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DEPARTMENT OF PSYCHOLOGY

Final Report

HUMAN PERFORMANCE IN INFORMATION PROCESSING AND STORAGE

Arthur W. Melton

ORA Project 05823

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PART I

TERMS AND OBJECTIVES OF THE CONTRACT PROGRAM

Contract No. AF 49(638)-1235 between the Air Force Office of Scientific Research and the University of Michigan was initiated June 1, 1963, with Dr. Paul M. Fitts as Principal Investigator. The term of the original contract was from June 1, 1963, to September 30, 1965. Supplemental Agreement No. 1(65-384), dated 1 May 1965, extended the term of the contract from October 1, 1965, to May 31, 1967, with additional funds. Change Order No. 2(65-412), dated 25 May 1965, changed the designated Principal Investigator from Dr. Paul M. Fitts to Dr. A. W. Melton, as a consequence of the death of Dr. Fitts on May 2, 1965. The program of research which was initiated under Contract No. AF 49(638)-1235 has been extended by Contract No. AF 49 (638)-1736 to cover the period from June 1, 1967, through May 31, 1969.

The statement of work specified that research would be conducted in the general field of Engineering Psychology, and specifically:

> "The contractor will conduct research on human performance. This research will be designed to produce a taxonomy of human information-processing functions to determine human capabilities and limitations in fulfilling basic information-processing functions, (~~and~~) to develop a model of human short-term memory, (and) to conduct such other studies and carry out such other activities as may seem desirable in the interest of advancing basic knowledge of human information processes, or application of that knowledge to military planning and operations, or the design of military systems."

The original proposal for this contract was entitled "A Human Performance Center" (February 15, 1963). It stressed the need for the establishment, in a University environment, of a laboratory for the study of human information processing skills (Dr. Paul M. Fitts), human memory capabilities (Dr. A. W. Melton), and information use in decision processes

(Drs. Ward Edwards and William L. Hays). At the request of ARPA, the research on decision processes was deleted from a revised proposal entitled "A Program of Research on Human Performance in Information Processing and Storage" (April 22, 1963), because that research was being supported by the Air Force Systems Command. However, the present contract remained the sufficient basis for the establishment of a Human Performance Center in the Department of Psychology, University of Michigan in June 1963, and the subsequent provision, by the University of Michigan, of required space and administrative support for such a Center.

Thus, an implicit obligation of the Principal Investigators on this contract has been the development of a permanent research facility for the investigation of human performance capabilities and limitations that are of importance for the performance of man in a wide variety of man-machine systems. Further, this obligation extended to the utilization of the facility, and the equipment and funds provided by the contract, not only for the conduct of the required research but also for the education and training of pre-doctoral and post-doctoral students to conduct such research. Since an accounting of the success of this implicit objective serves to identify the senior and junior research personnel involved in producing the research results to be reported, and also the research facilities and equipment made possible by the contract, data on the resources employed by the contract will be considered in Part II of this report and followed, in Part III, with a summary of the technical program accomplishments.

PART II

RESEARCH PERSONNEL AND FACILITIES

Research Facility

After the first summer of operations (1963), all senior scientists, research assistants and support personnel associated with this project had offices and laboratories within the Human Performance Center of the Department of Psychology. From October, 1963, to April, 1966, the Human Performance Center was located in remodeled space in the West Physics Building. In April, 1966, it moved to exceptionally adequate space in the Perry Building, 330 Packard Road, which was remodeled to accommodate the special requirements of the Human Performance Center and the project. Of the net 12,300 sq. ft. available for the functions of the Center, approximately 5,600 sq. ft. are occupied by staff and students engaged in research on the project, with 3,700 sq. ft. occupied by other projects under the direction of Dr. Pew (NASA) and Dr. Edwards (NASA, AFOSR, NIH, and Wood-Kalb Foundation), with 3,000 sq. ft. given over to general Center functions (Library, Electronics Shop, Stores, Seminar Room, and Undergraduate Laboratories for laboratory courses in human experimental psychology that are (generally) taught by staff of the Center).

Research Personnel

The program budget for the 4-year contract called for 2.52 man-years/yr. of senior scientists (who in all cases except visiting scientists have academic appointments and undergraduate and/or graduate teaching responsibilities), and for 4.58 man-years/yr. of graduate research assistance. Table 1 shows the research time charged to project funds, and also shows identifiable time spent on project work even though the individual was compensated from other sources (pre-doctoral and post-doctoral fellowships and

Table 1

Man Years Per Year of Project Efforts With or Without Project Compensation

Classification of Effort	Budgeted	Actual Effort: Project Funds	Actual Effort: Other Funds	Total
Senior Staff (Faculty and Visiting Scientists)	2.52	2.30	.04	2.34
Post-Doctoral Fellows and Trainees	-	-	.75	.75
Graduate Research Assistants	4.58	6.00	1.25	7.25
Totals (man years/yr.)	7.10	8.30	2.04	10.34

traineeships or volunteered time). As may be seen, the total senior staff effort (2.30 my/y) was less than planned. This is attributable entirely to the death of Professor Fitts on May 2, 1965, and our inability to acquire a suitable replacement. The work loads of others in the Human Performance Center (principally, Professors Melton, Edwards, and Pew) were adjusted to accomodate an increase in their effort on the project. Substantial assistance to the project in this time of stress was also given, without project compensation, by Professor Irwin Pollack and Associate Professor Daniel Weintraub, who took over the supervision of three doctoral dissertations that were initiated under Professor Fitts. Finally, the supervisory work-load, as reflected in the man-years of graduate research assistants on the project, was maintained at a higher than budgeted level (6.00 my/y versus the budgeted 4.58 my/y).

The support of project work by other funds is an expected consequence of becoming an identifiable facility for research of a programmatic nature, such as the Human Performance Center. This "free" effort toward the goals of the project accounts for 2.04 man-years/yr. of effort, as shown in

Table 1. This represents the contributions of individuals who worked in the Center under the direction of the staff of the project while holding pre-doctoral fellowships or traineeships (NSF, NIH, NASA, and Rotary International were represented), post-doctoral fellowships (NSF, and AAUW are represented), or appointments in the NSF-sponsored Summer Research Participation Projects for post-doctoral college teachers.

The details regarding all categories of senior research personnel involved in the project are shown in Table 2. This table lists separately the project staff who were on the regular staff of the Human Performance Center and the Department of Psychology, visiting scientists on the project, post-doctoral fellows who worked on project problems and in association with a member of the permanent staff, summer post-doctoral research participants, and consultants (not counted in manpower data).

Table 2

RESEARCH PERSONNEL

Permanent Staff	Dates of Service	Man-Months
Professor Paul M. Fitts (Psychology) (Ph.D., Univ. of Rochester, 1938)	1 Jun 63-2 May 65	13.5
Professor Arthur W. Melton (Psychology) (Ph.D., Yale Univ., 1932)	1 Jun 63-31 May 67	21.9
Assoc. Prof. W. M. Kincaid (Mathematics) (Ph.D., Brown Univ., 1946)	1 Jun 63-31 May 67	7.4
Professor Ward Edwards (Psychology) (Ph.D., Harvard Univ., 1952)	1 Jul 63-31 May 67	3.3
Asst. Prof. Edwin J. Martin (Psychology) (Ph.D., Univ. of Iowa, 1963)	1 Sep 63-31 May 67	19.0
Asst. Prof. Richard W. Pew (Psychology) (Ph.D., Univ. of Michigan, 1963)	1 Jun 63-31 May 67	15.2
Asst. Prof. Judith P. Goggin (Psychology) (Ph.D., Univ. of California, Berkeley, 1964)	1 Sep 65-31 May 67	9.3
Asst. Prof. Robert A. Bjork (Psychology) (Ph.D., Stanford Univ., 1966)	1 Sep 66-31 May 67	0.3

