of the turn last.

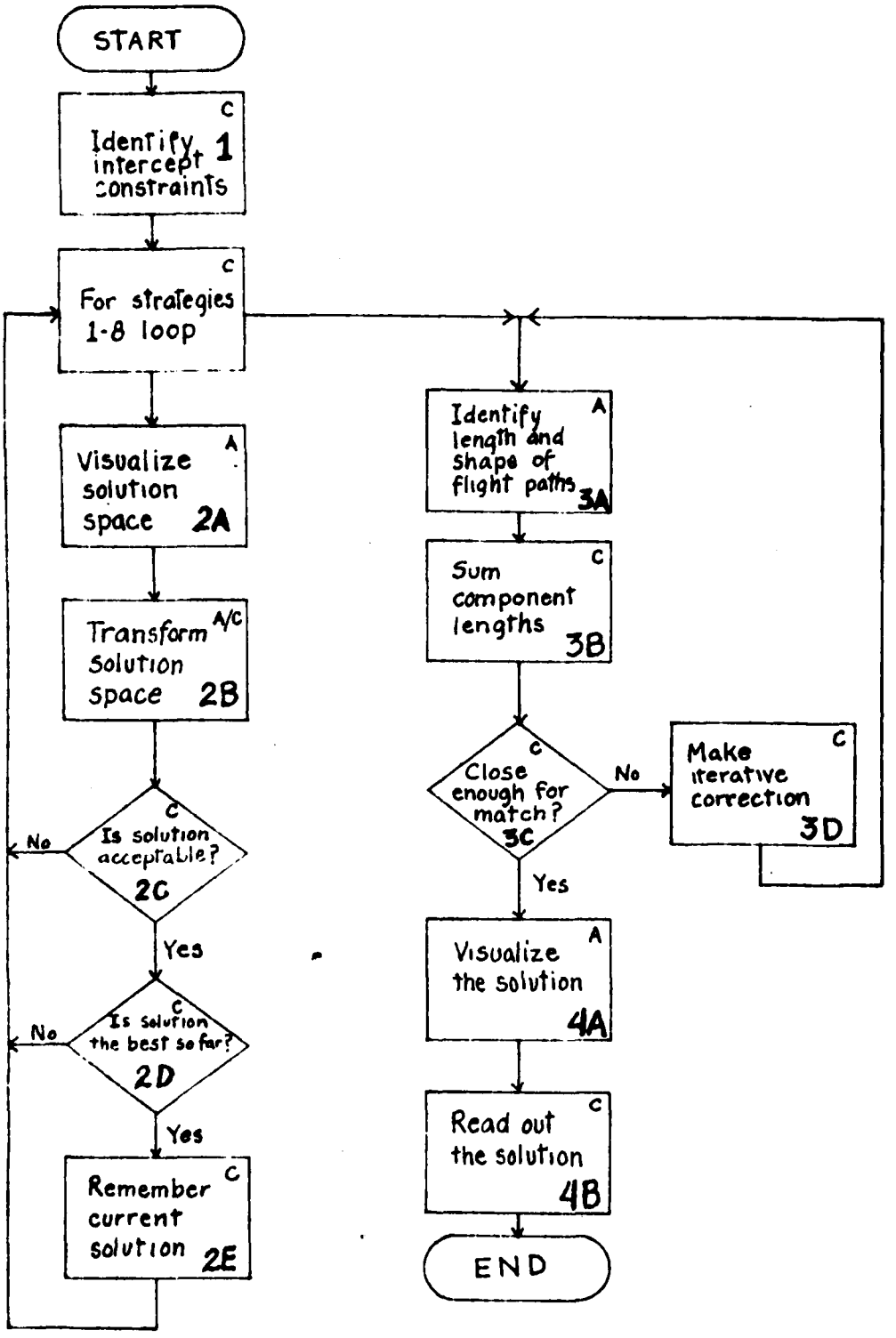


Figure 6. Air intercept flow chart of solution search. The "A" and "C" on the top of each box indicates whether the task component represents primarily an automatic or a controlled process.

be heading at the rendezvous). Identification of the intercept angle of the two aircraft and the temporal displacement should become automatic with practice. However, maintaining this information would require controlled processing resources.

The first component task (step 1) includes automatic identification of intercept angle and temporal displacement, and the controlled process maintenance of that information plus any constraints on the problem. The second task component is identifying acceptable solutions. This is a complex task, identifying any single solution is quite difficult. Table 1 shows the mathematical equations that must be solved to determine whether there is an acceptable solution for any given rollout heading given a specific strategy. In order to examine all possible solutions, the operator would have to solve that series of equations 288 times. This entails extensive calculating. In order for a modestly high speed micro-computer (LSI 11/23) to solve these equations it takes approximately 20 seconds. A human operator cannot solve these equations in real time. However, we believe the operator can solve these problems by visualizing potential solution spaces. There are eight potential strategies for solving our air-traffic control task. Table 2 lists the potential strategies. We assume that the operator visualizes a set of solutions for each strategy (Step 2A, see below). This visualization includes the automatic identification of the solution space for the standard intercept (e.g., 90 degrees). This solution is then transformed through controlled processing to the needs of the current intercept angle and the temporal displacement (Step ?B). At this point we assume the operator has a mental image for all of the solutions for that strategy given the specifics of the problem. We then assume that the operator identifies any solutions which are acceptable given current operational constraints (e.g., the requirement of a specific rollout heading) (Step 2C). The operator then assesses whether the current solution is better than any of the solutions of previously identified strategies (Step 2D). If this solution is the best solution so far, the operator stores this solution in short term memory (see Step 2E). This sequence of visualization and comparison will continue until all eight strategies have been examined.

Insert Figure 6 and Tables 1 & 2 about here

The third component task is verifying the solution. At the end of stage 2 the operator has a particular solution that appears to be the best given the current operational constraints. [In essence, the operator knows the approximate location of the solution.] However, in order to properly execute the maneuver, the operator may need to more accurately locate the point of rendezvous and the beginning of the turns of the two aircraft. Once the location is accomplished we assume that the operator then projects backwards from the rendezvous to the initial starting points of the two aircraft. We assume that the estimation of the total distance would be primarily an automatic identification of the length of each of the components of the turn (Step 3A). The distances for each aircraft would be added as a controlled process (Step 3B). Thereafter the two distances would be compared to see if they were within the acceptable tolerance for the rendezvous (Step 3C). If the lengths were not within range, the operator would attempt to iterate in the region around the solution to determine a solution that does fall within range (Step 3D).

The fourth component task amounts to executing the solution. We assume that once the operator has identified the point of intercept and the most appropriate solution strategy, he can automatically visualize (Step 4a) the path the aircraft will take from its initial starting point to the point of rendezvous. From this visualization we assume that the operator can read off (Step 4b) the point of the start of the turn, the direction of turn, and the final rollout heading of the aircraft. The operator can then communicate this information to the pilot, resulting in the execution of that rendezvous.

Proposed Air-Traffic Control Training Program

The following description is a specification of a training program that will develop automatic component skills for air-traffic control for inflight refueling. The purpose of this training program is to train operators to deal with solution spaces for the intercept problem such that they can quickly pick the best solution within the given operational constraints. This specification illustrates how the application of the above rules can generate a novel training program to develop complex skills. It also provides an illustration of how a training program using a microprocessor based trainer could incorporate the first ten training guidelines presented above. The training times specified for each stage are, at this point, only speculative. We will be carrying out this training program to assess the actual training time and performance criterion that result from such a training program.

