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ABSTRACT

The result of a number of experiemental studies of human auditory and visual information processing behavior and their possible relationship to the student pilot's acquisition of flying skill were explored in terms of a conceptual model developed for this study. The results were interpreted in terms of the potential interfering effects of the intake of and response to information processed during flying tasks and in terms of the student pilot's nonoptimal information processing strategies during his acquisition of flying skill. It was concluded that the experimental procedures employed could be adapted sucessfully for research in the area and that the relationships found between information procesing and flying skill warranted their further study. (Author)

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AIR FORCE HUMAN RESOURCES LABORATORY

VISUAL AND AUDITORY INFORMATION PROCESSING ASPECTS OF THE ACQUISITION OF FLYING SKILL

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December 1974

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The result of a number of experimental studies of human auditory and visual information processing behavior and their possible relationship to the student pilot's acquisition of flying skill were explored in terms of conceptual model developed for this study. The results were interpreted in terms of the potential interfering effects of the intake of and response to information processed during flying tasks and in terms of the student pilot's nonoptimal information processing strategies during his acquisition of flying skill. It was concluded that the experimental procedures employed could be adapted successfully for research in the area and that the relationships found between information processing and flying skill warranted their further study.

SUMMARY

Problem

Research on pilot skills since World War II has focused, generally, on the perceptual-motor components of the flying task. Recently, a conception of flying skill which emphasizes the pilot's information seeking and information processing functions has evolved which supersedes and incorporates the older view of flying skill as hand-eye coordination. An information processing model was developed to provide the basis for the present experimental analysis of flying skill. Thus, the objective of this study was to use the model to identify the information processing aspects of the pilot's flying task and to relate them to the student pilot's acquisition of flying ability.

Approach

An information processing analysis of the pilot's task was developed through review of the literature in the areas of human auditory and visual information processing, and task analyses of the pilot's aircraft system management functions. Subsequently, experiments were designed and executed to isolate information processing skills sensitive to individual differences and to determine the extent of their variability, to explore means for controlling and accounting for such individual variability, and to ascertain the degree to which these information processing tasks relate to and may be applied in improving pilot training.

Results

In a series of experiments, the importance of the following auditory and visual information processing variables were demonstrated: stimulus duration, stimulus similarity interference, response-induced interference, attention, digit span, and scanning strategies. A series of studies of audiovisual concept formation demonstrated that with simple problems, auditory or visual information was equally

effective when scanning time was unlimited, that visual pictorial information was more effective than visual verbal information when scan time was severely limited, and that there was no measurable effect of audiovisual redundancy on concept attainment performance over the range of test tasks studied.

Conclusions and Recommendations

The results of this exploratory investigation of information processing aspects of the pilot's flying task indicated that experimental procedures developed could be employed to probe further the nonoptimal information processing strategies of student pilots and to evolve more effective flying training methods. The results suggest the high potential of further research in this area for improving Air Force flying training.

PREFACE

This report represents a portion of the research program of Project 1138, Perceptual Motor and Cognitive Components of the Flying Task, Dr. William V. Hagin, Project Scientist; Task 113801, Cognitive Components of the Flying Task, Dr. Edward E. Eddowes, Task Scientist, being carried out by the Flying Training Division, Air Force Human Resources Laboratory, Williams Air Force Base, Arizona. It is a systhesis of the results of ten experimental studies of human information processing accomplished by the Department of Psychology, Arizona State University, Tempe, Arizona, under contract F41609-72-C-0037 with the Air Force Human Resources Laboratory. Dr. Robert C. Haygood was the Principal Investigator for Arizona State University. Dr. Merrilynn J. Penner and Dr. Edward E. Eddowes were Contract Monitors for the Air Force Human Resources Laboratory.

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I. INTRODUCTION

Basic research on flying skills since the second world war has focused primarily on the study of perceptual-motor tasks such as pursuit and error tracking (Birmingham & Taylor, 1954; Briggs, 1962) and the efficiency of display reading (Sleight, 1948). Such research efforts reflected the simplistic view of flying as an integrated sequence of scanning and control movement responses. While such an approach may have adequately characterized flying skill some twenty-five years ago, it is simply inapplicable to the piloting of modern high speed aircraft. The advent of highly sophisticated navigation, flight-control, and weapons control systems has produced a dramatic change in the pilot's role.

The military pilot of today functions primarily as an executive decision maker; that is, he must be able to process incoming information rapidly and accurately, and to make crucial decisions based upon such data. The dynamically changing nature of the aircraft operating environment demands great refinement of basic information processing skills much beyond those perceptual-motor responses previously considered to reflect flying skill. The relationship of the pilot to his informational environment--to the environmental sources from which he obtains information and the information he outputs to his environment--provides the basis for the present approach to flying skill.

The information processing paradigm would appear to provide an heuristic conceptual framework for the experimental study of flying skill. In contrast to earlier orientations which have stressed the development of skill as a build-up of habits--either expressed as connections between stimulus and response, or as a build-up of response tendencies resulting from reward--the present approach views the organism as an information processing system. That is, the individual dynamically interacts with the environment by gathering appropriate cue information and generating outputs in accordance with some processing algorithm. It should be readily apparent that behavioral components such as short-term memory, visual scan, and concept identification are of importance in the efficient processing of information. While much effort has been devoted to the experimental investigation of these areas, there has occurred little integration of relevant findings and even less application to practical problems. It would appear that the virtue of the information processing model is to provide a conceptual framework, whereby the complex interrelationships among various behavioral components can be identified and programmatically investigated. Rigid distinctions among sensory processes, perception, learning, memory, and verbal/motor skills do not provide the level of integration necessary for an adequate description of behavior in the dynamically changing environment of the modern pilot. However, the concept of information flow--from the energy environment through receptor systems, decoding, gating, shunting, and short-term buffer storage, to organized long-term storage, retrieval, encoding and comparator to language or motor response generation and feedback guidance and monitoring--does seem to offer a useful framework for the study of flying skill.

The goal of the present effort was to clarify the role of information processing variables in the acquisition of flying skill. To achieve this end, a combined analytic and experimental program was undertaken to: (1) identify significant information-processing skills required in the operation of aircraft, (2) review existing literature on laboratory studies of information processing; and (3) design and execute the necessary experiments to advance existing knowledge in directions relevant to pilot training.

II. THE CONCEPT OF INFORMATION

At the outset, it seems necessary to precisely define what is meant by information. Typically, one thinks of the mathematical theory of communication, now commonly called information theory (Shannon & Weaver, 1949). Accordingly, information theory defines a source from which messages originate, a channel through which they pass, and a receiver which accepts and accumulates messages. The channel has two important characteristics. First, it has a limited capacity and second, it is subject to noise which distorts the message. An attempt is made to quantify the information content of a message in terms of the number of alternative messages that might have been sent and the probabilities of the individual messages. The greater the number of alternatives, the greater is the receiver's uncertainty about which message will be received. The basic unit of information, the bit, represents the amount of uncertainty in the choice between two equally probable alternatives. The classic example is the single bit of uncertainty in the outcome of the toss of an unbiased coin, uncertainty which is resolved by receiving the information that the outcome was "heads" or "tails."

As the number of possible alternative messages increases, so does the uncertainty. With equally likely alternatives, the amount of uncertainty is the logarithm, to the base two, of the number of alternatives. Thus with four alternatives, there are two bits of uncertainty; with eight alternatives, three bits, and so forth. The alternatives need not be equally likely; if they have different probabilities, the less probable alternatives convey more information, but the average information for the whole set is reduced. In the limiting case, a message telling an outcome that is completely certain (that is, an outcome which is already known because it was received before or in some other way) conveys no information. Such a message is said to be redundant. Any message that conveys less than the maximum possible information is said to be partially redundant.

Much research during the past two decades has been concerned with the evaluation of information-theory constructs as tools for understanding human behavior (cf. Miller, 1956; Garner, 1962). Despite the original enthusiasm, (Quastler, 1955), the theory and its constructs have not lived up to their initial promise, and interest has waned noticeably. Despite its utility in the analysis of communication networks, computers, and guessing games, information theory provides at best an incomplete model of human information processing. In particular, human communication, especially that communication which we characterize as instruction, cannot be described adequately in the language of information theory.

First, except in the most trivial of cases, it is never possible to specify the population of alternative messages from which a particular message is drawn. The listener, told to standby for a radio communication of great importance, may or may not have in his expectations the message that is subsequently sent.