Table 2 (Continued)

Visiting Scientists

Dr. R. Conrad (Assoc. Director APRU, Cambridge, England) (Ph.D., Univ of Cambridge, 1953)	1 Sep 64-15 Apr 65	7.5
Dr. Jerzy Ekel (Asst. Prof., Univ. of Warsaw, Poland) (Ph.D., Univ. of Warsaw, 1963)	1 Feb 65- 1 Aug 65	6.0
Dr. Alfred H. Fuchs (Asst. Prof., Bowdoin College, Maine) (Ph.D., Ohio State Univ., 1960)	15 Jun 65-15 Aug 65	2.0
Dr. Daniel Kahneman (Lecturer, Hebrew Univ., Jerusalem) (Ph.D. Univ. of California, Berkeley, 1961)	1 Jun 66-31 Aug 66	3.0
Dr. Michael I. Posner (Asst. Prof., Univ. of Wisconsin) (Ph.D., Univ. of Michigan, 1962)	15 Jun 64-31 Aug 64	2.5

Post-Doctoral Fellows

Dr. Judith P. Goggin, NSF Post-Doctoral Fellow (Ph.D., Univ. of California, Berkeley, 1964)	1 Sep 64- 1 Aug 65
Dr. Valeria Cavazzuti, AAUW Fellowship (Ed.D., Univ. of Bologna, 1964)	1 Sep 66- 1 May 67

Summer Post-Doctoral Research Participants (on NSF grant to Univ. of Michigan)

The following participated in research studies under the supervision of Professor Melton, and with the support of the project because a contribution to the project was anticipated. The NSF Grant provided support for the individual for 2 months in every case.

Summer of 1963

Dr. Alfred H. Fuchs (Ph.D., Ohio State Univ., 1962), Asst. Prof., Bowdoin College, New Brunswick, Maine.

Dr. Archie B. Carran (Ph.D., Univ. of Cincinnati. 1960), Asst. Prof., Beloit College, Beloit, Wisconsin.

Dr. Donald A. Schumsky (Ph.D., Tulane Univ., 1962), Asst. Prof., Univ. of Cincinnati, Cincinnati, Ohio.

Summer of 1964

Dr. Alfred H. Fuchs (Ph.D., Ohio State Univ., 1962), Asst. Prof., Bowdoin College, New Brunswick, Maine.

Dr. James L. Fozard (Ph.D., Lehigh Univ., 1961), Asst. Prof., Colby College, Waterville, Maine.

Dr. John C. Jahnke (Ph.D., Northwestern Univ., 1955), Assoc. Prof., Miami University, Oxford, Ohio

Dr. Frank C. Leeming (Ph.D., Univ. of Mississippi, 1963), Asst. Prof., Memphis State Univ., Memphis, Tennessee.

Table 2 (Continued)

Summer of 1965

Dr. Richard Kammann (Ph.D., Univ. of Cincinnati, 1964), Asst. Prof., Oakland Univ., Rochester, Michigan.

Dr. Ethel Weiss (Ph.D., New School for Social Research, 1963), Asst. Prof., Bard College, Annandale-on-Hudson, New York.

Summer of 1966

Dr. David S. Gorfein (Ph.D., Columbia Univ., 1962), Asst. Prof., New College, Sarasota, Florida.

Dr. John C. Jahnke (Ph.D., Northwestern Univ., 1955), Assoc. Prof., Miami University, Oxford, Ohio.

Dr. Ethel Weiss (Ph.D., New School for Social Research, 1963), Asst. Prof., Bard College, Annandale-on-Hudson, New York.

Consultants

Bertelson, Prof. Paul	Professor of Psychology University of Brussels	Sept. 10-12, 1963
Bower, Dr. Gordon H.	Assoc. Prof. of Psychology Stanford University	Dec. 7-9, 1964
Broadbent, Dr. D. E.	Director, Medical Research Council Applied Psychology Research Unit, Cambridge, England.	Aug. 4-6, 1963
Crossman, Dr. E. R. F.	Department of Psychology University of Oxford, Oxford, England	Nov. 5-6, 1963
Elkind, Dr. Jerome I.	Bolt, Beranek and Newman Cambridge, Massachusetts	Feb. 17-18, 1964
Haber, Dr. Ralph N.	Assoc. Prof. of Psychology University of Rochester	Feb. 14-15, 1967
Johnson, Dr. Neal F.	Assoc. Prof. of Psychology Ohio State University	Sept. 18-19, 1966
Leibowitz, Dr. H. W.	Professor of Psychology Pennsylvania State Univ.	Feb. 1, 1967
Morton, Dr. John	Medical Research Council Applied Psychology Research Unit, Cambridge, England	Mar. 27-28, 1967
Murdock, Dr. B. B., Jr.	Professor of Psychology University of Toronto	Nov. 29-30, 1966
Peterson, Dr. L. R.	Professor of Psychology University of Indiana	Mar. 14-15, 1967
Posner, Dr. Michael I.	Assoc. Prof. of Psychology University of Oregon	Jul. 19-22, 1966

Table 2 (Continued)

Postman, Dr. Leo	Professor of Psychology Univ. of California, Berkeley	Jan. 22-23, 1965
Rappaport, Dr. Maurice	Stanford Research Institute	Jan. 23-24, 1964
Sternberg, Dr. Saul	Bell Telephone Laboratories	Nov. 11-12, 1965
Tulving, Dr. Endel	Professor of Psychology University of Toronto	Apr. 18-19, 1967
Wickens, Dr. D. D.	Professor of Psychology Ohio State University	Oct. 17-18, 1963

Research Assistance and Training

Table 3 lists the 33 graduate research assistants who have worked on the project during the 4-year period. All but 5 of those listed (Poirier, Radford, Robb, Rossman, and Steinberg) are or were students in the doctoral program in Psychology at the University of Michigan, and of these 28, 24 have had a continuing identification with the project until graduation or the conversion of the project from Contract No. AF 49(638)-1235 to Contract No. AF 49(638)-1736 on June 1, 1967.

Table 3

GRADUATE RESEARCH ASSISTANTS

Student	Highest Degree	Status:31 May 67	Man-Months ARPA	Man-Months Other
Adams, R. A. S.	A.B., Univ. Adelaide, Australia, 1966	Year II GS, Exper. Psychology, HPC	1	2
Beatty, J. T.	A. B., Univ. Michigan, 1964	Year III GS (Psychol.) Transferred from HPC	7	0
Bernbach, H. A.	Ph.D., Univ. Michigan, 1965	Asst. Prof., Cornell University	6	3
Biederman, I.	Ph.D., Univ. Michigan, 1966	Asst. Prof., State Univ. of New York at Buffalo	4	4
Bronstad, G. W.	M.A., Univ. Michigan, 1965	Leave of Absence	0	3

Table 3 (Continued)