The guiding principle of this program is to build automatic component skills such that performance is fast, accurate, and resistive to stress. Developing an automatic skill level requires many practice trials (e.g., 1000) at accurately performing the task. To maximize learning rate we minimize the problems of memory decay through speeding up of the displays and by doing part task training such that we do not overload the subject. The operator is presented many consistent, mildly speed stressed executions of the problem. The problem is represented in such a way that the operator can perceive the consistency from one problem to the next (see Stage 6). The task difficulty is increased adaptively so that the operator can maintain accurate performance throughout most of the training. In order to have many motivated trials of training, the task presentation is speeded up, feedback is made interesting, and performance is graded to encourage competition. Operators are exposed to the total context of the final task performance in order to facilitate integration of the component skills. After the skills have become fairly automatic, performance is tested to determine the reliability of the component skills under high secondary task stress.

Stage 1 -- Identifying rollout heading. The goal of this stage is to train the operator to quickly and accurately identify the heading of the aircraft. The operator is presented an aircraft with a pointer indicating its direction of flight (see Figure 7-1). The operator must specify whether the heading is at a greater or lesser degree heading than specified. The actual presented angle is + or - 4, 6, or 8 degrees. Both end of trial and end of block feedback is presented. The rating categories are set so that the operator perceives him or herself as always being near one of the cutoff points. The break points are ace - 90-100% correct, expert - 80-89%, good - 70-79%, fair - 60-69%, and poor - less than 59% correct. The rating category feedback is presented throughout all stages of the training. The plane moves in the specified direction with

Figure 7 Stages of Training

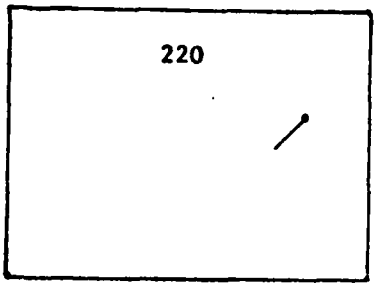
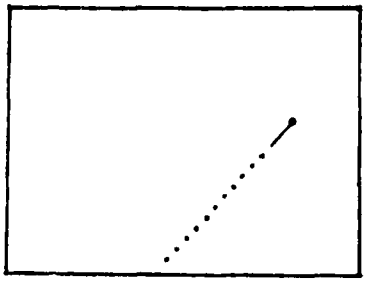
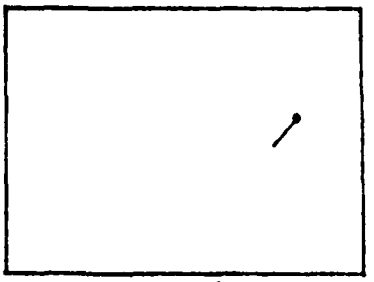
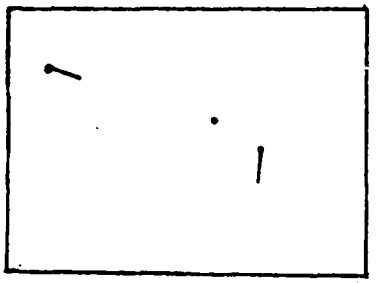
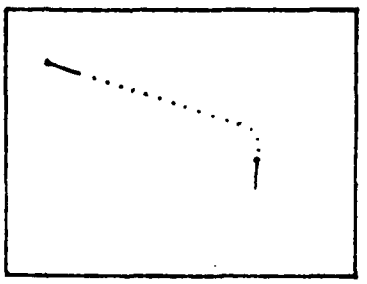
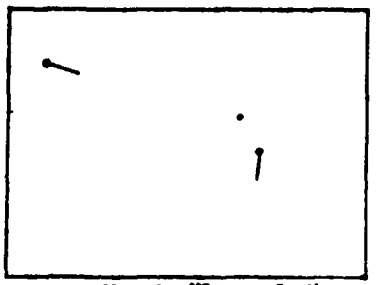
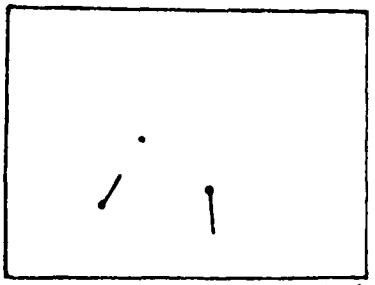
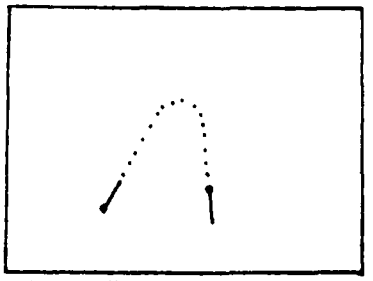
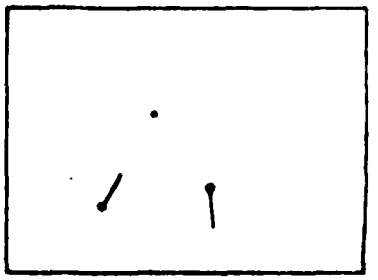
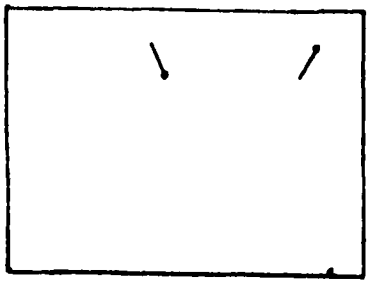
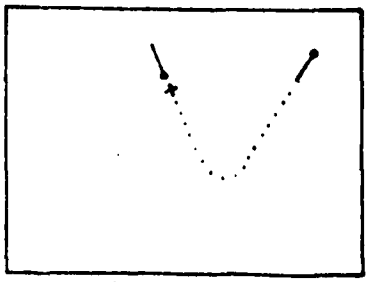
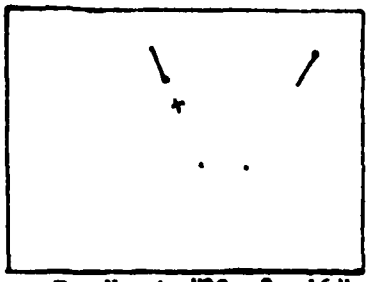
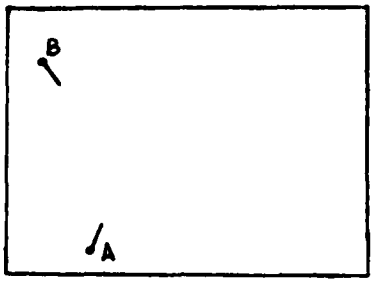
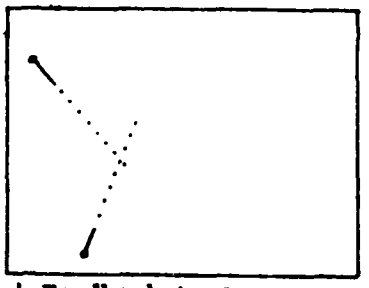
Test	Correct Feedback	Error Feedback
1. Rollout heading		
		
Enter angle too far/ near	+ Feedback tone sweep "3 correct"	- Feedback voice "220 2 wrong"
2. Rollout heading on start of turn		
		
Enter turn start early/ late	+ Feedback tone sweep	- Feedback "3 early"
3. Identify start of turn when heading vector off turn		
		
Enter turn start early/ late	+ Feedback tone sweep "22 miles"	- Feedback " 4 early"
4. Length estimation		
		
Enter length in miles	+ Feedback tone sweep "44 miles"	- Feedback "20, 8, 16"

Figure 7 Stages of Training (continued)