Second, information theory does not deal with the question of meaning, which is the essential ingredient in human communication. No matter how well the message is received, it conveys no information unless the reader understands the words themselves. For example, much communication in the training situation is, in fact, devoted to the transmission of the meanings by means of definitions and combinations of words, phrases, and other symbolic expressions.

Third, the theory does not take into account the operating characteristics of the human receiver who, unlike the idealized receiver of information theory, deliberately selects, rejects, filters, transforms, and forgets incoming information.

Fourth, information theory does not address itself to the question of the importance of messages. The various messages in a set are usually not of equal importance or concern to the receiver, and the various sets of messages themselves differ in value.

And finally, although not directly related to human communication, information theory does not permit the quantification of the information content of continuous signals. Intuitively, complex auditory signals seem informationally richer than sine waves, but there is no direct method of measurement.

It is apparent that information theory does not provide a comprehensive definition of information. Considering the limitations which have been pointed out, a taxonomy would seem to be more appropriate. Input information to the human operator can be categorized into several broad classes.

1. Discrete Event Signals. This category is closest in meaning to the "information" of information theory. Three distinct classes of discrete event signals may be defined, although there are cases in which considerable overlap may exist.

a. Abstract (Arbitrary) Event Signals. With this type of signal, there is no intrinsic relationship between the signal itself and the event signaled. Instead, the relationship is arbitrary. Much of aircraft communication is of this type. Call signs which designate particular aircraft are examples of this type of event signal.

b. Intrinsic Event Signals. With this type of signal, there is an intrinsic relationship between the signal itself and the event signalled. During a ground-controlled approach (GCA), the communication "turn to heading two one zero" bears an intrinsic relationship with what is to be done.

c. Occurrence Statements. Both types of discrete event signals require that the receiver knows the nature of the system and the population of outcome. When the receiver does not have prior information the signal must present all such data.

2. Continuous Level Signals. This category refers to those signals which present the quantity or amount of a variable, such as speed. One of the most important aspects of skilled performance is the response to continuously varying indications of quantity, position, direction, and velocity. Pilots systematically monitor heading, altitude, airspeed, etc., and make corrections to the state of the aircraft based on such information. Although certain displays may be digitized, the continuous nature of the information still remains.

3. Analog (Pictorial) Representation. One of the most common modes of conveying information is to provide

the receiver with a picture, model, or map of an object. This method is most useful in presenting information that is difficult to verbalize; under such conditions, a picture may indeed be worth a thousand words. Although the usual mode is visual, other modalities (taste, sound, etc.) also permit this method of representation. The basic limitation of this method is that it can be used only with concrete materials; pictorial representation of abstract concepts (e.g., "freedom") may be difficult or impossible.

4. Logical Relationships. This category of information concerns meaning rather than states or events. Three types of logical relationships may be distinguished.

a. Equivalence Classes. The most obvious case of equivalence class information is a verbal definition; e.g., "dc power in watts is equal to the product of the current and the voltage." Statements of mathematical identities also represent equivalence inputs. For simplicity we will include here messages of nonequivalence, including inequalities such as "A is larger than B," and negation.

b. Inclusive Relationships. A typical relationship expressed in symbolic logic is that of inclusion--a relationship that states that a particular object or event is a member of some well-defined category or class. For example, the statement that a T-37 trainer aircraft has two engines is an inclusion statement which places the T-37 in the class of all two-engine aircraft. Note, however, that the statement does not specify that these two concepts are equivalent. Information of this type occurs frequently in training situations.

c. Relationships of Natural Regularity. Here we include statements of sequential and causal relationship, for example, information that "A precedes B" or "A causes B." Such information may be derived from instruction or by an inductive or problem-solving process based on repetitive signals.

III. HUMAN INFORMATION PROCESSING

The study of human information processing focuses on the relationship of the individual to his informational environment--to the sources of information on which he draws, and the outputs he furnishes to that environment. Within the individual, the input, control, and output processing, as well as the characteristics of the information-storage systems are of central concern.

Categories of Information Processing

As indicated, human information processing can be divided into three categories, input processing, central processing, and output processing. Obviously, a clear distinction between these three processing categories cannot be made since all three are involved in any information-processing sequence. Nevertheless, the broad spectrum of information-processing research represents a series of attempts to clarify the functioning of the system by focusing on one or another portion of the system, or some combination of system elements.

Input Processing. As information comes into the system, it is first detected, then identified or recognized (categorized), and passed on to central processing. The mechanisms of identification and recognition involve component processes of gating, decoding, and filtering (selective processing or selective attention), comparing, and storage. Each of these processes utilizes information already stored, and involves various storage mechanisms, to be described later. Studies focusing primarily on input processing include experiments on signal detection, reaction time, speed and accuracy of display reading, pattern recognition, dichotic listening, visual and auditory short-term memory, visual scanning, and psycholinguistics and reading studies.

Central Processing. Despite its flavor of "mentalism," most authorities agree that we cannot escape the notion of a central processing mechanism, which includes the functions of rehearsal, decision making, reasoning, inductive problem solving and concept formation, organization of information for storage in memory, and imagery. The various functions of gating, coding, chunking, filtering, comparing, and storage also operate in central processing. In addition, it is usually presumed that the selection of output, the central monitoring of output (as opposed to monitoring which occurs through feedback), search control and allocation of attention are under central processing control. Representative studies of central processing are reasonably obvious from the list of mechanisms given above.

Output Processing. While the selection of output may be generally considered as a central processing function, the actual planning and generation of responses is clearly an output function. Overt responses can be categorized conveniently into four types: verbal, procedural, control, and search. These types of output have been described previously and need not be repeated. Verbal output generally is studied under the rubric psycholinguistics. It is of special importance to note that many studies of input and central processing also call for evaluation of the speed and correctness of verbal responses. The ability to make such responses is not at issue, however, and the responses are used primarily as indices of the efficiency or speed of other processes. Control outputs are generally studied in tracking experiments. Perceptual-motor performance in tracking is perhaps the best-studied output phenomenon in human behavior. In the area of search behavior, the primary effort has been in the allocation of search time as a function of the informational "richness" of a visual pattern. More recently, efficiency of visual scanning has come under experimental scrutiny. Orienting responses in the human have been studied primarily in determining the factors governing "involuntary" allocation of attention.

Information Storage

Currently, multi-store models are most frequently used in research on memory. In typical studies, information retrieval is tested at various intervals following input. Different functions are generally interpreted in terms of different storage systems. The majority of contemporary theorists rely on either a dual-storage (Broadbent, 1958, 1971; Crowder & Morton, 1969; Waugh & Norman, 1965) or triple-storage (Atkinson & Shiffrin, 1969) model. While it is not clear that more than a single memory store exists (Melton, 1963, 1970) and while the utility of the temporal interval of testing as an independent variable has been questioned (Craik & Lockhard, 1972) the multi-store model provides an attractive structure for the framework of the present research.

Recall performance is probably often a joint function of several memory systems (Atkinson & Shiffrin, 1968, 1971). First, is appears likely that memory can be divided vertically into (a) a sensory store which lasts only a short time and which apparently requires little, if any, special effort on the part of the subject; (b) an active or short-term store which consists of the subject's active rehearsal and, thus, is dependent on the subject's strategy and motivation; and (c) a long-term store which is like the sensory store in that it is passive, unlike the sensory store, however, it extends for much longer durations. Second, it appears that memory can be divided horizontally on the basis of the nature of the memory code; i.e., with which sensory modality it is most analogous.

Sensory Storage. Sensory storage is thought to be an inherently brief registration of information in a relatively unanalyzed form prior to the imposition of identities upon it. There is now a body of evidence obtained from a variety of experimental paradigms supporting the notion of sensory storage in both the auditory and visual modalities. Neisser (1967) refers to these storage systems as echoic and iconic memory, respectively.

Information in sensory storage is subject to masking, erasure, and (or) distortion from additional stimulation to the same sensory modality--even if the subject is not attending to this additional stimulation (Averbach & Coriell, 1961). Recent studies, however, show little interaction between storage at the sensory level and ongoing cognitive processes (e.g., classifying irrelevant stimuli during the presentation of the memory items and during the retention interval). This is to be expected if readout from sensory storage were based on more or less unanalyzed features of the stimuli.

Short-Term Storage. Short-term storage refers to the subject's rehearsal processes. It is assumed that short-term storage is limited in capacity and that information in this system is subject to rapid decay when rehearsal is prevented.