Collins, A. M.	B.B.A., Univ. Michigan, 1959	Candidate for Ph.D. at Univ. Michigan, 1967. To Bolt, Beranek, and Newman, Cambridge, Mass.	16	0
Crowder, R. G.	Ph.D., Univ. Michigan, 1965	Asst. Prof., Yale Univ.	7	0
Egeth, H.	Ph.D., Univ. Michigan, 1965	Asst. Prof., Johns Hopkins Univ.	5	0
Gardner, G. T.	A.B., Univ. Michigan, 1965	Year III GS, Exper. Psychology, HPC	7	4
Garskof, M.	A.B., Douglass College, Rutgers Univ., 1965	Year III GS, Exper. Psychology, HPC	9	2
Gelfand, H.	A.B., Univ. California at Los Angeles, 1963	Candidate for Ph.D. at Univ. Michigan, 1967. To Iowa State Univ.	8	0
Head, S. R.	A.B., Harvard Univ., 1965	Year III GS, Exper. Psychology, HPC	12	0
Kamlet, A.	M.S.E., Univ. Michigan, 1963; M.A., Univ. Michigan, 1965	Candidate for Ph.D. at Univ. Michigan, 1967. To Eng. Psychol. Lab., Aberdeen Proving Gd.	10	4
Ligon, E.	A.B., Univ. Florida 1963 (Mathematics)	Candidate for Ph.D. at Univ. Michigan, 1967.	3	8
Lively, B. L.	M.A Kent State Univ., 1964	Candidate for Ph.D. at Univ. Michigan, 1967. To Bowdoin College	8	5
Nemiroff, B.	A.B., Univ. Michigan, 1964	Year III GS, Psychology, Not HPC	1	0
Noyd, D. E.	A. B., Washington State Univ., 195[illegible]	Candidate for Ph.D. at Univ. Michigan, 1967. Capt. USAF, Cannon AFB	0	8
Peterson, J. R.	Ph.D., Univ. Michigan, 1965 (Eng. Psychol.)	Research: Minneapolis-Honeywell	5	0
Poirier, M. L.	A.B., Univ. Michigan, 1962	Not a GS at Univ. of Michigan	13	0
Radford, B. K.	A.B., Univ. Michigan, 1961	Not a GS at Univ. of Michigan	16	0
Reicher, G. M.	A.B., Univ. California at Berkeley, 1963	Candidate for Ph.D. at Univ. Michigan, 1967. To Univ. of Oregon	27	0
Robb, M.	Ph.D., Univ. Michigan, 1965 (Phys. Ed.)	Assoc. Prof., State Univ. of New York at Courtland	5	0
Roberts, K. H.	A.B., Univ. Michigan, 1962	Year III GS, Exper. Psychology, HPC	21	0

Table 3 (Continued)

Rossman, E.	A B., Univ. Wisconsin, 1965	GS (Psychol.) at Univ. California at Berkeley	6	0
Rubin, E.	M.A., Kansas State Univ. 1965	GS (Educ. and Psychol.) Univ. Michigan	4	0
Rubin, S. M.	A.B., City College of New York, 1962	Candidate for Ph.D. at Univ. Michigan, 1967. To Oberlin College	12	2
Shulman, H. G.	A. B., Univ. Rochester, 1965	Year III GS, Exper Psychology, HPC	8	2
Smith, E. E.	Ph.D., Univ. Michigan, 1965	Res. Officer, U.S. Public Health Service St. Elizabeths Hosp.	6	6
Steinberg, M.	A.B., Univ. Michigan, 1966	Not a GS at Univ. of Michigan	5	0
Thomas, J. K.	A.B., Univ. Michigan, 1963	Year III GS, Exper. Psychology, HPC	20	2
Triggs, T. J.	M.Eng. Sci. Univ. of Sydney, Australia, 1967	Candidate for Ph.D. at Univ. Michigan, 1967. (Engineering Psychol.)	17	2
Tversky, B.	A.B., Univ. Michigan, 1963	Candidate for Ph.D. at Univ. Michigan, 1967.	5	0
Wattenbarger, B.	A.B., Oklahoma State Univ., 1965	Year III GS, Exper. Psychology, HPC	4	3

Up to May 31, 1967, 6 of the 24 Graduate Research Assistants who were committed to the human performance area had received the Ph.D. in Psychology (Experimental Psychology or Engineering Psychology) based on a doctoral dissertation that represented a major contribution to the work of the project. These students have been well-placed in universities (Cornell, Johns Hopkins, State University of New York at Buffalo, and Yale) and in industrial (Minneapolis-Honeywell) and government (Public Health Service) research units. They have, with no exception, continued active research along the lines fostered by the project and reflected in their doctoral dissertations, the titles of which follow (in date order):

Crowder, R. G. Verbal short-term memory as a function of degree of learning on a perceptual-motor interpolated activity. University of Michigan Report 05823-3-T, December, 1964. (Supervisor: Prof. A. W. Melton)

Bernbach, H. A. Stimulus learning and recognition in paired-associate learning. University of Michigan Report 05823-7-T, August, 1965. (Supervisor: Prof. A. W. Melton and J. D. Birch)

Peterson, J. R. Effects of S-R coding on the rate of gain of information. University of Michigan Report 05823-8-T, December, 1965. (Supervisor: Prof. P. M. Fitts, then Asst. Prof. R. W. Pew)

Smith, E. E. The effect of familiarity on the perceptual recognition and categorization of verbal information. University of Michigan Report 05823-9-T, December, 1965. (Supervisor: Prof. P. M. Fitts, then Prof. A. W. Melton)

Egeth, H. E. Parallel versus serial processes in multidimensional stimulus discrimination. Human Performance Center Technical Report No. 2, January, 1966. (Supervisor: Prof. P. M. Fitts, then Assoc. Prof. Daniel J. Weintraub)

Biederman, I. Human performance in contingent information processing tasks. Human Performance Center Technical Report No. 3, October, 1966. (Supervisor: Prof. P. M. Fitts, then Prof. A. W. Melton)

At the termination of the contract on May 31, 1967, ten doctoral dissertations were in progress under contract auspices, with the expectation that they would be completed before the end of 1967. So far, 6 of these 10 students have been well-placed in colleges and universities (Bowdoin, Iowa State University, Oberlin, and Oregon), or in independent (Bolt, Beranek and Newman) or government (Human Engineering Laboratory, Aberdeen Proving Ground) where they may be expected to continue active research in the areas of project interest, as reflected in the topics of their doctoral dissertations, which follow (tentative titles):

Collins, A. M. Repetition effects in visual short-term memory. (Supervisor: Assoc. Prof. E. J. Martin)

Gelfand, H. Interresponse times as a measure of idiosyncratic and normative organization in free recall. (Supervisor: Prof. A. W. Melton)

Kamlet, A. S. Temporal factors in the utilization of coding rules. (Supervisor: Prof. I. Pollack)

Ligon, E. The role of amount and similarity of prior and interpolated activity in short-term memory. (Supervisor: Prof. A. W. Melton)

Lively, B. L. The von Restorff effect in short-term memory. (Supervisor: Prof. A. W. Melton)

Noyd, D. E. Proactive and intrastimulus interference in short-term memory for two-, three-, and five-word stimuli. (Supervisor: Prof. A. W. Melton)

Reicher, G. M. Perceptual recognition of letters as a function of the amount and meaningfulness of material and time for processing. (Supervisor: Prof. A. W. Melton)

Rubin, S. M. The effect of stimulus modality on proactive and retroactive inhibition in short-term memory. (Supervisor: Prof. A. W. Melton)

Triggs, T. J. Choice responses to two successive signals: The effects of instructional set, predictability of interval and S-R compatibility. (Supervisor: Prof. I. Pollack)

Tversky, B. Effects of retrieval task condition on the selective encoding of information for memory storage. (Supervisor: Prof. A. W. Melton)

Seven of the remaining 8 of the 24 graduate students are beginning Year III of graduate work in the project, and 1 is beginning Year II. In view of the continuation of the project after May 31, 1967, under Contract No. AF 49(638)-1738, and in view of the small Year II "class," the project has contracted with 8 first-year graduate students for research assistance during the academic year 1967-1968. All of these students were attracted to the project by the areas of research on human performance that it empahsizes.