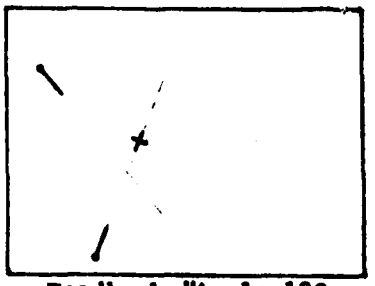
5. Intercept angle and displacement



Enter angle & displacement

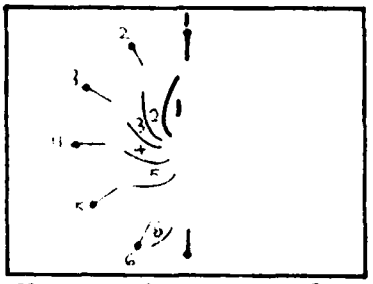


+ Feedback tone sweep

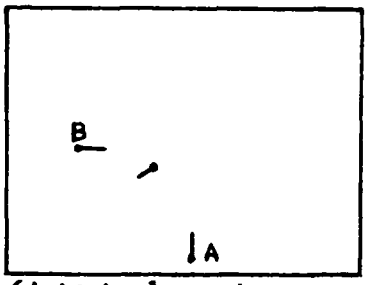


- Feedback "Angle 120, Displacement +6"

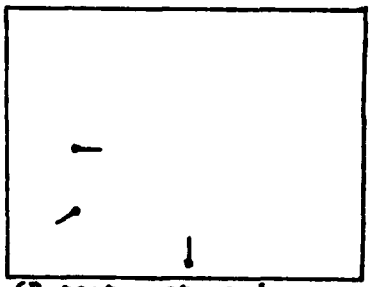
6. Solution space changing angle



Observe changing angle

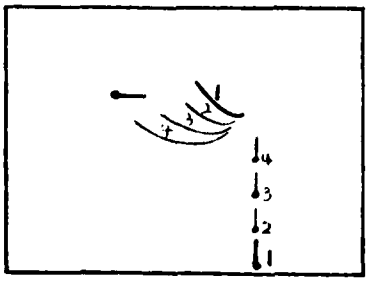


6A test plane at rendezvous

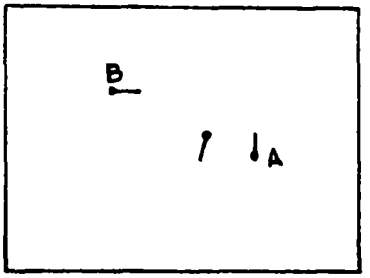


6B test past rendezvous

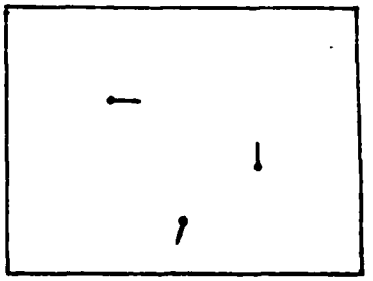
7. Solution space changing displacement



Observe changing displacement

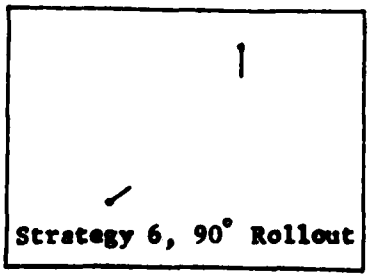


7A test at rendezvous

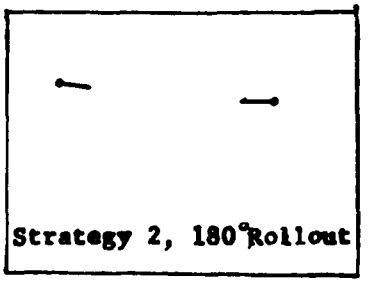


7B test past rendezvous

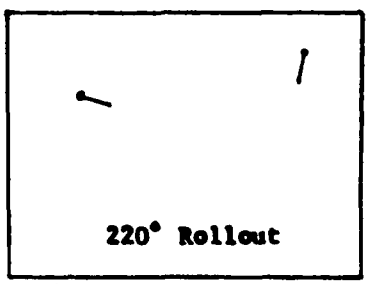
8. Running complete intercepts (note D and E not shown)



A indicate start of turns



B determine intercept location & indicate start of turn



C determine strategy, intercept location & specify turn

interesting sound effects representative of a flying aircraft. On an error, an airplane indicator is presented showing the true heading as well as the test heading and a computer voice speaks the proper heading. In addition, subjects receive computer voice prompts after a run of errors (e.g., "two wrong - try harder") or corrects (e.g., "excellent - ten correct"). The second type of feedback is cumulative accuracy feedback at the end of a block of trials. On the basis of the accuracy data the standard deviation of the operator's representation of the angle will be estimated (by assuming the angle distribution is normally distributed and fitting the accuracy data). When the operator's standard deviation of the internal representation has a standard deviation of 4 degrees or less, he/she will move on to the next stage. A single trial will require about 3 seconds. The estimated training time will be 1,080 trials or approximately 1 hour of training.

Insert Figure 7 about here

This part of the training program illustrates observation of training rules two through seven. The task allows many trials of performing the critical heading component skill (Rule 2, i.e., 1080 trials in one hour). The task does not overload temporary memory and minimizes memory decay (Rule 3). The stimuli are always present on the screen as the operator makes his heading judgment. The aspects of the task which vary in the operational situation are varied during the training program (Rule 4). Each time the aircraft is presented on the screen it is at a different angle and different location. The operator is required to be an active observer (Rule 5) by requiring him to judge the heading on each trial. Motivation is maintained (Rule 6) by providing both interesting trial performance feedback and competition inducing accuracy feedback. Finally, the operator is trained under mild speed stress (Rule 7). Rule 8 requires training of strategies which will result in minimizing operator workload in the final task. In training the heading identification skill, the operators will not be allowed to consult heading indicators around the face of the scope. By developing an automatic component heading skill which does not require reference to an external indicator, this component task will show less work load in the more complex performance stages.

Stage 2 -- Identifying start of turn when the indicated heading is on the turn. The goal of this stage is to get the operator to automatically identify the start of the turn as well as the rollout heading on the turn. This task is illustrated in Figure 7-2. The operator is given the initial and final vectors of the aircraft and the direction of turn. The final vector of the aircraft is always on the turn of the aircraft. A dot will be presented along the starting trajectory of the aircraft. The dot will be either slightly before or beyond the point where the turn should begin (e.g., + or - three nautical miles). The operator will push a button indicating whether the specified turn location is too late or too early. On a correct response the start of the turn point will be indicated and the aircraft will fly the specified pattern at about 200 times normal speed (typically .5 seconds). On an error in specifying the start of turn, the correct start of turn will be indicated but the aircraft will not fly the pattern. When an error occurs the operator will hear an error tone. The performance criterion for moving to the next stage will be when the standard deviation of the operator's start of turn is less than 3 nautical miles with 2

seconds or less mean reaction time. The estimated training time is 600 trials or about 1 hour. This stage illustrates Rules 2-8.

Stage 3 -- Identifying start of turn when heading vector off turn. Figure 7-3 shows this task. The task is basically equivalent to that of Stage 2, except now the final vector of the aircraft is not on the turn but displayed in a position it would be after it has rolled out of the turn. An additional component will be added to the performance feedback. On correct trials the operator will hear the distance in miles of the specified trajectory. The estimated training time to a criterion is 1,000 trials or 2 hours.

Stage 4 -- Line length estimation. The goal of this stage is to train the operator to properly estimate the distances that an aircraft will travel between two points during the execution of a turn. Figure 7-4 illustrates the task. The distance between the starting and ending position has three components. There is a straight vector from the initial position of the aircraft to the start of turn. There is a distance during the turn. And there is the distance from the end of the turn to the final position of the aircraft. The operator will be presented with the starting point of the aircraft and the ending point of the aircraft. The operator must estimate the total distance from the start until the end of the turn. A response will be considered correct when the total distance is within 5% of the actual distance. On a correct trial the plane will fly the specified pattern and the operator will be given the total distance verbally. On an error, the operator will be verbally presented the three component distances with each component highlighted. The operator must correctly add the three distances and enter the result. This illustrates the observation of Rules 2-9. The estimated training time is 1,000 trials or 2 hours.