Once information is copied into the short-term store it is no longer vulnerable to interference from unattended external stimulation (Averbach & Sperling, 1961), but it is subject to interference from ongoing cognitive processes (Posner & Rossman, 1965). This result would be expected if it were assumed that both recycling of the memory trace and cognitive processing were different functions performed by the same system (Atkinson & Shiffrin, 1971).

Long-Term Storage. Long-term storage refers to information which is stored on a relatively permanent basis. Information does not enter into long-term storage randomly, but rather it apparently is "carefully" placed in an organized position so that when one references the particular item in long-term storage, semantically related information is available at the same time. The structure of long-term memory and the organization which it imposes on incoming stimuli is one of the most intriguing yet least understood areas of experimental psychology.

Information flow diagrams generally depict information initially in sensory storage, then transferring to short-term storage and finally into long-term storage. However, as many of the properties generally attributed to short-term storage; e.g., categorization and rehearsal, require access to long-term storage, a more credible diagram would require two transfer systems from sensory storage: one going through short-term to long-term and one by-passing short-term and entering long-term directly.

Executive Processor

Unfortunately, the specification of storage systems does not address the question of how decisions are made with respect to the material to be stored and that to be eliminated. Neisser (1967) suggests a central processing system which operates over and above the processing systems discussed above. Some sort of "executive" is necessary to control activities, allocate attention, and to integrate sequences. In general the "executive" constitutes all of those cognitive activities which previously fell under the heading of consciousness, attention, and voluntary mental activity.

Capacity Limitation

The processing capacity of the human information processing system is limited in two ways. The first limitation is in terms of storage capacity; i.e., immediate memory for a series of unrelated items is limited to the number 7 ± 2. The source of this limitation appears to be restricted to the short-term store. The sensory store and the long-term store are thought to be high capacity systems. The second limitation in capacity is in the rate at which information can be processed. The rate limitation is thought to reflect a limitation in the executive processor rather than the specific storage systems.

IV. IDENTIFICATION OF INFORMATION PROCESSING COMPONENTS OF FLYING SKILL

One of the major goals of the present project was the identification of significant information-processing skills in flying. To do so, a wide variety of documents were reviewed and analyzed in an attempt to extract such data. These included Air Training Command materials currently used in the Air Force's undergraduate pilot training program as well as numerous research documents (Shannon, Waag, & Long, 1973; Baum, Goebel, & Smith, 1972, Smode, Hall, & Meyer, 1966). Interviews were conducted with numerous flight training personnel at Williams AFB, Arizona. At the

Flying Training Division, Air Force Human Resources Laboratory (AFSC), Williams AFB, Arizona, the investigators were briefed and given practice in the operation of various flight simulation devices. The 82d Flying Training Wing, also at Williams AFB, provided the principal investigator a familiarization flight in the T-37 training aircraft.

Early in the project, it became evident that the analysis of individual piloting skills, even though phrased in information-processing language, would be largely redundant with previous analyses of the same character (Kidd, 1962; Fleishman, 1967). Instead of generating another list of skills or tasks which the pilot must perform, the decision was made to produce a conceptual model of the flying environment which emphasizes the most salient processes. The resulting analysis represents an attempt to structure the field of information processing as it pertains to flying.

The Informational Environment

Figure 1 presents a working model of the environment composite informational system existing during a routine training flight. It is not intended to be comprehensive, but rather, an expository device only.

Input. The student pilot draws information from a variety of sources. Indications of aircraft state are given by visual cues from cockpit displays and control positions, and by kinesthetic cues from control pressures and motion accelerations. Auditory cues relevant to the state of the aircraft are also provided in the cockpit. The instructor pilot provides information directly in the form of instructional cues and demonstrations while external information is obtained from radio communications. In addition to information received from external inputs during flight, the student also accesses his own stored information; that is, his own memory. The student's memory contains cognitive and motor information concerning proper methods of performing a task, along with their criteria, emergency procedures, and other informational items previously acquired and stored.

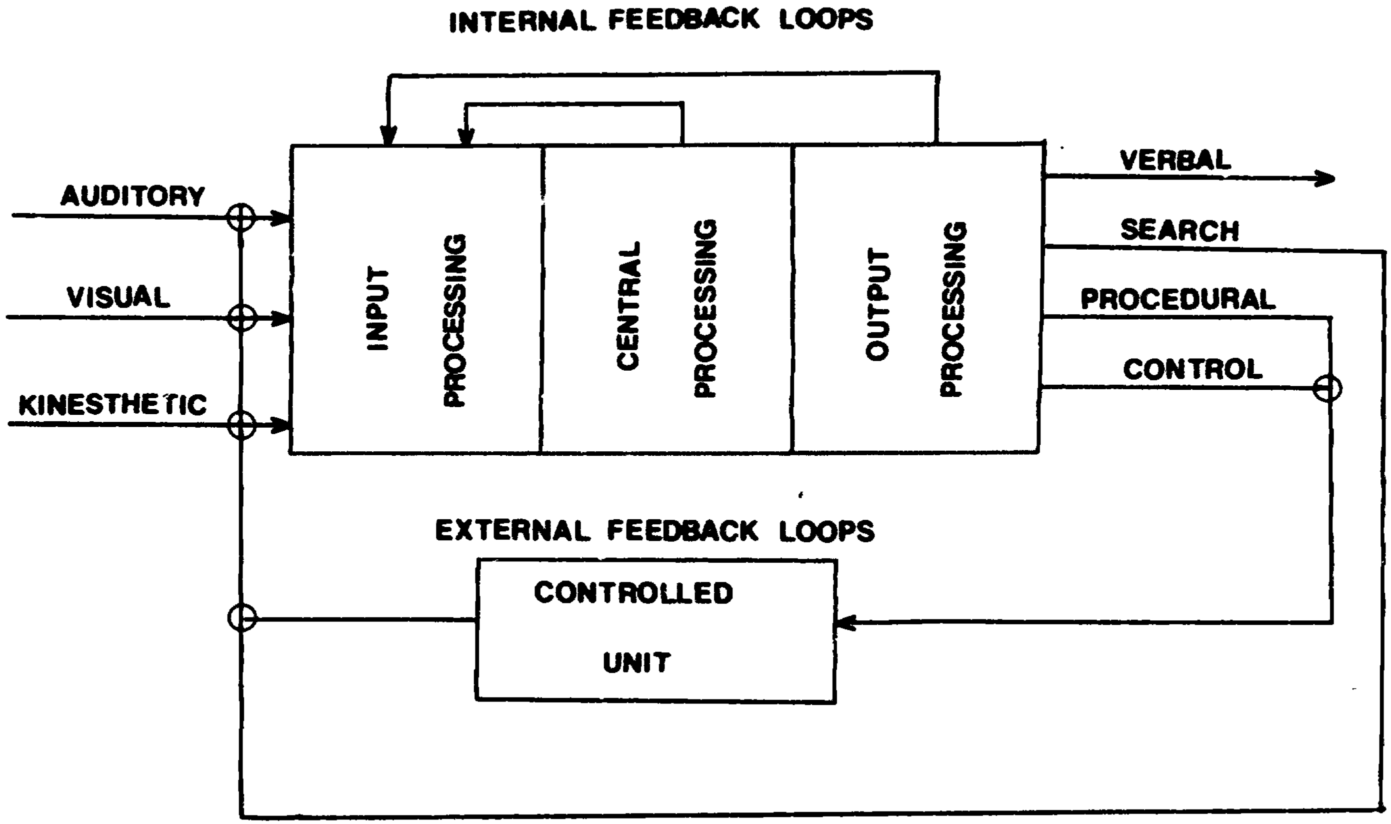

Figure 1. Model of the Environmental Composite System During Flying Training.

Output. Each response of a student pilot can be considered an output of information. In some cases such as statements to the instructor and radio communications, the information is discrete and verbal. Information is also provided to the aircraft through the direct manipulation of controls within the cockpit. Such information is likewise transmitted to the instructor who is observing such actions and their effects on the state of the aircraft. Every control input will in some way alter the state of the aircraft, which in turn provides informational cues concerning the effect of such inputs. In this manner, a feedback loop is completed. Finally, the student engages in active search behavior in order to secure necessary information which will serve as input cues.