Research Equipment

One explicit objective of the contract program was the development of equipment, and the necessary methods and procedures for its use, that would adapt advanced instrumentation techniques to the advancement of the variety, flexibility, and precision of the experimental analysis of human information handling processes and short-term memory. The major special-purpose equipments developed, procured, or used in this program are described in the following paragraphs:

1. Automatic Reaction Time Equipment. This device is a completely automatic system for the display of alphanumeric (or other predetermined)

stimuli and the recording of the accuracy and speed of response. A number of different stimulus display and response-key consoles may be employed with the equipment. Feedback for speed and accuracy of response is likewise automatic, given that certain arbitrary dichotomies of speed are employed. This equipment was used by Dr. Fitts in an extended series of studies of the effect of differential payoff for speed and accuracy in choice reaction time; also by Dr. Biederman in his research on contingent information processing. While it is no longer considered adequate for the speed-accuracy trade-off problem, in view of the use of a dichotomy of speed rather than a continuum, it is serving many research purposes in the information-handing area.

2. Continuous Recognition Memory Device (CRM-1). This device is designed for use with one subject in studies of continuous sequential testing of recognition memory for any type of visual information that can be reduced to 35 mm. slide projection. Stimuli are back projected on a milk-glass screen by means of a Carousel slide projector or Graflex film-strip projector. Dials control the overall duration of (a) the display, (b) the time allowed for S to respond before a "respond now" signal occurs, and (c) the time allowed for recording S's response and/or providing feedback on correctness. Several different push-button response panels may be used, with some providing for only "old" or "new" responses, others providing for 3 or 5 levels of confidence for each judgment. Feedback panels inform S either that he is right or wrong in his judgment, or that his response should have been "old" or "new." The identity and latency of key-press responses are recorded on event-recorders and printing timers. The system has been used in a number of early studies of short-term "continuous" recognition memory.

3. Multiple-Subject Continuous Recognition Memory Device (CRM-2). This device consists of a Carousel slide projector or Graflex film-strip projector for stimulus presentation, a 3-event recycling timer, a high-speed paper-tape punch, and push-button response consoles for 5 subjects. These response consoles allow differentiation of up to 5 levels of confidence for each response ("old" or "new"). Programs are available for computer analysis of the paper-tape records. This apparatus has been used extensively in studies of recognition memory, the relation between stimulus recognition and paired-associate learning, and the relation between recognition of repetition of stimuli and their retrieval in free recall.

4. Double-Projector STM Device (STM-1). This device uses two Carousel slide projectors for the separate display of to-be-remembered information and stimuli for rehearsal-preventing "filler" activity, both in the "simultaneous" mode of visual presentation. There is no interval (or "dark" time) between the disappearance of the to-be-remembered material and the "filler" material. A control console allows the experimenter to vary the exposure duration of the to-be-remembered material (range, .25 to 4.00 sec.), the duration (1 to 8 sec.) and number (1 to 8) of "filler" slides, and the durations of "rest" and "ready" intervals between tests. The automatic control of the duration of the to-be-remembered information may be overridden by the E or S when duration is defined as one "reading" or S-paced "study period." This equipment was heavily used during the first 3 years of the project, and has been overhauled and extensively redesigned within the past year.

5. Sequential Visual STM Device (STM-2). This device combines a BinaView display device and a punch-tape reader, for high-speed sequential presentation of alphanumeric characters in studies of very-short-term memory. The punch-tape reader programs not only the specific letters or digits to be seen but also the independently defined duration of presentation of each character. The principal purpose of this device is to require S to read off each element as it appears (4 digits/sec. or 3 consonants/sec.) in a "shadowing" procedure, and then present one element of the series as a test "probe," with S required to recall the element that followed the probe element. After extended preliminary studies, this equipment has been used in a doctoral thesis now nearing completion (E. Ligon). Two other slightly varying forms of the device have been assembled during the past year.

6. Mylrea 16-Channel Projector. This device, which was designed by Dr. Fitts and Mr. Mylrea, permits the tape-programmed display of up to 16 different stimuli, either simultaneously or sequentially, with microsecond turn-on time for each stimulus. Durations of presentation and sequences or combinations of stimuli are determined by external systems. This device has been extensively employed in studies of selective factors in information handling, and was judged sufficiently novel to warrant publication of a description (see Mylrea, K. C., American Journal of Psychology, 1966, 79, 314-317).

7. 10-Channel Block Display Device. This device was designed by Dr. Melton and Mr. Bielby. By means of a high-speed block tape-reader and a specially devised memory and timing system, the device may be used for simultaneous or successive display of 1 to 10 alphanumeric characters or nonsense characters constructed from the 17 elements in each display unit, with no more than 10 msec. "dark time" between successive displays in the same unit if the duration of each display is at least 150 msec. Stimuli may be displayed sequentially in the same single unit or block of units (up to 10), in different units in the 10-unit block with or without correlation of temporal and spatial position, or in stepping sequence (in the manner of the Times Square news sign) across the blocks. The duration of each display within a sequence may be individually determined, within a set of 16 fixed times ranging from .25 sec. to several seconds, by the same punched tape that defines the character to be displayed. While this device was constructed to serve specific experimental studies of the rate of presentation and the effect of spatial-temporal order correlation on short-term memory, it has general utility for a wide variety of studies of information processing and short-term memory that were not heretofore possible without a digital computer.

8. 3-Channel Tachistoscope. This is a procured device (Scientific Prototype Model GB) which permits a wide range of durations of exposure, and control of pre-exposure and post-exposure fields, for studies of perceptual, attentional, and memory factors in visual stimulus detection and identification, of the characteristics of preperceptual visual information storage, and of times required for various higher-order information processing tasks (filtering, condensing, transforming, contingent processing). It has been heavily employed in research since it was delivered on 1 Decmeber 1965.

9. Pupillary Response Recorder. Initial studies of the pupillary response as an index of the difficulty of information-processing in progress within the subject were accomplished with a borrowed 35-mm. camera (Grass

C4-D) and infra-red film. In view of the promising results of the research, an improved camera set-up which employs a Bolex camera and 16-mm. infra-red film has been assembled. This equipment is suitable for a wide variety of studies of short-term memory and information-handling in which an objective index of the subject's information-processing effort may yield information of exceptional value in the refinement of theory.

10. PDP-1 Digital Computer. This device became available for project work on completion of Dr. Ward Edwards' contract with the Decision Sciences Laboratory, Air Force Electronic Systems Division, and has been used with great benefit in four project studies, two of which would not have been possible without it. A proposal has been submitted (A. W. Melton, Principal Investigator) for the retention of this equipment for use on this ARPA project and further studies of decision processes by Dr. Edwards (now supported by AFOSR and NASA). However, no final decision has been announced. If retained, the University of Michigan will replace ancillary equipment removed by another contractor (AEC supported) when a joint-use agreement was terminated. This equipment has made possible the discovery of a critical limitation of the trade-off of speed and accuracy in reaction-time studies, and of the "random-walk" model for the decision process involved therein. Also, it has made possible the exploration of the "stimulus-correction" procedure in studies of learning and memory (a procedure in which the S is shown the stimulus appropriate to the response he made, rather than the response appropriate to the stimulus shown as a cue, which is the traditional method). Finally, the PDP-1 Computer has been used extensively in the preparation of punch-tape stimulus sequences and condition sequences for all studies involving punch-tape programs. These studies make clear that the further work of the project (under Contract No. AF 49(638)-1736) will require a digital computer with at least the capabilities of the PDP-1.

PART III

RESEARCH PROGRAM*

A. Taxonomy of Human Information Handling

Our work on a taxonomy for the field of human performance has been focused at two levels. On the one had we have worked on a description that emphasizes the classification of information processing tasks at a macroscopic level. The essence of the taxonomy we are developing at this level is embodied in the papers of Posner (1964, 1965, 1967) and of Fitts (1964, 1967).

Tasks are classified as to whether they are information conserving (one to one mapping of stimuli to responses) or information reducing (many-to-one mapping of stimuli to responses). Within the class of information reducing tasks we have identified three distinct types:

(1) Gating or filtering tasks in which, on the basis of preparatory set or attention, some information can be ignored;

(2) Classification tasks in which information must be labeled or assigned to supraordinate categories; and

(3) Non-isomorphic translation tasks such as addition or multiplication in which a well-defined algorithm or combination rule is provided.