Stage 5 -- Estimating intercept angle and distance displacement. The possible set of solutions for any intercept task is defined by the angle of the intercept and the displacement of the two aircraft. Figure 7-5 illustrates the basic task. The intercept angle is the relative angle between the two aircraft. The displacement is found by projecting the paths of the two aircraft assuming no turn. The displacement is determined by the distance of each aircraft relative to the point of intercept of the two aircraft trajectories. To illustrate, assume you have two aircraft A and B. At the point that aircraft B crosses the path of aircraft A, aircraft A is 10 nautical miles beyond the point of path intersection. Hence, the displacement for aircraft A would be plus 10 nautical miles. Being able to estimate these two parameters of an intercept is critical for identifying the solution space (see Stages 6 and 7). The operator's task is presented in Figure 7-5. After being presented the two aircraft, the operator must specify the intercept angle and the displacement of the two aircraft. The trial will be considered correct if the intercept angle was specified correctly (within 10 degrees), and the temporal displacement was specified within 5%. On correct trials, the two aircraft will fly the specified trajectories at 200 times the real speed (about .5 second). On incorrect trials the specified intercept will be displayed dimly. The correct angle and displacement will be highlighted on the screen with spoken correct answers. The operator will have to enter the angle and displacement if these were in error. The performance criterion will be 90% accuracy with 3 second or less responses. This stage illustrates Training Rules 2-8. Training time is expected to be 600 trials or 2 hours.

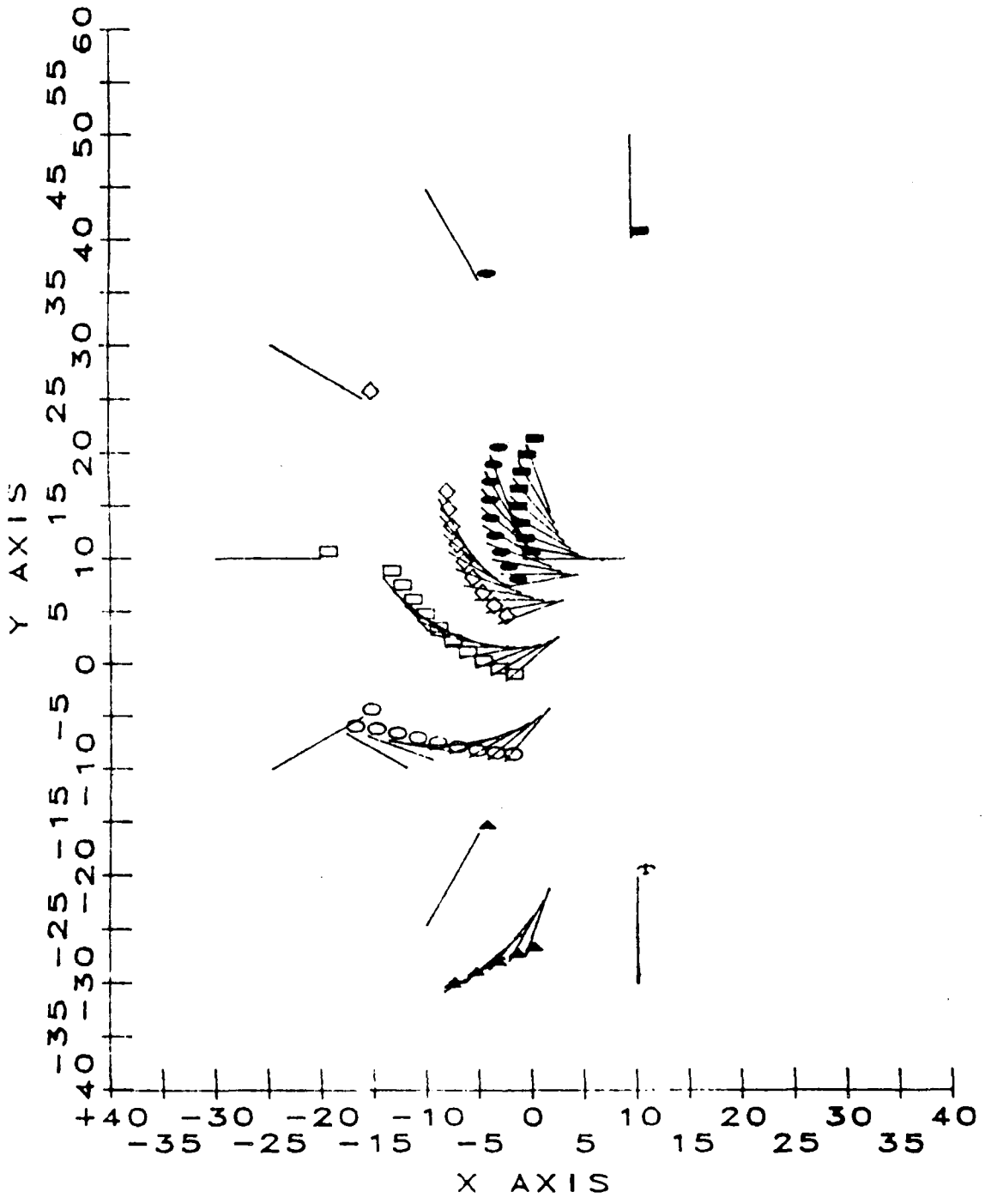


Figure 8. This figure shows the changes in the Strategy 6 solution space as a function of changing intercept angles. One plane is always heading 0 degrees. The second is shown coming at angles from 30 to 180 degrees. The intercept angles are 30, 60, 90, 120, and 180 degrees for filled triangles, open elipses, open rectangles, open diamonds, filled elipses, and filled rectangles, respectively. The series of lines represent the intercept points and rollout headings for each intercept angle. Operators see the angles change dynamically so they can visualize how the intercept solution space varies as a function of intercept angle.

Stage 6 -- Solution space as a function of angle and strategy. The goal of this stage is to teach the operator to visualize the solution space for each strategy at different angles of intercepts. There are eight strategies as illustrated in Table 2. The strategies depend on whether or not each aircraft is turning port or starboard and whether aircraft 1 intercepts aircraft 2 while it is on the turn or vice versa, thus giving a 2 by 2 by 2 set of strategies. Figure 8 illustrates the solution space for Strategy 6 (Starboard turn aircraft B, port turn aircraft A, aircraft A intercepts aircraft B while aircraft B is still in the turn). As the angle of intercept changes from 30 to 180 degrees, a set of solutions moves from the lower center corner toward the center left of the display. Presented on a dynamic computer display, the operator can observe how the space is deformed when moving from one angle to another.

Insert Figure 8 about here

The human ability to perform spatial operations on complex displays is both fast and quite accurate. For example, Cooper (1975) showed that subjects could accurately rotate 21 point polygons through 50 degrees in a tenth of a second in order to compare complex shapes. She also found that there was little change in rotation speed as the complexity of the shapes increased. Results suggest that humans are capable of performing spatial rotations of complex figures in 3 dimensions at rapid rates. The purpose of the present training stage is to develop such complex spatial transformation capabilities for rendezvous solution spaces.

The operator will be trained to deform the solution space for each strategy in order to determine whether a particular point appears on that solution space. The training is done for each of the strategies individually. This is because the transformations of the individual strategy solution spaces are well behaved, whereas the eight combined spaces are not. In this context, a well behaved transformation implies that a single simple rule defines how the space is transformed as the angle changes. For example, in Figure 8 the transformation is a movement of the solution space towards the center and towards the left. Since different strategies operate under different transformation rules, it would be more difficult to have an operator transform the total space of eight solution strategies as the angle changes. For this reason the operator is trained to transform the solution space for each individual strategy.