The physical actions of the pilot in controlling the aircraft have been dichotomized by Smode, Hall, and Meyer (1966) into procedural and control actions. Procedural actions are relatively discrete, intermittent control activations such as moving switches and manipulating controls. A typical procedural action is that of lowering the landing gear. Control actions are those which require the pilot to make continuous adjustments so as to control directly the flight path of the aircraft. The two types of actions are distinguished more in terms of purpose than in terms of which control is used. For example, when the throttle position is changed to lower speed on landing, this is essentially a procedural action. In contrast, the throttle can be used as a continuous control device to maintain position relative to another aircraft in formation flying.

The Normal Landing Pattern

As an example of information processing requirements, consider the student returning to base under supervision of an Instructor Pilot (IP). The student must perform a complex sequence of actions in real time using information from the sources described earlier. In addition, the external environment input must be entered into storage, compared to the student's knowledge of task requirements (which resides in long-term quasi-permanent storage), and used to generate responses in real time so as to match the required flight regime. While the actions required to land the aircraft would take too much space to describe in detail here, major groups of task elements include the initial overhead approach to the duty runway, the pitchout and upwind turn, the downwind leg, the final turn, final approach, roundout, touchdown, landing roll, and taxi back to the flight line. The student must keep in mind the verbal information received by radio, such as landing runway, wind and temperature information, and traffic advisories. As he approaches for landing, he must repeatedly monitor his position and ground track, and such aircraft state indicators as airspeed, rate of descent, altitude, and heading. Appropriate control actions must be generated to satisfy maneuver requirements. Superimposed on these continuous tasks are the intermittent procedural actions (e.g., lower landing gear, lower flaps) which must be accomplished at specific prescribed points in the landing. In addition, the student must be alert continuously for indications of hazardous states or malfunctions of the aircraft subsystems.

Since human information processing capacity is limited, the student pilot must shift his attention rapidly to secure the information he needs to execute the required procedural and control actions. What is usually called a continuous control task may be continuous with respect to the required output, but is usually discontinuous with respect to the pilot's behavior and his information inputs. Only in artificial settings, such as laboratory-type single-dimensional tracking, can the attention be focused continuously on one input channel. In the normal landing pattern the student must time-share inputs since his capacity will not permit simultaneous monitoring of several active information sources. To do this, the student scans the relevant instruments and areas of the external world one at a time, checking each against his concept of the required state which must be achieved so that the future position, velocity, direction, and trim of the aircraft will match the maneuver requirements.

V. RESEARCH PROGRAM

Within the context of an information processing approach, a program of research was initiated for the investigation of components believed to be relevant to flying skill. Since the research was basically exploratory in nature, a broad spectrum of information processing tasks were investigated ranging from simple identification of nonverbal stimuli to complex rule learning in concept formation. The research program was designed to encompass three major areas: (a) Sensitivity and Variability--to isolate information processing skills which are sensitive to individual differences and determine the extent of such variability; (b) Control--to explore means for controlling or accounting for such individual variability; and (c) Application--to ascertain the degree to which these tasks are applicable to pilot training and to provide a means for their implementation. The present report deals primarily with experimental results concerned with the first two areas. Although the results are based on data obtained exclusively from a college student population, there is no reason to believe that the present findings do not hold for pilot trainees since they are selected exclusively from this group. However, to insure generalizability, a longitudinal effort using pilot trainees at Flying Training Division, Air Force Human Resources Laboratory does appear to be necessary, especially to investigate the third area of concern, applicability to training.

VI. THE PROCESSING OF AUDITORY AND VISUAL SIGNALS

The pilot must continuously process incoming visual and auditory signals which emanated from the environment. As a result of high processing demands which occur under conditions of task overload, it seemed that the investigation of the memory processes involved in the retention of rapidly presented auditory and visual signals would prove to be of value. To study the processing of rapidly presented information, an experimental paradigm was employed; the observer is presented certain information which he is required to retain for later recall. It was assumed that the observer actively processed the information not only during actual presentation of the stimulus, but also during the time period subsequent to its presentation. To determine the extent of this processing and its importance for subsequent recall, an attempt to interfere with his processing was made by presenting an additional interfering stimulus. The interfering stimulus was presented subsequent to the presentation of the target stimulus.

Consider the following thought experiment. Suppose an interfering stimulus is presented long after the target stimulus in a typical experiment in visual information processing. It is not unreasonable to assume that the interfering stimulus will have a small or negligible effect on retention of the target stimulus. If, on the other hand, the interfering stimulus is presented shortly after the target stimulus, it is reasonable to conjecture that the interfering stimulus will produce a decrement in performance. In the present work, the effect on memory performance of the delay between presentation of the target stimulus and presentation of the interfering stimulus was investigated in an attempt to obtain a measure of the time course of processing. It was hypothesized that when the target stimulus was closely followed by an interfering stimulus; that is, with no time between the interfering stimulus, a maximal decrement in performance would be obtained. Furthermore, as the delay of the interfering stimulus was increased, performance should improve monotonically. In this way, measures of the time required to process auditory and visual information could be obtained.

Measurement of Auditory Processing: Stimulus Interference

Using this experimental paradigm, the processing of simple auditory information was studied (Leshowitz & Cudahy, 1972; Cudahy & Leshowitz, 1973). A pure tone having a characteristic pitch was presented, and the observer was asked to remember the pitch of the target tone. Following presentation of the target tone, an interfering tone was presented. The duration of the target tone was 10 msec; the duration of the interfering stimulus was 500 msec. One second after the presentation of the interfering tone, a third tone, called a comparison tone, was presented. The comparison tone was either the same or different in pitch from the original target tone. The probability of the comparison tone being different was .5. The subject was asked to compare the pitch of the target and comparison tone and respond whether or not the comparison tone was the same or different.

The experimental variable of major interest was the delay between termination of the target tone and onset of the interfering tone. The function relating the probability of a correct response and delay of the interfering tone provided a graphic representation of the time course of processing. It was observed that as the delay of the interfering tone was increased, the probability that the subject correctly identified the comparison tone increased monotonically. The finding that identification of the comparison was nearly perfect for delays of the interference tone of about 100 msec is in accord with the simple notion of interference with processing produced by a subsequently-presented irrelevant stimulus.

Experimental Variables Affecting Processing

Stimulus Duration. Several experimental variables were found to affect the magnitude of the interference effects produced by a retroactive masking tone. First and most important was the duration of the target tone. The interfering tone produced a decrement in performance only when the target tone was very brief. For target tones longer than 20 msec, presentation of an interfering tone had no effect on performance. These data can be understood by assuming that a very brief tone is characterized by a few critical features. Presentation of an interfering tone decreases subsequent recall of the target tone because the critical features of the target tone are not processed when an interference tone is presented. Longer duration tones, on the other hand, are characterized by a great redundancy in information. Thus, long-duration stimuli provide more opportunity for the subject to discriminate than critical features. Since a retroactive interfering stimulus cannot obliterate all of these critical features, interference effects are less pronounced.

Channel. Another critical dimension in information processing is the channel in which the interference is introduced. It is assumed that auditory processing is carried out in two independent channels, the left and right ears. To test the assumption of independence of channels, the interfering effects produced by a contralateral interference tone were investigated. This means that if the target stimulus is presented to the left ear, the interfering stimulus is presented to the right ear. On the assumption that processing in the two channels is independent, interference exerted by contralateral masking tones should be minimal. This result should hold even for brief target tones which have been shown to be susceptible to interfering effects introduced in the ipsilateral channel. In accord with this prediction, the obtained results showed that the interference produced by a tone contralateral to the target was in all cases minimal and thus suggested that the two auditory channels were independent.

Similarity. The similarity of the interfering and target stimuli is thought to be an important variable in determining the extent to which normal information processing is altered. In the auditory processing task described above, similarity was investigated by varying the spectral (frequency) content of the interfering stimulus. A simple notion of interference would predict that the greater the similarity of target and interfering tone, the greater the interfering effects. In the present experiment, however, small effects of similarity were found. That is, as the frequency separation between target and interfering stimuli increased, little or no change in performance was observed. Apparently, common elements shared between target and interfering stimuli play a very small role in interference with auditory information processing. The present data can be interpreted as indicating that the role of an interfering stimulus is to produce a general level of interference.