This level of taxonomy provides a starting point for practically oriented engineers to abstract task requirements analyzable in terms of scientific data. For the research scientist it provides an aid to the process of delineating the domains to which his data are applicable.

*References at the end of Part III are categorized as "project products" and "other references." The data of the former will be underlined in the text.

On the other hand we have been working on a more microscopic approach to taxonomy that emphasizes the human internal processing capacities and limitations that are assumed to contribute to integrated skilled performance. Work in our laboratory (Biederman, 1966; Egeth, 1966, 1967; Smith, 1965, 1967) and elsewhere has led to the identification of distinct steps in the processing of specific stimuli that are distinguishable in terms of inferences from distinct experimental operations. These processing stages include a preprocessing stage, in which stimuli are encoded for later processing; a recognition or identification stage in which encoded stimuli are compared with stored replicas or characteristic features and having as an output the label identifying that stimulus; a response selection phase that associates an appropriate response with the labeled stimulus; and finally a response execution phase in which the pattern of muscle activity appropriate to the particular response is generated. The enumeration and quantitative description of each of these processing stages is far from complete, but this level of taxonomy has much long range potential. It focuses on the operator characteristics rather than system characteristics and tends to maximize the capacity to generalize to any class of skilled task. It is, in short, a theory of the mechanisms involved in the adaptive information-processing behavior of man.

Memory, which is the conservation of information from previous experience, whether long-term or short-term, has a key role in all information processing tasks. At the macroscopic level it now seems clear that an operational distinction is required between a pre-perceptual storage of information in a short-term sensory storage system and a post-perceptual storage system which may, itself, involve distinct characteristics for very-short-term storage (i.e., up to 2-3 sec. or 5-6 intervening events) and

intermediate or long-term storage. Likewise, the memory process is now clearly seen as one involving separable processes associated with storing (what gets into storage), storage (what happens during storage), and retrieval (what happens at the time of retrieval, and how this influences the output of the memory system). These matters will be discussed further in a later section on memory.

Closely allied with the taxonomy of information handling tasks and processes is the assembly, collation, and summarization of knowledge in the domain of our research. This has received special emphasis within the project, and a number of significant integrative reviews of the literature have been published. Dr. Martin published a review of theoretical models of concept utilization (1965a) and a review and theoretical integration of the determinants of positive and negative transfer in verbal learning (1965b); Dr. Melton reviewed the role of process concepts in theory and experiments on individual differences in memory, learning, and information handling (1967a); Dr. Egeth reviewed data and theory on selective attention (1967); Dr. Smith published an analysis of the major theoretical positions with respect to choice reaction time (1967a); Dr. Fitts made an analysis of cognitive factors in information processing, which was published posthumously (1967); Dr. Posner published an analysis of the roles of memory and thought in human intellectual performance (1965); and Dr. Pew published a summary of human information-processing concepts for engineers (1965a) and a review of psychological research relevant to the human factors engineering of man-machine systems (1965b). A number of other literature review efforts were in progress at the time Contract No. AF 49(638)-1235 terminated, and will be completed under Contract No. AF 49(638)-1736.

B. Selective Information Handling Processes

In our view, selective information handling and retentivity (memory) are the two most fundamental characteristics of the operation of the central nervous system in the control of adaptive behavior. These selective processes operate at a number of different points in the flow of information within the organism (from input to output), and it is not yet known whether all of these selective processes are coordinate. Our work has given major emphasis to selective attention and perception, the choice of appropriate actions, and retrieval from short- and long-term memory.

Selective Attention and Perception

In an information processing system the acquisition and encoding (recognition) of information is hypothesized to be a necessary stage before any further processing or storage can take place (Smith, 1967). Since the ear, the eye, and other senses are sensitive to much more information than can be economically utilized by the limited-capacity CNS, the study of information handling leads immediately to questions of how this input information is selected, the mechanisms of attention, or alternatively, how unwanted information is gated or filtered out.

In recent years the conceptualization of the mode of operation of this attentional, or filter, mechanism has been a focal issue in research. The critical issue is whether this initial stage of selective processing occurs only on a single "channel," as defined by an attentional set, or whether it occurs simultaneously in parallel channels. It was originally hypothesized (by Broadbent, 1957) that attention was a single-channel mechanism, and that the appearance of parallel processing was the result of (a) the short (less than .5 sec.) switching time of attention, and (b) a short-term preperceptual storage of incoming sensory information. Thus,

the performance of human operators in divided-attention tasks was considered to be a consequence of demands of the task for sampling the information in the two (or more) channels if accurate perception and response were to be achieved. More recently, the evidence brought forward by Treisman (1964) and others suggests that the filter acts more like an attenuator of unwanted signals than like an all-or-none gate.

Our research to date on this problem has been directed toward the observation of performance in a variety of divided-attention tasks, with emphasis on discovering the degradation of performance, if any, in such tasks. Thus it has been found that there is no deterioration in performance on a visual tracking task or on a tactual detection task when these are performed simultaneously (Triggs, Unpublished). In another study (Fitts and Dawson, Unpublished), it has been found that the speed of 2-choice reaction is decreased when the task is time-shared with a continuing memory-span task, with the amount of the effect increasing as the memory load increases and as the RT task shifts from high S-R compatibility to low S-R compatibility. In still another study, it has been found that the accuracy of report of a visual stimulus is not related to the temporal interval (0-500 msec.) between it and an auditory stimulus to which the subject also attended, but that the accuracy of report of the auditory stimulus showed marked effects of the interstimulus interval (Kamlet, 1965). These results suggest that the subject's ability to process information in parallel depends on the number and nature (visual, auditory, tactual) of the sense modalities that receive the information, the very-short-term sensory storage for those modalities, or both.

It needs to be recognized that there are two kinds of questions that can be asked about the attentional filter. One is whether and under

what conditions attention can be restricted to a particular attribute, category, or modality of input information. This is the problem of "concentration of attention" and distraction, and it is noteworthy that the evidence against an all-or-none single-channel mechanism is the demonstration that information on a non-attended input channel may be perceived and responded to appropriately even though the channel source is not recognized (Treisman, 1964). The other is the question whether attention can be shared by two or more discriminable aspects of the input information, and under what conditions this sharing can be accomplished without degradation of performance. Both of these modes of operation of attention are important in real-life information processing tasks, and it is our expectation that a general theory of selective information handling will be applicable to both modes. To date, our major effort, and the effort of others, has been devoted to the question whether attention can be shared simultaneously by different aspects of the input. In our view, this issue is far from decision, and it may be that the so-called single-channel mode represents an extreme case of attenuator operation. If this is so, then factors such as (a) the discriminability of the cues for attentional selection, (b) the informational characteristics of the stimulus sequences, (c) the compatibility of the output responses, (d) the practice of the subject on the processing task, and (e) the feedback and payoff to the subject, may be the critical variables in determining the degree of approximation of selective attention to the single-channel or parallel-channel modes.

The problems discussed thus far may be thought of as relating to the more molar aspects of selective perception, i.e., determination of whether or not input information is responded to and how man can handle

simultaneous inputs each of which much be responded to. Another equally important set of problems that has been worked on even more intensively by ourselves and others may be thought of as the micromolar aspects of selective perception. These are involved whenever it can be demonstrated that man responds more quickly or correctly to a specific stimulus within a class (or a "channel") for which he has been preset. The main bulk of the project work to date on selective information handling has been devoted to this selectivity of perception at the micromolar level. The reason for this emphasis is that, in our view, the processing of an input signal to the point where it is identified (recognized) is the keystone of a theoretical model of information processing behavior.