Figure 7-6 illustrates the basic task. The operator is presented the two aircraft and the solution space for all the possible intercepts for one of the strategies. One of the aircraft then rotates maintaining a fixed distance of intercept. As the aircraft rotates the solution space is updated for each possible angle of intercept. The operator will observe the spatial rotation through a 360 degree range during a 6 second period. Thereafter the operator will be presented a series of 10 test intercept points (7-6A). A displacement test intercept will present the two starting positions of the aircraft and a potential final rendezvous point, with the correct heading, that could be either too early or too late. The operator must quickly decide whether the test position is too far or near. In a similar manner the angle test intercept will present the intercept at the proper point but the angle will be either too small or too large. After the operator has become accurate at detecting rendezvous

which are presented directly on the solution space, rendezvous which are some distance away from the solution space will also be tested (7-6B). For this test, the operator is expected to identify whether the two aircraft could have rendezvoused and maintained heading up to the specified point on the display.

The performance feedback on correct responses will include displaying the solution space, and having the two aircraft perform the appropriate rendezvous in fast time (e.g., 1 second). On error trials the solution space and test point will be presented. The estimated training time is 1600 trials or 200 trials per strategy. This would require about 6 hours.

This stage illustrates Rule 1 by consistently presenting the solution space to the operator. For any particular intercept angle there are many possible solutions to the problem. For example, in Figure 8 there are ten possible solutions to the 90 degree intercept problem for a strategy 6 intercept. When the problem is represented at the level of the solution space, each time the 90 degree intercept appears the same set of ten potential rendezvous points are available. By consistently presenting the full set of ten possible solutions, the operator is expected to develop a template for this particular strategy of solution. Because the strategy is presented consistently, the operator should gain an ability to automatically generate that template. Note the strong contrast between training solution spaces by presenting them to the operator relative to the traditional method of presenting the operator individual solutions (particular rendezvous). The 30 degree intercept problem has 100 potential solutions (see Figure 4). It is unlikely that an operator presented the individual solutions would be able to identify the consistency of the solution spaces for each of the strategies. Due to memory decay problems the operator could not integrate over 100 individually presented solutions. By training the operator to explicitly identify solution spaces. It is believed that this critical component skill can become automatic. By testing the operator's ability to manipulate his space, we can require the operator to examine the total solution space about 200 times per strategy in a 6 hour training period. If we were to present the same information by examining individual solutions, this training phase would require 72 hours of training at high speed presentations and 4600 hours at real time training speeds. Training the operator to deal with solution spaces presents the information consistently at the level at which the operator must deal with the information, condenses a great deal of information into each display, and trains the operator at performing the critical component task of identifying the possible location of the solution.

Stage 7 -- Identifying solution space as a function of changing spatial displacement. The goal of this stage is similar to stage 6 except that the temporal displacement of the intercept is changed, rather than changing the angle of the intercept. Figure 7-7 shows the basic task. One of the aircraft now moves forward and backward along its trajectory. As the displacement of the two aircraft change, the solution space for a given strategy is deformed. The training in this stage is equivalent to that of Stage 6. Initial training will test operators with a prototypical (90 degree) intercept. After initial training each trial will present a different angle of intercept and a range of displacements. The estimated training time is 2100 trials or about 8 hours.

Stage 8 -- Running complete intercepts. The purpose of this stage is to perform complete intercepts on a task given appropriate constraints. In this task the operator is presented the two aircraft and required to carry out the intercept (see Figure 7-8). There are three constraints the operator must consider for specific rendezvous tests. These are the heading, location of the rendezvous, and strategy (i.e., direction of turn of the two aircraft and which intercepts the other). In Test A the operator would be given the rollout heading, the strategy, the location of the intercept and be required to indicate the start of the turn of each aircraft. In Test B the operator would be given the strategy and the rollout angle and be required to determine the location of the intercept and specify the start of the turn. In Test C the operator would be given the angle and be required to specify the strategy, the location of the rendezvous, and the start of the turn of the two aircraft. In Test D the operator would be given the final location of the rendezvous and be required to specify the stratey, the rollout angle and the location of the start of the turns. In Test E the operator would be given the final location and the strategy and be required to specify the angle and the start of turns of the two aircraft. On half the trials (Tests A - E) the operator will be given component feedback indicating their accuracy on each component of the task. If for example the operator enters the wrong rollout heading, the computer will provide the operator feedback indicating the correct heading before the operator moves to the stage of specifying the start of the turns. On the other half of the trials, feedback will be presented only after the total rendezvous has been specified. On correct trials the strategy solution space will be dimly lit and the two aircraft will run the appropriate rendezvous. On incorrect trials the proper solution will be presented and the operator must specify the parameters of that solution. This training stage illustrates Rules 1-9. The criterion for moving to the next stage would be a 95% accuracy of specifying the appropriate intercepts.

Stage 9 -- Testing under high secondary task load. The goal of this stage is to test whether the component tasks can be performed under high secondary task load. This is to assess whether performance has become automatic enough to be presumed reliable in an operational environment. The task is the same as Stage 8B except the operator performs a secondary task. The operator will be required to perform a digit cancelling task at the same time as executing the rendezvous. The operator will hear a series of digits presented over the headset. The operator will be required to verbalize the digit that was presented two digits back. For example the operator will hear the sequence of 8, 5, 3, 9, 2. When the operator hears the digit 3 he would respond 8, after hearing the digit 9 he would respond 5, after hearing the digit 2 respond 3, in each case responding with the digit which is two digits back. Testing will be alternated between trials with and without the concurrent digit cancelling task. The accuracy criterion will be that performance will decrement no more than 10% with the concurrent digit cancelling task. The estimated training time would be 900 trials at 16 seconds a trial or 6 hours.

This task illustrates Rule 10 in the use of secondary tasks to assess performance competence. When the operator is trained to perform well even under high secondary task load, his or her efficiency in a field environment is likely to be much higher. In contrast to the teaching environment, the field environment typically puts the operator under very high work load. This stage is intended to train the operator to perform the task with substantially reduced

resources available for the task.

Stage 10 -- Transfer to the real time rendezvous task. The purpose of this stage is to transfer the operator to performing the task at real time speed. All of the training up to this point typically presented the task to the operator at least 60 times real time speed. What the operator observed happening in 1 second typically required 1 minute in the operational environment. In Stages 1 - 9 this speed up presentation had the advantages of presenting many more trials, minimizing memory decay, and maintaining operator motivation. However, it is necessary to move to the real environment in which things happen relatively very slowly. The task here is the same as in Stage 8B except for the slowing. The operator will perform 1 trial at real time and 10 trials at high speed. The expectation is that there will be near perfect transfer from the high speed training to the slow speed task. This is because the operator is trained to perform the task as a spatial task rather than a temporal task. The estimated training time is 20 trials at the slow speed of 600 seconds and 100 trials at the high speed of 12 seconds for a total of 4 hours.

The above ten stage training program illustrates how one might use microcomputer control trainers to develop automatic component skills to perform a complex control task. It is expected that the above 40 hour training program would substantially enhance controllers' ability in comparison to current traditional training methods. Table 3 illustrates the basic stages of this training program and the number of trials in which the operator will perform the component skills in each stage. In order to make a component skill automatic the operator must experience hundreds and perhaps thousands of trials of practice at each component. Using the above rules and tuning the training program it is quite possible to present the operator thousands of trials of practice at each of the component tasks even during a short training program (e.g., 40 hours). Given that the operator can consistently deal with the task, receives thousands of trials of training, and maintains motivated performance throughout that training, it is expected that the operator will develop substantial automatic component skills to perform the air-traffic control task.