The failure to find similarity effects is paradoxical in light of the observation that not all extraneous stimuli produce interference effects. Recall that a contralateral interference tone had little or no effect on performance. Moreover, similar experiments in the literature demonstrate that interfering stimuli entering through the visual modality have little effect on recognition of auditory stimuli. Apparently, interfering stimuli must be presented in the same auditory channel as the target tone if they are to be effective (Leshowitz, Zurek, & Robbins, 1974).

Measurement of Auditory Processing: Response-Induced Interference

It should not be assumed that interference with information processing can be produced only by stimulus events. The subject's own responses can serve as an important source of interference. Several investigations, both theoretical and empirical, have been devoted to a study of interference produced by the subject's own responses. In the first experiment, the effects of information retrieval on recognition memory for pitch were investigated (Leshowitz & Hanzi, 1973; Leshowitz & Green, 1973). The observer was presented a list of tones which were to be retained. The list of tones were chosen in the frequency region between 250 and 1000 Hz. After presentation of the initial stimulus list consisting of either 6 or 8 tones, the subject was presented 4 or 5 test tones. The task of the subject was to determine whether a given test tone had been included among those presented initially. One-half of the tones in the test set were included in the original set. The probability of the subject correctly labeling a tone as "old" is called the "hit" rate. The probability that the subject falsely labeled a new tone as old is the "false alarm" rate. The relative proportion of hits and false alarms is used to compute memory strength (d') and gives a measure of recognition memory.

The purpose of using tones as the test material as opposed to simple vocabulary words was to control for linguistic associations normally part of the subject's language repertoire. In other words, we attempted to ascertain the strength of stimulus and response-induced interference in a memory task in which prior experience does not play a role. The attempt was to obtain a pure measure of interference.

The results of this experiment were surprisingly similar to those presented in the verbal learning literature. Specifically, both stimulus-induced and response-induced interference effects were obtained. The data analysis permitted isolation of precisely the amount of interference attributable to stimulus events from that portion attributable to response interference. Probability of correct recognition as a function of position in the original stimulus list provided a meausre of stimulus interference. Performance as a function of position in the test list provided a measure of response interference.

In verbal learning, it is common to find that items presented at the beginning of the list and items presented at the end of the list are remembered better than items in the middle of the list. Such results are the classical serial positions effects of "primacy" and "recency," respectively. These effects were again demonstrated for the memory of pitch. Moreover, the magnitude of these serial position effects was related to the amount of time allowed the subject to rehearse the items in the stimulus set. When items were presented in rapid succession with little or no time allowed for rehearsal, the serial position effects differed markedly from conditions in which the set was presented at a slower rate. What seems to be of prime importance is the opportunity to rehearse the items in the set.

Analysis of recognition as a function-set position showed that internal sources of interference may be even greater than external sources of interference. The amount of interference produced by the subject's own responses can be measured by comparing memory performance for items presented at various test-set positions. Suppose the initial test item is recognized at near-perfect levels, independent of the item's position in the original stimulus set, and that items further down the test set are recognized less well. The decrease in performance as a function of position in the test set provides a direct measure of response-induced interference. The present results showed a monotonically decreasing function of recognition performance as a function of test-set position.

These results indicate that in testing, the sheer act of comparing the test item and a replica of this item in memory has a profound effect on memory for other items. In other words, the comparison process itself produces a marked decrease in recognition performance for other items. It appears that response-induced interference is at least as great as stimulus-produced interference.

Interference produced by the retrieval of information was especially marked when little or no time was allowed for rehearsal of the original material. For items where rehearsal was impeded by presenting items at a rapid rate, subjects had little or no difficulty in recognizing the initial test-list items. However, recognition of all succeeding items was drastically curtailed. It appears that without sufficient time for rehearsal, items in memory are particularly susceptible to response-induced interference. If the task does not permit sufficient processing, this information can be easily wiped out by the observer's own responses. This finding has some important practical implications to which we shall return in a later section.

Measurement of Visual Processing: A Partial Report Recognition Paradigm

In the next series of studies (Leshowitz, Hanzi, & Zurek, 1973), several experiments on visual information processing were designed using general principles derived from the previous studies on simple auditory information processing.

The purpose of the experiment was to determine how much of the array the subject could process. A second interest was to determine whether a visual interference stimulus could produce decremental effects. Also, an attempt was made to contrast stimulus-induced and response-induced interference in processing complex visual arrays, and to determine strategies used by observers in processing visual arrays, specifically, do observers scan from left to right?

An objective recognition memory paradigm was employed in assessing the human information processing capacities governing visual memory. The subject was presented the visual array for a brief period. Since it has been shown that observers have great difficulties in recalling large amounts of visual information, a partial-report paradigm was employed. Rather than asking subjects to report all twelve letters of the array, they were asked to report on only a partial sample of these letters. Subsequent to the array, an indicator tone was presented which signaled report of either the upper, middle, or lower row of the array. In order to measure memory decay of the original stimulus array, an experimental variable of interest was the delay between termination of the array and onset of the indicator tone. Following presentation of the indicator tone, the subject was presented a test list of letters. The test list was located to the right of the visual field that contained the original stimulus array. The task of the observer was to indicate whether or not the test letters presented in a given row-column had been presented in the original list. If the letter had been presented in the indicated position, the subject was instructed to vote "old." If this letter had not been presented in the indicated pattern, the subject was asked to vote "new." As before, hit and false alarms rates were computed as well as memory strength scores. Recall that memory strength provides a direct measure of the degree to which subjects retain information.

Experimental Variables Affecting Visual Processing

Scanning Strategy. A number of significant main effects were obtained. First, subjects have a pronounced proclivity to scan the visual array from left to right. In addition, subjects preferred the middle row in contrast to the upper and lower rows. As a result of these biases for certain positions, recognition memory for these preferred stimulus positions was markedly superior to recognition of letters in the other locations of the stimulus array. Of special note is the observation that these biases manifested themselves across all three observers in the experiment.

Delay of Partial-Report Cue. In agreement with the classical data on memory decay, recognition performance was a decreasing function of indicator tone delay. For zero delay of indicator tone, performance was nearly perfect. When the delay was 2 seconds, performance approached near chance levels. Thus, it appears that visual information contained in complex visual arrays decays in about 2 seconds.

Interference Stimulus. In an attempt to interfere with normal processing of visual information, a paradigm nearly identical to the one described above in the auditory information processing experiments was used. Following presentation of the stimulus array, a masking stimulus consisting of a homogeneous array of dots was superimposed on the visual array. This retroactive masking stimulus always followed presentation of the visual stimulus array. In agreement with our notions developed for interference with auditory processing, under all conditions, presentation of the masker produced a significant decrease in subsequent memory performance. That is, recognition memory for letters decreased upon presentation of the masking stimulus. Although increasing the duration of the original visual array from 50 to 500 msec, and thereby permitting greater time for processing of the original array, increased performance, the addition of a masking stimulus had a significant debilitating effect on memory.

Response-Induced Interference. The final analysis was devoted to an analysis of the interfering effects produced by the subject's own responses. The function relating performance as a function of position in the test set provides a direct measure of interference produced by the subject's own responses. In marked contrast to the previous set of data on recognition memory for pitch, memory for items at the end of the list was no less than the recognition memory for the test set items at the beginning of the set. It appears that retrieval interference is of negligible importance when the subject is required to process a visual array. While an immediate explanation of the difference between retrieval interference for visual and auditory information processing is not apparent, it does appear that the highly codable visual array consisting of English letters is less susceptible to retrieval interference. The unidimensional, noncodable auditory pitch, on the other hand, is clearly susceptible to this retrieval interference. On a codability dimension, interference associated with the retrieval process becomes a less important factor in recognition memory as the information becomes more easily coded. For relatively noncodable material, sufficient time for rehearsal of the original stimulus list also mitigates the interfering effects inherent in the retrieval process. In summary, opportunity to encode a to-be-retained item is of great importance. This finding has important implications for flying training.

VII. SHORT-TERM RETENTION OF AUDITORY INFORMATION

A pilot is constantly required to process complex arrays of information which, in many cases, are presented over several communication "channels" simultaneously. The channels might be within the same sensory modality (e.g., two different messages, one to the left ear and one to the right ear) or they might be between two sensory modalities (e.g., one message spoken and one message pictorially displayed). For a more concrete example, while listening for landing instructions from a control tower (auditory channel), a pilot must also maintain visual contact with his instrument panel (visual channel), and in addition, commence a rather complicated series of movements in preparation for landing (tactile and kinaesthetic channels).