The basic question in selective perception at the level of specific stimuli (like the letter "F") is the determination of the speed and accuracy of the recognition response. However, in all objective analyses of such recognition processes it is necessary to have a distinctive overt response indicator of the recognition response, such as saying "F" or pressing a key marked "F." A lengthened RT or an error may index a slower and inaccurate recognition response or a slower and inaccurate translation of the correct recognition response into the overt response that is observed. Our work (see Fitts, 1967; Fitts and Biederman, 1965; Peterson, 1965), as well as the work of others, indicates that RT to the letter "F" is much slower for incompatible S-R relationships (such as would be the case with a keypress response on a scrambled typewriter keyboard) than for a highly compatible S-R relationship (such as saying "F"). Such slower RTs and/or increased error rates seem more likely to be the fault of the Recognition Response-Overt Response code than a fault of the recognition response *per se*. On the other hand, an increase in RT with impoverishment

of a stimulus display (such as obtained by representing "F" by a pattern of only 6 black dots), when a highly compatible naming response is used as the overt response, seems more likely to be a fault of the recognition response *per se*.

Our approach to the experimental analysis of the recognition process has employed several different task situations. Our early work was largely limited to the choice reaction task with chief reliance placed on the measure of reaction speed over large blocks of trials. With this method (and highly compatible S-R codes) it has been shown that RT is a function of the size of the functional set of alternative stimuli which may not always be as small as the size of the normal set (Fitts and Switzer, 1962). RT also shows the effects of practice and the transfer of practice from a larger to a smaller set and vice versa (Fitts, *1967*), the effects of involving rule-type mediational processes in the translation of a recognition response into an overt response (Fitts, 1964), the effects of stimulus redundancy, i.e., unequal probabilities of occurrence (Fitts, Peterson and Wolpe, 1963; Ekel and Fitts, *Unpublished*), and the effects of costs and payoffs (Fitts, *1966*) and of the criteria for "slow" and "fast" responses (Pachella and Pew, *In press*) on the relation between response latency and response accuracy.

In recent work on selective perception we have employed a variety of perceptual and memorial "search" tasks of the types introduced by Neisser (1963), and Sternberg (1963). For example, the subject is required to answer "yes" or "no" to indicate whether a presented stimulus does or does not contain a "target" stimulus or stimuli. Neisser (1963) has reported that well-practiced subjects (having worked for many days with the same "target" stimuli) are able to search for many targets simultane-

ously with the same speed that they search for a single target. This implies a capability for parallel processing of input information into recognition or non-recognition responses. Our studies (Egeth and Smith, Unpublished) confirm this finding only for highly practiced subjects and for searches for 2 or 4 target stimuli; a search for a single target stimulus is always faster. Further negative evidence on the parallel processing mode has been obtained by Egeth (1966) in a study designed to determine whether the several dimensions of two stimuli that must be called "same" or "different" are compared simultaneously or as a self-terminating serial process.

In another line of investigation, using a technique similar to that of Sternberg (1963), Smith (1965) examined the effect of stimulus familiarity and target familiarity when the target set (1, 2, or 4 words) was held in recent memory and a single stimulus word was said to be present or not present in the target set. The data support the interpretation that familiarity has its effect on memory, rather than perception, which is to say that the principal factor in speed of recognition is the degree of learning of the recognition response and its associative connections with concept labels.

A number of competing theoretical notions about the recognition process are current. Our early observations on choice reaction time appeared to favor an interpretation of stimulus recognition, and of the effects of size of stimulus set, redundancy, and practice on it, as a statistical decision process based on sequential sampling of stimulus input with optional stopping (Fitts, 1966, 1967). However, very recent work by Edwards and Swensson (Unpublished) suggests that the data of Fitts which implied a continuous trade-off function for speed and accuracy may have been an artifact of the arbitrary definition of "fast" and "slow" responses or the discrete payoff for "fast" and "slow" responses, both of which were forced by equipment limitations.

Edwards and Swensson studied the trade-off function using our PDP-1 computer, which permitted immediate display of feedback to S in the form of a cost which was linearly related to his reaction time, with this cost being subtracted from the payoff which was earned for correct or incorrect responses. There was no evidence for a continuous speed-accuracy trade-off with the simple discrimination required in this experiment, and the results therefore contradict the expectations of the "random walk" model and imply that processing of sensory information in quantized "chunks" may be unalterable.

While our present data on choice reaction time appear to demonstrate that the random walk model does not apply to some recognition processes, they may indicate merely that with very simple stimuli and tasks incomplete information processing is impossible. Other search models have been proposed by Hick (1952) and Welford (1960) for the choice reaction time data, and still others, with additional hypotheses about self-terminating or exhaustive search, have been proposed for the types of data obtained by Egeth and Smith (Unpublished), Smith (1965), and Egeth (1966). Much remains to be done before a choice can be made between the various theoretical models of the recognition process, or before the appropriateness of different models to different task situations can be specified with confidence.

Performance Factors in Selective Information Handling

In stating the preceding area of work which emphasized the analysis of selective attention and perception, it was necessary to make statements conditional upon the operation of such factors as practice in the task, level of learning of a category response, S-R compatibility and other characteristics of the reaction system involved in the task, and principles of

response selection (decision). A complete and well-founded sub-process theory of selective attention and perception will need systematic information about the effects of these variables if the theory is to be useful in moving to analysis and prediction in real-life tasks, with a detailed task taxonomy as the intermediary. For this reason, we have identified a set of principal variables that deserve special emphasis in our effort to achieve a useful theory and task taxonomy. Our present thinking about these variables is indicated in the following subsections.

Type of processing required.-- A basic distinction in our taxonomy of information handling tasks is the one between information conserving and information reducing tasks. This distinction remains valid even though information conserving tasks are known to involve selective attention and perception and therefore have subprocesses (e.g., attentional filtering and recognition as discussed in the preceding section) that involve information reduction. Thus, all human behavior is information-reducing if one uses the environment or even the effective stimulation of the sensorium of the organism as the point of measurement of input information. Such pre-perceptual information reduction is of considerable theoretical and applied interest under some circumstances. For example, the human capability to resist "distraction of attention" in any type of information processing task, and the techniques for giving support to such resistance to distraction (e.g., quiet, padded chairs, music, etc.) have interested students of human performance for some years. While recognizing this as a legitimate area of interest, we consider the distinction between tasks that involve post-perceptual information conservation and post-perceptual information reduction to be more interesting, more important, and more subject to fundamental human engineering. In such tasks the reference point for the measurement of input information, with later processes in the

information flow determining whether conservation or reduction occurs, is the information that must be responded to (coded, identified, recognized) in the attended "channel" or "channels." The prefix "post-perceptual" will be implied in our further discussion of information conserving and information reducing tasks.

Information conserving tasks may differ widely with respect to (a) the information load placed on short-term memory, and (b) the requirements for speed and accuracy in output responses. These differences seem to be quantitative, and are the particular objects of our work in the program on short-term memory as well as our work with choice reaction times. By contrast, tasks that fit the information reducing category involve differences that appear to be qualitative and structural, as well as a quantitative difference in difficulty or complexity (processing load). They also differ along the two quantitative dimensions that apply to information conserving tasks. The major sub-classes of information reducing tasks appear to be those that are described as filtering (search) tasks and information condensing tasks. In a filtering task, such as scanning a map display for airfield symbols, all information must be processed, but only the airfield symbol is reflected in the output response. In a condensing task, such as the determination of the number of aircraft in the traffic pattern above and below 5,000 ft., the operator is required to reflect all input information in the output response, but the response "loses" a part of the input (e.g., the exact coordinates of the aircraft). All formal categorization tasks are of this sort, as are tasks of addition, multiplication, probability estimates, and in fact any decision in which converging information channels are reduced to a single judgment or act (Posner, 1965).