Insert Table 3 about here

It is useful to contrast what the operator would experience under the proposed training method relative to current military training programs. In the current military training programs, the operator is trained basically to perform intercepts in real time situations. The operator could be expected to experience 120 intercepts in a 40 hour period (however in practice the actual number of intercepts per week is far less). The operator would have no experience in performing solution space transformations or at performing the task under particularly high work load. The operator would of course have more experience at slow intercepts in the traditional method relative to the new method (120 versus 20). Because training in real time results in very severe memory decay, presents to the operator relatively few trials, does not present the information consistently, and may not maintain substantial motivation, it is unlikely that the traditional training method could develop automatic component skills. Certainly present methods could not develop such skills in a 40 hour

Table 3

Proposed ATC for Inflight Refueling Training Program

Stage	1	2	3	4	5	6	7	8	9	10	TOT	Current Methods Tot/cur
Hours of training	1	1	2	2	2	6	8	8	6	4	40	40
Skill												
Angle identification	1080	600	1000					2100	900	120	5800	120
Start turn		600	1000	1000				2100	900	120	5720	120
Length Estimation				1000				2100	900	120	5720	120
Intercept angle					600			2100	900	120	3720	120
Distance Displacement					600			2100	900	120	3720	120
Solution space angle transform						1600		2100	900	120	4720	0
Solution space spatial transform							2100	2100	900	120	5420	0
Full intercepts								2100	900	120	3120	120
Dual Task intercepts										20	20	0
Slow intercepts (real time)										20	20	120

TOT - refers to the total number of executions of each component skill using the proposed training method.

Tot/cur - refers to the total number of executions of each component using traditional training methods.

training program. Should operators learn as much per trial in the proposed training program as they do in the traditional training program, the proposed training program would be 26 times more efficient. We do not presently have the data to allow us to estimate what the true efficiency of the two training programs might be. However, the fact that operators learn primarily from consistent correct executions and learn more if there is less memory decay, suggests that operators might actually learn more per trial in the proposed than in the traditional training program.

The proposed training program is still a hypothetical training program operating in a basic research laboratory. The above program illustrates that by carefully training component skills one can expect that automatic performance levels could be achieved in complex real world environments. The observance of the 11 rules of skill development resulted in a novel approach to the training of this task. Theoretical work suggests that substantial performance improvements can be obtained by careful analysis of complex tasks and identification of methods of representing the task. Future research will explore the effectiveness of the training rules for speeding perceptual learning of the complex air-traffic control task. We feel the rules may speed development of skills in a wide variety of tasks (e.g., reading, typing, aircraft control).

Technical Reports and Working Papers

I. Technical Reports

8001 Schneider, W., & Fisk, A. D. Independence of foveal retinal locus and visual detection paradigm.

8002 Schneider, W., & Fisk, A. D. Dual task automatic and controlled processing in visual search, can it be done without cost?

8003 Eberts, R., & Schneider, W. The automatic and controlled processing of temporal and spatial patterns.

8004 Schneider, W., & Fisk, A. D. Visual search improves with detection searches, declines with nondetection search.

8005 Schneider, W., & Fisk, A. D. Degree of consistent training and the development of automatic processing.

8006 Fisk, A. D., & Schneider, W. Controlled and automatic processing during tasks requiring sustained attention: A new approach to vigilance.

8007 Fisk, A. D., & Schneider, W. On the learning of distractors during controlled and automatic processing.

8008 Schneider, W., & Eberts, R. Automatic processing and the unitization of two features.

8101 Schneider, W. Automatic/control processing concepts and their implications for the training of skills.

8102 Ackerman, P. L., Schneider, W., & Wickens, C. D. Individual differences and time-sharing ability: A critical review and analysis.

8103 Fisk, A. D., & Schneider, W. Category and word search: Generalizing search principles to complex processing.

8104 Schneider, W., Dumais, S. T., & Shiffrin, R. M. Automatic/control processing and attention.

8105 Fisk, A. D., Derrick, W. L., & Schneider, W. The use of dual task paradigms in memory research: A methodological assessment and an evaluation of effort as a measure of levels of processing.

8106 Fisk, A. D., & Schneider, W. Task versus component consistency in the development of automatic processes: Consistent attending versus consistent responding.

II. Working Papers

8009 Schneider, W., & Fisk, A. D. Context dependent automatic processing.

8010 Schneider, W., & Fisk, A. D. On the concept of consistency for development of automatic processing: Consistent attending versus consistent responding.

8011 Schneider, W., Fisk, A. D., & Coleman, W. On the relationship between processing time and development of automatic processing.

80-1 Schneider, W., & Fisk, A. D. Single versus multiple frame training and the development of automatic processing in visual search.

80-2 Schneider, W., & Fisk, A. D. Distribution of consistent training: Is it an important factor for rate of automatic processing development.

80-3 Fisk, A. D., Derrick, W., & Schneider, W. Mental effort, task appropriate controlled processing, and the adequacy of processing resources as an index of levels of processing.

80-4 Schneider, W., & Eberts, R. Consistency at multiple levels in sequential motor output processing.

References

Colle, H. A., & DeMaio, J. Measurement of attentional capacity load using dual-task performance of operating curves. Interim report AFHRL-TR-78-5, Air Force Systems Command, Brooks AFB, Texas, April 1978.

Cooper, L. A. Mental rotation of random two-dimensional shapes. Cognitive Psychology, 1975, 7, 20-43.

Eberts, R. & Schneider, W. Computer assisted displays enabling internalization and reduction of operator workload in higher order systems, or, pushing the barrier of human control beyond second order systems. Proceedings of the Human Factors Society, 1980, 59-62.

Fisk, A. D., & Schneider, W. Control and automatic processing during tasks requiring sustained attention: A new approach to vigilance. Human Factors, 1981, 23, 737-750.

James, W. Principles of psychology (Vol. 1). New York: Holt, 1890.

Hasher, L., & Zacks, R. T. Automatized and effortful processes in memory. Journal of Experimental Psychology: General, 1979, 108, 356-388.

Horne, J. L., & Cattell, R. B. Refinement and test of the general theory of fluid and crystallized general intelligences. Journal of Educational Psychology, 1966, 57, 253-270.

Hunt, E. A computational theory of thought applied to traditional problems. In M. Lansman & E. Hunt (Eds.), Proceedings of the Lake Wilderness Attention Conference (Tech. Rep. 10). Seattle: University of Washington, Department of Psychology, July 1981.

LaBerge, D. Attention and the measurement of perceptual learning. Memory and Cognition, 1973, 1, 268-276.

LaBerge, D. Perceptual learning and attention. In W. K. Estes (Ed.), Handbook of learning and cognitive processes (Vol. 4). Hillsdale, NJ: Erlbaum, 1976.

LaBerge, D., & Samuels, S. J. Toward a theory of automatic information processing in reading. Cognitive Psychology, 1974, 6, 293-323.

Logan, G. D. Attention in character-classification tasks: Evidence for the automaticity of component stages. Journal of Experimental Psychology: General, 1978, 107, 32-63.

Logan, G. D. On the use of a concurrent memory load to measure attention and automaticity. Journal of Experimental Psychology: Human Perception and Performance, 1979, 5, 189-207.

Maccoby, N., Michael, D. N., & Levine, S. Further studies of student participation procedures in film instruction: Review and preview, covert practice and motivational interactions. In A. A. Lumsdaine (Ed.), Student response in programmed instruction. Washington, D.C.: National Academy of

Science - National Research Council, 1961.

Margolius, G. J., & Sheffield, F. D. Optimum methods of combining practice with filmed demonstrations in teaching complex response sequences: Serial learning of a mechanical-assembly task. In A. A. Lumsdaine (Ed.), Student response in programmed instruction. Washington, D.C.: National Academy of Science - National Research Council, 1961.

Michael, D. N., & Maccoby, N. Factors influencing the effects of student participation in verbal learning from films: Motivating versus practice effects, "feedback", and overt versus covert responding. In A. A. Lumsdaine (Ed.), Student response in programmed instruction. Washington, D.C.: National Academy of Science - National Research Council, 1961.

Norman, D. A. Categorization of action slips. Psychological Review, 1981, 88, 1-15.