Pilots, then, are apparently able to do several things at once. This leads us to some questions: (a) How are they able to do it; i.e., what processing strategies are they employing? (b) Are the strategies trainable; i.e., if we find a trainee deficient in employing optimal strategies, can we provide instructions to remedy the difficulty? (c) How can we isolate the processes used so that we might construct devices; i.e., simulators, the operation of which would permit more efficient and inexpensive training? The answers to these questions necessitate research with tasks involving multi-channel input.

The Dichotic Paradigm

Dichotic memory refers to a set of experimental operations in which subjects receive two different lists of items simultaneously, one to each ear, with instructions to reproduce as many of the items as possible following list presentation. In studies using these operations both lists consist of digits and presentation rate typically is 2 pairs/sec. Subjects tend to report the digits from one ear and then the other rather than alternating between ears and reporting items according to the order of their presentation. The ear-by-ear report pattern suggests that subjects monitor (attend to) only one message and report it first during recall. They are still able, however, to report items from the other ear (although not as accurately), so both digit lists (right and left ear) must have been stored initially.

The dichotic paradigm would further appear to offer a fruitful area of investigation as a result of previous work by Gopher and Kahneman (1971) in which Israeli Air Force cadets were tested using a dichotic listening procedure. The results indicated that measured performance on this task was significantly related to two flight criteria: (1) success--that is, whether a cadet was rejected from flight training and, if rejected, at what stage; and (2) flight assignment--that is, cadets scoring higher were assigned to high performance aircraft. Such findings suggest that the dichotic paradigm might provide a useful laboratory analogue for studying the information processing requirements of the flying task.

Attended and Unattended Messages

In the first study using the dichotic paradigm, subjects were given a sequence of four pairs of digits on each of forty-two trials. One member of each pair was presented to the right ear and one was presented to the left ear. Subjects were instructed to attend to only one ear during presentation and to either: (a) recall first the digits received by the attended ear followed by those from the unattended ear (Attended-Unattended or A-U report), or (b) recall first the unattended digits and then the attended digits (Unattended-Attended or U-A report).

Several interesting findings emerged from this experiment. The items on the attended ear were more accurately recalled than those on the unattended ear regardless of the order of report (i.e., A-U or U-A). The order of report requiring the least switching of attention, Attended-Unattended, produced the most accurate retention. When subjects were required to attend to one ear and to report the unattended ear first, the attended message was significantly impaired.

Verbal and Written Monitors

The second experiment in this series was a replication of the first with the exception that subjects were required to monitor the attended message. Two types of monitors were employed, written and verbal. In the written condition, subjects were required to write the attended message during presentation, while in the verbal condition subjects were required to shadow (report aloud) the attended message during presentation.

While the attended message was recalled with equal accuracy by both groups, the unattended message was more accurately recalled by the written monitor group. Apparently, when one must encode (store) and decode (output) with the same system (auditory-verbal), greater interference results than when different systems (auditory and manual) are employed.

Digit Span

There occurred considerable between-subjects variability in the first experiments. The primary source of variability was in errors of omissions; i.e., some subjects recalled more items than others. Some subjects were overloaded with messages containing 4 digits per ear while others managed to store and output the information with high accuracy. Some subjects, therefore, appeared to have a greater storage capacity than others. In an attempt to control for storage capacity, individual digit span tests were administered in the next experiment. Each subject received five digit span assessments, and groups with digit spans of 5, 6, 7, 8, 9, and 10 were formed.

In this study, the correlation between digit span and overall dichotic performance (i.e., collapsed over attended and unattended ears) was +.891. Digit span, therefore, was identified as a potent source of variability in dichotic research. Further correlations were run between digit span and attended ear and unattended ear in both A-U and U-A reports. The highest correlations were obtained on the unattended ear; i.e., where switches of attention occurred between input and output.

Interference Effects in Dichotic Memory

In the first three experiments, different serial position functions were obtained for attended and unattended ears. Serial position functions for the attended ear were relatively flat (all positions were recalled with approximately equal accuracy), while unattended ear serial position functions showed a marked recency effect (items in the terminal positions were recalled with greater accuracy than items occurring in the primary serial positions).

In the next experiment, we investigated the effect of a redundant auditory element (stimulus suffix) at the end of each dichotic list. Previous work has indicated that such a manipulation interferes with information which has not been fully processed. In this experiment, unattended ear recall accuracy was found to be significantly impaired when the locution "uh" was presented binaurally at the end of the list. Furthermore, the magnitude of the effect appeared to be a function of digit span.

Although a relationship between stimulus suffix effect magnitude and digit span was not expected, digit spans were assessed and the two subjects with a low digit span were found to have experienced more interference than the two subjects with high digit span.

Digit Span and Interference

Two groups of subjects were run in the next experiment. One group consisted of subjects with high digit spans ($\bar{X}$ = 9.75) while the other contained only subjects with low digit spans ($\bar{X}$ = 6.25). The subjects participated in two test sessions. In the first session, subjects received dichotic lists consisting of five pairs of digits. In the second session, a stimulus suffix was presented binaurally at the end of each dichotic list. Subjects with high digit spans showed reliably less interference than did those with low digit spans.

In yet another condition, the high span subjects were given dichotic lists consisting of six pairs of digits with and without the addition of a stimulus suffix. The interference produced in that experiment (6 pairs) was comparable in magnitude to that of the low span subjects in the last experiment (5 pairs). This relates back to the problem of task overloading mentioned earlier. Apparently, the effect of a stimulus suffix is to add more information to the task. For those subjects whose capacity was already overloaded without the suffix, the effect of the suffix was to radically degrade recall accuracy. For subjects whose capacity matched the condition without the suffix, the effect of the suffix was minimal. The implications of these findings in the improvement of Air Force flying training will be considered further in a later section of this report.

VIII. AUDIOVISUAL CONCEPT FORMATION

In ordinary language, the word concept has many meanings, referring among other things to inner images or ideas, to abstract relationships among environmental properties or events, to operations which an organism performs on stimulus inputs, and so forth. Among experimental psychologists, however, the term has come to have a more precise, but limited, meaning: a principle by which all objects or events can be classified into two categories, examples of a concept (positive instances) and nonexamples (negative instances). Concept formation concerns the learning or utilization of such classification principles. Thus, studies of concept formation are usually conducted within the framework of a task in which the subject must sort or classify a set of stimulus patterns into categories. The "problem," as it is usually called, is for the subject to learn or discover the correct principle for sorting, using information provided by the stimulus patterns and by corrective feedback signals given after each sorting response.

Experimental procedures used in the study of concept formation almost universally require the subject to discover or infer the correct concept from a series of positive or negative instances. While there are many variations, most procedures fall into one of two classes, depending on whether the experimenter chooses the sequence of stimulus information (reception paradigm) or the subject has an active role in selecting each stimulus to be examined (selection paradigm).

All of the studies to be reported here have used the reception paradigm. The distinguishing aspect of reception learning is that the subject has no control over the selection and ordering of stimuli. On each of a series of trials, the subject is presented with a stimulus pattern, is required to classify it (as a positive or negative instance), and is told whether his response was correct or not (informative feedback). Trials proceed in this fashion until the subject can show his knowledge of the correct classification principle, either by verbal statement or by meeting an arbitrary performance criterion such as 15 consecutive correct responses. Conventional performance measures are the number of errors made, the number of trials to last error, or the amount of the time taken to reach the criterion of problem solution.

Two structural features of concepts can be identified. The first is a set of one or more specific, perceptible stimulus properties which constitute the defining properties of the concept. Conventionally, these are called the relevant attributes, in contrast to other characteristics which vary from pattern to pattern, but have nothing to do with the concept and are therefore called irrelevant attributes. The second feature is a conceptual rule which specifies how the attributes are combined or otherwise elaborated to form the concept. For example, in the concept "red triangle," the class of all things which are both red and triangular, the relevant attributes are redness and triangularity. But the concept also includes a particular relationship between these two attributes, that of conjunction or joint presence. Only those patterns which are both red and triangular are examples of the concept. The same pair of attributes may be related by a variety of other rules, such as inclusive disjunction (either red or square or both).