Our work (Fitts and Biederman, 1965) has indicated that human

operators achieve a certain amount of filtering with considerable efficiency, the irrelevant information producing only a slight degradation of performance. In fact, as previously cited, there is evidence that practiced subjects can search for four or more targets as well as for two (Egeth and Smith, Unpublished). In contrast, those tasks that involve information condensing appear to require greater time and involve a higher error rate. However, there are strong interactions introduced by the response modes employed, such that performance on a 4-Stimulus--4 Response information conserving task is faster and more accurate than performance on a 4S-2R reducing task when a compatible S-R coding is employed, but the reverse is true when an incompatible S-R coding is employed (Fitts and Biederman, 1965). In other work it has been shown that the difficulty of an information condensing task is closely related to the amount of reduction of information from the perceived input to the output response (Posner, 1964). This has led to the hypothesis that different amounts of information reduction involve different amounts (or proportions) of the information processing capacity of the subject, and thus leave less capacity available for the conscious or unconscious rehearsal of previously stored information (Posner and Rossman, 1965). The work of Crowder (1964) on the effect of serial reaction time tasks on short-term memory for verbal messages, has shown that effects on memory for recent events comparable to those observed by Posner and Rossman may be obtained by increasing S-R incompatibility or decreasing the redundancy of the stimulus sequence.

There appear to be many ways of increasing the "information processing load" of man, and that the amount of this load is related to the speed and accuracy of performance on a primary task and to performance on

time-shared secondary tasks. Obviously an index of "information processing load" that is independent of task performance would have great utility in further analysis of information handling performance. Following the suggestive evidence of Hess and Polt (1964) and Kahneman and Beatty (1966), who showed that dilations of the pupil are related to mental activity in problem solving and to performance in short-term memory, we have studied pupillary responses in a pitch discrimination task (Kahneman and Beatty, 1967) and pupillary responses during multiple-trial learning of a list of paired verbal units (Kahneman, Beatty, and Melton, Unpublished). The results continue to be promising, although there are problems with the rapid adaptation of the pupillary response.

Human adaptive capacities.-- Except in the writings of Fitts (e.g., 1964) about human information handling capabilities and limitations there has been very little systematic concern for practice or training as an important parameter, perhaps even a critical parameter, in the theoretical and taxonomic analysis of such tasks. Most often it appears that the investigator or theorist assumes that his adult subjects have reached asymptotic performance after only relatively brief exposure to his task. On the basis of observations of the type referred to in earlier pages of this report, it may be suggested that this assumption is grossly in error. Thus the slope of the function relating reaction time in a choice reaction task to the number of alternatives becomes effectively zero with very highly practiced subjects (Mowbray and Rhoades, 1959) or even with the casual subject if the S-R coding has very high compatibility (Leonard, 1959); information reduction through filtering in a search task appears to operate in a serial mode with subjects at low levels of practice but in a parallel mode at high levels of practice (Egeth and Smith,

Unpublished); performance in the perceptual and memorial search task of the type used by Smith (1965) is greatly influenced by the familiarity (degree of learning, or frequency of occurrence) of the words that stand in stimulus and target positions; etc.

Once it is recognized that a model of human information handling processes cannot ignore developmental changes that may occur as a function of specific practice on the task at hand or transfer of learning from other tasks that have been practiced, several important consequences follow. First, a set of concepts adequate to describe these changes must be invented and validated or imported from learning theory. The literature on skill learning and concept learning seem to be the most appropriate source for concepts to describe these cognitive skills so many of which depend on category utilization. Secondly, these effects and the appropriate conditions for their occurrence must be investigated in the specific context of human information handling processes and tasks. Finally, the adaptive changes in task characteristics must be incorporated in our taxonomy of tasks and in the assessment of individual and population capacities and limitations with respect to those tasks.

Fitts made several important contributions to this emphasis on adaptive changes in information handling processes before his death (Fitts, 1964; Fitts, 1966; Fitts and Radford, 1966), in addition to his repeated emphasis on the importance of the compatibility of S-R codes (e.g., Fitts and Biederman, 1965; Peterson, 1965; Biederman, 1966). Compatibility of S-R codes is largely a product of prior learning.

In addition to this emphasis on long-term observation and shaping of performance capabilities and process characteristics, we have also been concerned with the linkage--in both theory and experiment of the performance

theory and learning theory approaches to the formation and utilization of categories and concepts. Initial theoretical steps in this direction have been taken in Martin's (1967a) paper on "Formation of concepts" and in an experiment by Martin and Melton (Unpublished) in which the effect on short-term memory of extended training in discriminative responding (Donders Type b and c) to two arbitrary categories of consonants was determined. Memory for mixed-category quadrigrams was shown to be substantially less than for within-category quadrigrams.

Decision processes.-- A feature of all selective information handling is response or act selection i.e., the selection of some particular response as the output of the system. Such response selections, or decisions, are not, however, limited to output response of the organism, even though some output response must occur as the terminus of any information flow of which we have objective evidence. The process and subprocess conceptualizations of various decision-theory models, especially signal detection theory, have proved useful in the understanding of stimulus recognition, of execution of classification response following recognition, and of retrieval of information from memory. Even though perhaps not the appropriate model in some instances, of particular significance is the conception of sequential sampling of information for decision making. At least equally important are our adaptations of the methods of signal detection theory to the measurement of the "receiver operating characteristics" (d' and β) in our studies of short-term recall and recognition memory (Bernbach, 1965; Conrad, 1967). The important ties with decision theory have been developed and expanded by Edwards (Edwards, 1965; Edwards and Swensson, Unpublished).

C. Information Storage and Retrieval (Memory)

A major objective of the contract program was to subject human short-term memory (STM) to intensive analysis in order to understand the capacities and limitations of man in the storage and retrieval of rapidly shifting information when such is his principal task (as when he is merely an information transmitting link in a system) and when such is a necessary sub-process in other information-processing tasks (as when he must "hold in mind" some information while performing some mental operation on other information). For both theoretical and practical reasons, major emphasis has been placed on the dependent relationship between accuracy of recall or recognition of a to-be-remembered unit (the message) and (a) the characteristics of the message, (b) the characteristics of the events that intervene between the storage of the message and the moment of attempted retrieval, (c) the characteristics of the events that precede the storage of the message, and (d) the effect of duration and frequency of presentation of the message. The work of the project will be summarized under these headings, with a final section on theoretical implications.

Characteristics of the Message

A message may vary in length, as defined by the number of elements in it, in the nature of the elements (e.g., letters, digits, words, objects), and in the organization or structure of the elements.

Number of elements.-- It has been well-known for many years that there is a limit to the number of elements that man can recall without error (either in elements or order) after a single presentation. This is the "memory span." Because of intraindividual variability in performance, and perhaps also because of the variability in the structural characteristics of messages of the same length, as perceived by the individual subject, the

memory span must be given a statistical definition. It is the number of arbitrarily arranged elements that can be recalled in completely correct order 50 per cent of the time after a single presentation that has sufficient duration to allow veridical perception of each element. The opportunity for recall is given immediately following the presentation of the last element in the message. For experimental subjects of the type used in our experiments, the average memory span is approximately 8 random digits, 7 random consonants, and 5.5 unrelated high-frequency words (4-letter nouns).

While the function relating percentage of perfect recall to the number of elements in the message, from which the 50 per cent span value is determined, reflects the effect of number of message elements on STM, it fails to reveal many facts of interest and theoretical importance about that relationship. However, before turning to these additional facts and the methods used to obtain them, one implication of memory-span data that is frequently neglected is worth emphasizing. A man who has a memory span for digits of, say, 8.0 will sometimes falter in the immediate recall of a 5-digit sequence. Therefore, when one is considering man as an information transmitting link in a system in which the overall error tolerance should be very low (e.g., $p_{error} = .001$) the veridical memory span (VMS) of man is much lower than the memory span. For example, Cardozo and Leopold (1963) have shown that the VMSs for random digits and random letters are approximately 6 digits and 4.3 letters with sequential auditory presentation and 6 digits and 5.1 letters with simultaneous visual presentation. Our data on STM for strings of unrelated 4-letter nouns suggest that the VMS for such messages presented visually (and simultaneously) is slightly greater than 3.0.