Posner, M. I., & Snyder, C. R. R. Attention and cognitive control. In R. L. Solso (Ed.), Information processing and cognition: The Loyola Symposium. Hillsdale, NJ: Erlbaum, 1975.

Reed, H. B. Part and whole methods of learning. Journal of Educational Psychology, 1924, 15 107-115. (a)

Reed, H. B. Part and whole methods of learning. Journal of Educational Psychology, 1924, 15 389-393. (b)

Schneider, W. Dumais, S. T., & Shiffrin, R. M. Automatic and control processing and attention. In R. Parasuraman, R. Davis, & J. Beathy (Eds.), Varieties of attention. New York: Academic Press, in press.

Schneider, W., & Fisk, A. D. Degree of consistent training. Improvements in search performance and automatic process development. Perception & Psychophysics, 1982, 31, 160-168.

Schneider, W., & Fisk, A. D. Attention theory and mechanisms for skilled performance. In R. A. Magill (Ed.), Memory and control of motor behavior. Amsterdam: North Holland, in press. (a)

Schneider, W., & Fisk, A. D. Concurrent automatic and controlled visual search: Can processing occur without resource cost? Journal of Experimental Psychology: Learning, Memory, and Cognition, in press. (b)

Schneider, W., & Shiffrin, R. M. Controlled and automatic human information processing: I. Detection, search, and attention. Psychological Review, 1977, 84, 1-66.

Sheffield, F. D. Theoretical considerations in the learning of complex sequential tasks from demonstration and practice. In A. A. Lumsdaine (Ed.), Student response in programmed instruction. Washington, D.C.: National Academy of Science - National Research Council, 1961.

Shiffrin, R. M., Dumais, S. T., & Schneider, W. Characteristics of automation. In J. B. Long & A. D. Baddeley (Eds.), Attention and performance IX. Hillsdale, NJ: Erlbaum, 1981.

Shiffrin, R. M., & Schneider, W. Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. Psychological Review, 1977, 84, 127-190.

Treisman, A., & Gelade, G. A feature integration theory of attention. Cognitive Psychology, 1980, 12, 97-136.

Welford, A. T. Skilled performance. Glenview, IL: Scott, Foresman, 1976. (Chapter 5).

Distribution List

Schneider March 1982

E. Aiken, Navy Personnel R&D Center, San Diego, CA
A. Bittner, Naval Biodynamics Laboratoy, New Orleans, Louisiana
R. Blanchard, Navy Personnel R&D Center, San Diego, CA
Chief, Naval Education & Training Liaison Office, Williams AFB, AZ
M. Curran, Office of Naval Research, Code 270, Arlington, VA
P. Federico, Navy Personnel R&D Center, San Diego, CA
J. Ford, Navy Personnel R&D Center, San Diego, CA
S. Harris, MSC, USN, Naval Air Development Center, Warminster, Penn
J. Hollan, Navy Personnel R&D Center, Code 304, San Diego, CA
C. Hutchins, Naval Air Systems Command Hq, Washington, DC
N. Kerr, Chief, Naval Technical Training, Millington, TN 38054
W. Maloy, Naval Training Command, Code 00A, Pensacola, FL
R. Martin, Capt., USN, USS Carl Vinson (CVN-70), Newport News, VA
J. McBride, Navy Personnel R&D Center, San Diego, CA
G. Moeller, Naval Submarine Medical Res. Lab., Groton, CN
W. Montague, Navy Personnel R&D Center, San Diego, CA
T. Yellen, Code 201, Navy Personnel R & D Center, San Diego, CA
Library, Code P201L, Navy Personnel R&D Center, San Diego, CA
Technical Director, Navy Personnel R&D Center, San Diego, CA
Commanding Officer, Naval Research Laboratory, Code 2627, Washington, DC
Psychologist, ONR Branch Office, Boston, MA
Psychologist, ONR Branch Office, Chicago, IL
Office of Naval Research, Code 437, Arlington, VA
Office of Naval Research, Code 441, Arlington, VA
Personnel & Training Research Programs (Code 458), ONR, Arlington, VA
Psychologist, ONR Branch Office, Pasadena, CA
Chief of Naval Operations, Research Development & Studies, Washington, DC
F. Petho, Selection & Training Research Division, Pensacola, FL
G. Poock, Operations Research Dept., Naval Postgraduate School, Monterey, CA
B. Rimland, (03B), Navy Personnel R&D Center, San Diego, CA
A. Rubenstein, Office of Naval Technology, Arlington, VA
W. Scanland, Research, Development, Test & Evaluation, NAS, Pensacola, FL
S. Schiflett, SY 721, US Naval Air Test Center, Patuxent River, MD
R. Smith, Office of Chief of Naval Operations, OP-987H, Washington, DC
A. Smode, TAEG, Dept. of Navy, Orlando, FL
W. Thomson, (Code 7132), Naval Ocean Systems Center, San Diego, CA
R. Weissinger-Baylon, Naval Postgraduate School, Monterey, CA
R. Weitzman, Naval Postgraduate School, Monterey, CA
R. Wherry, Chalfont, PA
R. Wisher, (Code 309), Navy Personnel R&D Center, San Diego, CA
M. Wiskoff, Navy Personnel R&D Center, San Diego, CA
J. Wolfe, Navy Personnel Research & Development Center, San Diego, CA
Technical Director, Army Research Institute, Alexandria, VA
J. Baker, Army Research Institute, Alexandria, VA
B. Farr, Army Research Institute, Alexandria, VA
M. Kaplan, Army Research Institute, Alexandria, VA
M. Katz, Army Research Institute, Alexandria, VA
H. O'Neil, Army Research Institute, Alexandria, VA
R. Sasmor, Army Reseach Institute, Alexandria, VA
J. Ward, U.S. Army Research Institute, Alexandria, VA
U.S. Air Force Office of Scientific Research, Washington, DC
Air University Library, AUL/LSE 76/443, Maxwell AFB, AL
E. Alluisi, HQ, AFHRL (AFSC), Brooks AFB, TX