Selection of two attributes as relevant in a concept-learning problem generates a contingency table consisting of the four categories of stimulus patterns defined by the presence or absence of the two attributes. For example, given red and square as attributes, the four contingencies are red square, red not-square, not-red square, and not-red not-square. This contingency table is equivalent to a truth table in symbolic logic, in which the four contingencies are designated TT, TF, FT, and FF (T standing for true and F for false). The specification of a logical rule further maps these four contingencies into a two-response system of examples and nonexamples of the concept. For example, in a conjunctive concept, the first contingency (TT, or red square) is placed in the positive category while the other three are negative. The four basic two-dimensional rules are shown in Table 1; the plus and minus signs indicate that the instance is positive or negative, respectively.

Haygood and Bourne (1965) pointed out that essentially all studies prior to that time had used instructions which may be characterized as attribute identification. In attribute identification, the conceptual rule is carefully explained to the subject, and his task is to discover the relevant attributes. Haygood and Bourne developed an alternative procedure, called rule learning, in which the subject is told the relevant attributes and must discover the correct rule of combination. With the exception of the audiovisual redundancy experiment, all of the experiments to be reported here used attribute identification instructions. The rule-learning procedure will be described later.

The study of auditory concept formation is a relatively

TABLE 1

DISTRIBUTION OF INSTANCES INTO POSITIVE AND NEGATIVE CATEGORIES FOR FOUR BASIC CONCEPTUAL RULES

Stimulus Patterns		Logical Truth Table		Conceptual Rules			
Color	Form	Red	Square	Conjunction	Inclusive Disjunction	Conditional	Biconditional
Red	Square	T	T	+	-	+	+
Red	Not Square	T	F	-	+	-	-
Not Red	Square	F	T	-	+	+	-
Not Red	Not Square	F	F	-	-	+	+

recent enterprise, beginning only about 15 years ago. Thus, little is known about the process except for a few basic studies of abstract auditory concepts. The purpose of the series of experiments to be reported here is to extend the study of audiovisual concept learning to meaningful comparisons of learing from auditory and visual materials.

Concept Identification in Three Modalities

In the training situation, the trainer has the option of presenting his materials in any one of three modalities. These modalities are pictorial, in which pictures of the concepts or relationships to be learned are shown, visual verbal, in which verbal descriptions of the pictorial materials are shown, and auditory verbal, in which the verbal materials are presented orally or by recording. The same material can also be presented in two or all three modalities, creating what is called audiovisual redundancy; redundancy is covered in later experiments.

Despite existing folklore to the effect that "one picture is worth a thousand words," there is little in the way of scientific data to support such a contention, and some recent theories of information processing suggest that discrete pictorial information is recoded to verbal form for storage and utilization in human information processing.

In any training program, the goal is to teach the trainee concepts by having him read printed verbal materials, telling him about concepts, or showing him examples and nonexamples of concepts. The purpose of the first experiment was to provide a direct comparison of concept learning in these three modalities.

The standard concept-formation procedure was used, in which the subject's task is to discover the correct concept by being shown a series of positive and negative instances, guessing their classifications, and receiving corrective feedback. Each subject learned under one of the three modalities described above (pictorial, visual verbal, and auditory verbal), a concept constructed with one of two rules (conjunction or inclusive disjunction) and one of two pairs of relevant attributes (blue-triangle or two-squares). In the visual conditions, the subject was shown a card containing the stimulus pattern. After his response, feedback was given by telling the subject if his response was correct or not, and by placing the card face up in the correct one of two sorting boxes (positive and negative instances) placed on the table directly in front of the subject. In the auditory condition, the subject was told what the pattern was; no cards or sorting boxes were used, and the subject's feedback consisted only of being told the correctness of his response. Subjects worked at their own speed, and instructions stressed accuracy rather than speed.

The results showed clearly that learning is faster for conjunctive concepts, and for problems using blue and triangle as relevant attributes. However, in contrast to the striking results for these variables, modality of presentation had little effect, and the effect was not statistically significant overall. Post hoc analysis showed a slight, but significant superiority for visual verbal over auditory verbal conditions. It was decided to suspend judgment concerning modality differences until a second experiment could be performed which would eliminate the possible role of the sorting boxes in the superiority of the visual conditions.

Comparison of Visual and Auditory Verbal Presentation

This experiment was designed to eliminate the confounding caused by the fact that subjects in the visual verbal conditions could see the last positive and the last negative instance (in the sorting boxes), while subjects in the auditory conditions did not have such a memory aid. This type of memory aid has been shown to increase efficiency of learning in previous research.

The purpose of this experiment was to compare three types of verbal presentation. The first is the visual verbal condition of Experiment 1, with the sorting boxes eliminated. The second was the auditory verbal condition of Experiment 1. The third was an augmented auditory verbal condition, in which the information gained on each trial was repeated at the end of each trial (e.g., "the last pattern, one large red square, was a positive instance). The task and procedure were essentially the same as those of Experiment 1, with the changes noted above. In addition, the disjunctive concepts were eliminated, and all concepts were conjunctive.

The results showed no significant differences among the three modality conditions, indicating that the superior performance in visual conditions of Experiment 1 resulted from the memory aid provided by the previous instances showing in the sorting boxes. Taken together, the two experiments provide a clear picture. For simple concepts, presented in a relatively uncluttered context (few irrelevant stimulus dimensions and discrete and easily identifiable levels of the relevant dimensions), there is essentially no difference between seeing the stimulus patterns, seeing a verbal description of the patterns, and being told the verbal description. This finding provides a baseline from which to examine more complex visual concepts, such as the appearance of the runways when the aircraft reaches the proper point for turn to final approach, concepts for which verbal presentation may not be as informative as visual presentation.

The Effects of Limiting Inspection and Response Time

The first two experiments indicated that modality of presentation has little or no effect in this type of concept-formation task when unlimited time is available to examine stimulus patterns and formulate responses. It is well known that limiting inspection-response time has a degrading effect on performance in visual problems. Any differences in the rates at which pictorial and verbal information can be processed should show up in this type of experiment if the time allowed to examine stimuli and respond is limited. The purpose of this experiment was to compare performance in visual verbal and pictorial conditions when time constraints are imposed. Unfortunately, a suitable method for controlling "inspection time" for oral presentation has not as yet been devised, so this condition could not be tested.

The method was essentially the same as that used in the first experiment, with the exception that automatic equipment with slide projection was used in place of manual presentation of cards. This change was made to provide control of timing. The subjects' responses were made by pressing pushbuttons, and feedback was given by turning on a lamp directly over the correct pushbutton. Each subject learned either from pictorial stimuli or printed (and projected) verbal stimuli under one of three timing conditions. The three timing conditions were 1.0 sec, 3.0 sec, or unlimited time to inspect the stimulus and respond. Many subjects were unable to respond during the 1.0 and 3.0 sec intervals until the concept had been learned; however, all but seven subjects were able to complete the task satisfactorily.

Limiting the presentation-response time severely degraded performance, and the degradation was far worse for verbal conditions than for pictorial conditions. For the pictorial conditions, performance at 3.0 sec was actually slightly, but not significantly, better than performance with unlimited time. The simplest explanation of these results would be that it takes longer to read and extract the information from the verbal slides than from the pictorial slides. A follow-on pilot study supported this interpretation by showing that it takes subjects 0.2 sec longer to make a simple identification response (e.g., "is this next pattern blue triangle") when the pattern is verbal, compared to pictorial. Further research with a variety of different materials is needed to substantiate this pilot finding.

These results suggest that when discrete patterns must be presented quickly, as would be the case when large amounts of discrete stimulus information must be presented in a short period of time (as in a briefing), pictorial presentation should be used in preference to visual verbal presentation. Obviously, further research is needed to establish whether these baseline findings can be generalized to the more complex conceptual materials used in flying training.

Audiovisual Redundancy

Redundancy exists when the same information is given in two or more different ways. In concept-formation studies using pictorial stimulus materials, stimulus redundancy has been shown to be beneficial under a wide variety of task conditions. Although it is widely believed that providing auditory (verbal) information which is redundant with pictorial information is highly beneficial in learning, there is very little evidence to support this belief. The purpose of this experiment was to determine if presenting redundant auditory information would improve performance over that found with pictorial presentation alone.

Two methods of introducing auditory redundancy were used. The first was to describe to the subject the exact pattern he was seeing (e.g., "the pattern on this card is one large red square"). This added redundancy information was not expected to aid performance, since the stimulus characteristics showing on the card were obvious to all subjects. The second method of adding redundancy was to describe to the subject the "truth table" representation of the stimulus pattern, as shown in the first two columns of Table 2 (e.g., "this pattern is not-blue, not-triangle"). Two rules were used, inclusive disjunction and biconditional. It has been proposed that much of the extreme difficulty of the biconditional rule results from the inability of the unskilled subject to recode the stimulus pattern to its truth-table representation. If this is the case, then teaching the subject its representation should help performance.

Each subject learned either a disjunctive or biconditional concept under one of three redundancy conditions (no redundancy, complete pattern descrption, or truth-table description). The results showed no significant difference for the three redundancy conditions. If anything, performance without the verbal cue was slightly superior, suggesting the possibility that the verbal cues may have distracted subjects from thetask. The results make it clear that describing to the subject what he is seeing is of no help when the stimulus materials are simple and schematic as they are in these experiments. Even with the much more difficult biconditional rule, there is no benefit, a finding which tends to contradict previous interpretations of biconditional difficulty as stemming from inability to reduce stimulus patterns to truth-table categories.

Redundancy with Nonconjunctive Concepts

Previous studies of stimulus redundancy in multidimensional concept formation had always used conjunctive concepts in which every combination of levels of the relevant dimensions was represented by a separate response category. For example, with color and shape relevant, using two-level dimensions, the four response categories might be red squares, red triangles, green squares, and green triangles. Three-level dimensions had never been studied, nor had the more common two-category response scheme used in these experiments, in which the positive category is defined by one attribute combination (e.g., red squares) and all other combinations form the negative category. Finally, redundancy in disjunctive concepts had not been studied. The purpose of this experiment was to extend previous findings to the two-choice response scheme, to disjunctive concepts, and to stimulus dimensions with more than two levels.

The task and procedure were essentially the same used in the first experiment. Each subject learned one of three classification schemes, two-choice conjunction, four-choice conjunction, and two-choice inclusive disjunction. Redundancy was introduced by correlating the levels of the stimulus dimensions; for example, if size and number were redundant, small patterns were always single, medium patterns double, and large patterns triple. Two levels of redundancy were used, zero redundancy and two redundant relevant dimensions (e.g., size redundant with number and color redundant with shape). The intermediate condition of one redundant dimension was not used.

The results confirm and extend previous findings in the study of redundancy. There is a redundancy gain under all conditions, and the gain is greater for the more difficult problems. These results thus provide no surprises, and it appears that previous findings can be generalized to nonconjunctive rules and to different kinds of response schemes.

IX. IMPLICATIONS OF INFORMATION PROCESSING FOR FLYING TRAINING

Visual and Auditory Scanning and Interference

The present work clearly demonstrates that events emanating from both the external environment and the subject's own processing of information produce delilitating effects on memory. We have shown that stimulus events, extraneous to the task, when presented in close temporal proximity to the actual information processing, cause this processing to be ineffectual. Similarly, the sheer act of evaluation and comparison of stimuli interferes with recall of previously processed material. In other words, interference with processing is both a self-induced and externally-induced phenomenon.

The empirical findings suggest several guidelines for preventing interference with information processing. For example, if the interfering event is delayed with respect to the initial processing, the extraneous stimulus will have little effect on performance. Similarly introduction of a potentially interfering event to a processing channel independent of the channel involved in active processing will hardly affect performance. In addition, it has been shown that appreciable rehearsal of the to-be-learned material can attenuate interference with processing. These summary statements appear to govern information processing of both simple and complex material presented to auditory and visual modalities.

The obtained data have direct implications for flying training. For example, in flying an aircraft, decisions are based on information obtained from scanning a control panel. Can we instruct the pilot as to the optimal strategy for processing arrays of visual information? The answer appears to be affirmative. Recall that the results of the visual information-processing experiment described above indicated that observers tended to have consistent strategies for visual scanning. In the auditory experiment it was observed that when rehearsal of items in memory is permitted, memory for this information was facilitated. And finally, a comparison of the auditory and visual processing experiments strongly suggested that when information is amenable to verbal coding, as was the case for memory for English letters, interference emanating from retrieval processes is minimized.

Let us now apply the empirical results in developing an optimal scanning procedure. Scanning should proceed at a slow but steady rate, allowing processing of such successive items of information on the control panel. The attempt here should be to allot enough time, say a fraction of a second, for processing and rehearsing of each reading on the control panel. Each instrument reading should be fully coded before additional information is scanned. A verbal code, rather than a pictorial or figural representation in visual memory, is required if subsequent recall is to be maximized. Observe that the process should be serial, with information being processed item by item. Obviously, a great deal of additional research needs to be devoted to developing actual teaching methods for imparting this strategy to student pilots. The important issue here is that such an approach lies within the bounds of educational technology.

It is further speculated that nonoptimal scanning strategies are employed by student pilots in scanning and processing control panels. It is proposed that follow-up research be devoted to examining the actual visual scans of the eyeball when processing information in the cockpit. This can easily be carried out with existing physiological recording instruments. Physiological scanning data could be correlated with actual flying performance measured either in the simulation laboratory or in actual flight. The effort would focus on defining the relationship between objective measures of scanning with actual information processing.

Auditory-Verbal Information Processing

Research by Gopher and Kahneman (1971) indicated potential utility of tasks employing selective attention and short-term memory for predicting an individual's chance of success in pilot training. Several advances were made in this area in the present research employing dichotic listening. First, approximately 80% of the variance in dichotic performance was accounted for by digit span. This result suggests that digit spans should be assessed for pilot trainees in a longitudinal screening study. This can be accomplished with minimal demand of trainee time. Twenty or thirty members of a class could be tested at a time and only 15-20 minutes would be required for test administration. The predictive value of digit span could be assessed in several classes. If it were found that trainees with lower digit spans had a higher probability of being dismissed from the program two approaches could be taken. First, digit span could be used as a screening device for the program. In this approach, a minimum digit span (e.g., 7 digits) would be set up as a criterion for admission into the program. Those falling below that digit span would not be selected. Second, an information processing training program could be initiated for individuals with a low probability of completing pilot training. These individuals could be given training in tasks involving selective attention and short-term memory with the aim that some of these abilities can be improved with practice. In this latter case, the digit span data would be used as a screening device for additional training and not for dismissal.

Another major advance in the present research was the finding that a redundant acoustic locution at the end of a stimulus list (stimulus suffix) interfered with the retention of items thought to be relatively unanalyzed following stimulus presentation. Further, the magnitude of the impairment was in direct proportion to the disparities between an individual's digit span and the number of digits in the series presented for auditory processing.

Previous research with stimulus suffix effects has indicated that the greatest impairment of retention occurs when the suffix is physically similar (same pitch, intensity, and tempo) to the stimulus list. Consistent with the present research these data point up some implications for transmitting auditory-verbal information. The capacity for receiving information is sharply limited. To be effective it is suggested that messages be kept short. The suffix experiments suggest that if two messages are to be received in rapid succession, it would be more efficient if the second message were spoken in a different voice or at a different intensity than the first message. This enables the pilot to rapidly shift attention to the second message and precludes loss of some first message information due to second message presentation.

Audiovisual Concept Formation

The concept-formation studies conducted as part of this research program employed problem-solving methods comparable to those used in the popular "learning-by-discovery" techniques. They are directly applicable to instructional situations in which the subject is attempting to learn, by trial-and-error or discovery, simple concepts representing compounds of discrete stimulus elements. Two major findings are evident from the present research.

The first finding stems from the experiments comparing visual and auditory presentation. The results show clearly that, with simple problems using discrete stimulus characteristics, it makes no difference whether the subject receives the information through pictorial, printed verbal, or auditory-verbal methods--provided there is unlimited time to inspect the stimulus pattern and generate a response. When inspection/response time is severely limited, pictorial presentation is superior to printed verbal presentation, apparently because it takes longer to read and understand the words than to abstract the same material from a pictorial stimulus.

The second major finding concerns audiovisual redundancy. Describing simple visual patterns verbally to the subject is of no benefit and may, in fact, distract the subject so as to interfere with performance. Considered in the light of previous research, this finding suggests that "show-and-tell" is of benefit primarily with complex materials, or materials in which the relevant visual characteristics are either obscure or change rapidly over time.

Conclusion

The present work has developed several principles underlying information processing of visual and auditory stimuli. We refer to the principles of channel capacity, rehearsal, coding, stimulus and response-induced interference. As a direct result of this work, tools have been made available with which to probe nonoptimal processing strategies of student pilots and to teach more effective techniques for flying. The follow-up research to the present program will include a greater emphasis on information overload and continuity in the task.

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