A. Fregly, AFOSR/NL BLdg. 410, Bolling AFB, Washington, DC
G. Haddad, AFOSR, Bolling AFB, DC
S. Mayer, HQ Electronic Systems Division, Hanscom AFB, Bedford, MA
3700 TCHTW/TTGH Stop 32, Sheppard AFB, TX
H. Greenup, (E031), Education Center, MCDEC, Quantico, VA
Special Assistant for Marine Corps Matters, ONR, Arlington, VA
Chief, Psychological Research Branch, U.S. Coast Guard, Washington, DC
Defense Technical Information Center, Alexandria, VA
Military Asst., Office of Under Secretary of Defense, Washington, DC
DARPA, Arlington, VA
P. Chapin, Linguistics Program, NSF, Washington, DC
S. Chipman, National Institute of Education, Washington, DC
W. McLaurin, Camp Springs, MD
A. Molnar, Science Education Dev. & Research, NSF, Washington, DC
H. Sinaiko, Program Director, Smithsonian Institution, Alexandria, VA
F. Withrow, U.S. Office of Education, Washington, DC
J. Young, Director, Memory & Cognitive Processes, NSF, Washington, DC
J. Anderson, Psychology Dept., Carnegie Mellon Univ., Pittsburgh, PA
J. Annett, Pschology Dept., Univ. of Warwick, Coventry, England
Psychological Research Unit, Dept. of Defense, Canberra, Australia
A. Baddeley, MRC Applied Psychology Unit, Cambridge, England
P. Baggett, Psychology Dept., Univ. of Colorado, Boulder, CO
J. Baron, Psychology Dept., Univ. of Pennsylvania, Philadelphia, PA
A. Barr, Dept. of Computer Science, Stanford Univ., Stanford, CA
J. Beatty, Psychology Dept., Univ. of California, Los Angeles, CA
R. Biersner, Navy Medical R&D Command, Bethesda, MD
I. Bilodeau, Psychology Dept., Tulane Univ., New Orleans, LA
R. Bock, Education Dept., Univ. of Chicago, Chicago, IL
Liaison Scientists, ONR, Branch Office, London, FPO New York
L. Bourne, Psychology Dept., Univ. of Colorado, Boulder, CO
J. Brock, Honeywell Systems & Research Center, Minneapolis, MN
J. Brown, XEROX Palo Alto Research Center, Palo Alto, CA
B. Buchanan, Dept. of Computer Science, Stanford Univ., Stanford, CA
C. Bunderson, WICAT Inc., Orem, UT
P. Carpenter, Psychology Dept., Carnegie-Mellon Univ., Pittsburgh, PA
J. Carroll, Psychometric Lab, Univ. of N. Carolina, Chapel Hill, NC
W. Chase, Psychology Dept., Carnegie-Mellon Univ., Pittsburgh, PA
M. Chi, Learning R&D Center, Univ. of Pittsburgh, Pittsburgh, PA
W. Clancey, Dept. of Computer Science, Stanford Univ., Stanford, CA
A. Collins, Bolt Beranek & Newman, Inc., Cambridge, Ma
L. Cooper, LRDC, Univ. of Pittsburgh, Pittsburgh, PA
M. Crawford, American Psychological Association, Washington, DC
K. Cross, Anacapa Sciences, Inc., Santa Barbara, CA
D. Damos, Arizona State Univ., Tempe, AZ
R. Dillon, Dept. of Guidance, Southern Illinois Univ., Carbondale, IL
E. Donchin, Psychology Dept., Univ. of Illinois, Champaign, IL
W. Dunlap, Psychology Dept., Tulane Univ., New Orleans, LA
J. Eggenberger, National Defence HQ, Ottawa, Canada
ERIC Facility-Acquisitions, Bethesda, MD
R. Ferguson, The American College Testing Program, Iowa City, IA
W. Feurzeig, Bolt Beranek & Newman, Inc., Cambridge, MA
G. Fischer, Liebiggasse 5/3, Vienna, Austria
E. Fleishman, Advanced Research Resources Organ. Washington, DC

J. Frederiksen, Bolt Beranek & Newman, Cambridge, MA
A. Friedman, Psychology Dept., Univ. of Alberta, Edmonton, Alberta, Canada
R. Geiselman, Psychology Dept., Univ. of California, Los Angeles, CA
R. Glaser, LRDC, Univ. of Pittsburgh, Pittsburgh, PA
M. Glock, Cornell Univ., Ithaca, NY
D. Gopher, Technion-Israel Institute of Technology, Haifa, Israel
J. Greeno, LRDC, Univ. of Pittsburgh, Pittsburgh, PA
H. Hawkins, Psychology Dept. Univ. of Oregon, Eugene, OR
B. Hayes-Roth, The Rand Corporation, Santa Monica, CA
F. Hayes-Roth, The Rand Corporation, Santa Monica, CA
J. Hoffman, Psychology Dept., Univ. of Delaware, Newark, DE
G. Greenwald, Ed., "Human Intelligence Newsletter", Birmingham, MI
L. Humphreys, Psychology Dept., Univ. of Illinois, Champaign, IL
E. Hunt, Psychology Dept., Univ. of Washington, Seattle, WA
J. Hunter, Lansing, MI
E. Hutchins, Navy Personnel R&D Center, San Diego, CA
S. Keele, Psychology Dept., Univ. of Oregon, Eugene, OR
W. Kintsch, Psychology Dept., Univ. of Colorado, Boulder, CO
D. Kieras, Psychology Dept., Univ. of Arizona, Tuscon, AZ
S. Kosslyn, Psychology Dept., Harvard Univ., Cambridge, MA
M. Lansman, Psychology Dept., Univ. of Washington, Seattle, WA
J. Larkin, Psychology Dept., Carnegie Mellon Univ, Pittsburgh., PA
A. Lesgold, Learning R&D Center, Univ. of Pittsburgh, Pittsburgh, PA
C. Lewis, Rijksuniversiteit Groningen, Groningen, Netherlands
E. McWilliams, Science Education Dev. and Research, NSF, Washington, DC
M. Miller, TI Computer Science Lab, Plano, TX
A. Munro, Behavioral Technology Laboratories, Redondo Beach, CA
D. Norman, Psychology Dept., Univ. of California - San Diego, La Jolla, CA
Committee on Human Factors, JH 811, Washington, DC
S. Papert, Massachusetts Institute of Technology, Cambridge, MA
J. Paulson, Portland State Univ., Portland, OR
J. Pellegrino, Dept. of Psychology, Univ. of California, Santa Barbara, CA
L. Petrullo, Arlington, VA
M. Polson, Psychology Dept., Univ. of Colorado, Boulder, CO
P. Polson, Psychology Dept., Univ. of Colorado, Boulder, CO
S. Poltrock, Psychology Dept., Univ. of Denver, Denver, CO
M. Posner, Psychology Dept., Univ. of Oregon, Eugene OR
D. Ramsey-Klee, R-K Research & System Design, Malibu, CA
M. Rauch, Bundesministerium der Verteidigung, Bonn, Germany
F. Reif, SESAME, Physics Department, Univ. of California, Berkely, CA
L. Resnick, LRDC, Univ. of Pittsburgh, Pittsburgh, PA
M. Riley, LRDC, Univ. of Pittsburgh, Pittsburgh, PA
A. Rose, American Institutes for Research, Washington, DC
E. Rothkopf, Bell Laboratories, Murray Hill, NJ
L. Rudner, Takoma Park, MD
D. Rumelhart, Ctr for Human Information Processing, U. of Calif., La Jolla, CA
A. Schoenfeld, Mathematics Dept., Hamilton College, Clinton, NY
R. Seidel, Instructional Technology Group, HUMRRO, Alexandria, VA
Committee on Cognitive Research, Social Science Research Council, New York, NY
D. Shucard, National Jewish Hospital Research Ctr., Denver, CO
R. Siegler, Dept. of Psychology, Carnegie-Mellon Univ., Pittsburgh, PA
E. Smith, Bolt Beranek & Newman, Inc., Cambridge, MA
R. Snow, School of Education, Stanford Univ., Stanford, CA

R. Sternberg, Psychology Dept., Yale Univ., New Haven, CT
A. Stevens, Bolt Beranek & Newman, Inc., Cambridge, MA
T. Sticht, Director, Basic Skills Division, HUMRRO, Alexandria, VA
D. Stone, Hazeltine Corporation, McLean, VA
P. Suppes, Inst. Math. Studies/Social Sciences, Stanford Univ., Stanford, CA
K. Tatsuoka, CERL, Univ. of Illinois, Urbana, IL
D. Thissen, Psychology Dept., Univ. of Kansas, Lawrence, KS
J. Thomas, IBM Thomas J. Watson Research Center, Yorktown Heights, NY
P. Thorndyke, The Rand Corporation, Santa Monica, CA
D. Towne, Behavioral Technology Lab, U of So. California, Redondo Beach, CA
J. Uhlaner, Perceptronics, Inc., Woodland Hills, CA
W. Uttal, Institute for Social Research, Univ. of Michigan, Ann Arbor, MI
W. Vaughan, Oceanautics, Inc., Annapolis, MD
H. Wainer, Div. of Psychological Studies, ETS, Princeton, NJ
D. Weiss, Univ. of Minnesota, Minneapolis, MN
G. Weltman, Perceptronics Inc., Woodland Hills, CA
K. Wescourt, Information Sciences Dept., RAND Corp., Santa Monica, CA
S. Whitely, Psychology Dept., Univ. of Kansas, Lawrence, Kansas
C. Wickens, Psychology Dept., Univ. of Illinois, Champaign, IL
J. Woodward, Psychology Dept., Univ. of California, Los Angeles, CA


DATE
FILME
7 — 8