Further evidence on the severely limited capacity of man to transmit alphanumeric or verbal messages without error comes from studies of the accuracy of recall of messages well below the memory span when some rehearsal preventing activity is interpolated between message presentation and recall, even though the interval is quite short. Following the lead of Brown (1958) and Murdock (1961), we have done four experiments in which the number of elements in the to-be-remembered message and the duration of the retention interval filled with dissimilar but rehearsal-preventing activity were varied in a factorial design. Melton, Crowder, and Wulff (Unpublished, but described in Melton, 1963) studied retention of 1-, 2-, 3-, 4-, and 5-consonant messages after .7, 4, 12, and 32 sec., when presentation was visual and simultaneous; Melton and Crowder (Unpublished) compared visual and auditory sequential presentation of 2-, 3-, and 4-consonant messages after .7, 4, 12, and 32 sec.; Noyd (Unpublished) studied retention of 2-, 3-, and 5-noun visual messages after 4, 8, and 24 sec.; and Melton and Fuchs (Unpublished) studied the retention of 3- and 5-noun messages after 0, 4, 8, and 16 sec. when the message had been read off from visual presentation 1, 2, 3, and 4 times before later attempted recall. Under all conditions there was a very orderly relationship between the slope of the forgetting curve and the number of elements in the to-be-remembered message. Further, the recall of the first element in the message is subject to the same degrading effects of number of elements as are other elements which involve both element and order memory, and even a message of only one element is not perfectly recalled if the interval before recall is as great as 4 sec. Clearly, the number of elements in a message is an important factor in short-term forgetting even though the number is well below the veridical memory span. This fact is referred to as intrastimulus interference (II)

based on the number of elements drawn from a single category of elements.

A much more complex question is the effect of similarity of elements within the message and of the coding or recoding of elements within the message into a smaller number of subjective units or "chunks." The complexity derives from the observation that preëstablished sequential relationships between elements in a to-be-remembered message have a beneficial effect on STM at the same time that similarity of elements within a message is expected to have, at least under some circumstances, a detrimental effect on STM. According to the latter principle, the mixture of letters and digits in a message should have a beneficial effect on STM to the extent that the II from letter to letter is greater than the II from digit to letter, and vice versa. However, letter-letter sequences are more likely, on the average, to be compatible with prior habits than are letter-digit sequences (exceptions would be A-1, K-9, B-4), and beneficial effects on STM should be expected from messages that are homogeneous with respect to category of elements (letters, digits, words). Since digits have a smaller range of variation in element-sequence preference or predictability than letters, any sequence of 3 digits (DDD) should be less likely to be remembered as well as a very high frequency non-word trigram (e.g., BUF) and more likely to be remembered better than a very low-frequency trigram (e.g., ZJT). Obviously, STM for messages near the limit of man's memory span (such as 7-element telephone numbers) can benefit from mixtures of letters and digits if, and only if, the letters occur together and form an easily "chunked" subset based either on high-frequency letter-sequence habits or an easily recoded portion of a familiar word (e.g., CAM for CAMbridge, STL for St. Louis).

The work of a number of investigators has shown that these

expectations about the positive transfer of letter-sequence habits to STM for letter sequences are valid. They will not be reviewed or referenced here. Our work has been concerned principally with the intra-stimulus interference effects that result from (a) identity of elements at two positions within a message, (b) acoustic and semantic similarity of elements within a message, and (c) the mixture of categories of elements within a message.

In an exploratory study, Crowder and Melton (1965) confirmed the presence of interference in the immediate recall of 7-digit messages when the same digit occurred in the second and fifth positions or in the second and sixth positions, and perhaps in the second and seventh positions. No effect, or perhaps a facilitative effect, was observed when the repeated element was in the second and fourth positions. Jahnke and Melton (Unpublished) have extended these observations in experiments in which repeated digits occur in all possible positions within an 8-digit message and in which S begins recall with the first or fifth digit of the message. These studies show that marked facilitation of recall occurs when a digit is repeated in adjacent serial positions and interference with recall occurs when the three or four other digits occur between the repeated digits. Also, it is shown that the locus of the interference is in the recall process rather than in the storage process, i.e., it is the second occurrence of the repeated digit in recall that is last rather than the second occurrence of the digit in message presentation. Jahnke and Melton (Unpublished) have also studied the effects of acoustic confusability of letters in different positions within a message, rather than identity of letters, and these data are now being analysed.

The acoustic confusability of letters in a message composed of an otherwise random sequence of letters has been shown by a number of investigators to be a major source of error in STM. In fact, it is a very much more powerful factor than the size of the vocabulary of letters used to construct the messages (Conrad and Hull, 1964), or the frequency of particular letters or letter sequences (bigrams) in the English language (Conrad, Freeman, and Hull, 1965). This interference occurs whether the messages are presented visually or auditorily and has been shown not to occur in deaf children (Conrad and Rush, 1965). While working on our project, Conrad (1967) examined the nature of the errors in recall of quadrigrams after 2.4 and 7.2 sec. He found that errors attributable to acoustic confusability occurred with non-chance frequency only at the shorter interval, which he interprets as evidence that acoustic similarity influences only very short-term memory and that this, in turn, argues for a decay process in STM. Several investigators have maintained that STM differs from LTM in that STM is subject to II based on acoustic confusability while LTM is subject to II based on semantic confusability. Goggin and Melton (Unpublished) have tested this hypothesis about STM with 6-word messages that were composed of pairs of homophones or synonyms. Three rates of presentation (.5, 1.0, 1.5 sec./word) were used to test the hypothesis that the dominance of the acoustic or semantic similarity as a source of interference would depend on the time allowed for processing the words into storage. Acoustic similarity was found to produce more degradation of the immediate recall of the words, as compared with semantic similarity, although the difference was not nearly so great as has been previously reported. There was no significant interaction of this difference with rate of message presentation.

The effects of mixtures of categories of natural elements (e.g., letters and digits) within a message have been examined by a number of investigators. The results are, however, ambiguous and sometimes conflicting, perhaps because random sequences of letters and digits of the same length differ in difficulty, the digits being easier. We have completed one study (Martin and Melton, Unpublished) which takes a different approach to this problem. Our Ss were first trained for several days to make a differential response to two arbitrary subsets of 6 consonants that were otherwise equivalent. Following this training, which was with one group of Ss by the Donders b reaction-time technique (press key 1 to a letter from one set and key 2 to a letter of the other set) and with another group by the Donders c reaction-time technique (press the key to a letter from one set, do nothing to a letter of the other set), the Ss were tested for STM for quadrigrams that were homogeneous (all letters from one set) or heterogeneous (2 letters from one set then 2 letters from the other). Recall of the homogeneous quadrigrams was markedly superior to recall of the heterogeneous quadrigrams. In the heterogeneous quadrigrams the major difficulty in recall occurred at the transition from the bigram of one set to the bigram of the second set. Although further work needs to be done before the implications of these findings for the problem of message structure are clear, it appears that a meaningful new method of attack on the problem has been developed.

In addition to the intra-message factors mentioned above, which relate to the number and similarity of the elements in a message, it is clear that higher levels of organization of messages are involved in everyday communication and STM. At a relatively primitive level, it is clear that a common English word acts like a single element in STM, whether seen

or heard, even though composed of several letters or phonemes. Thus, it is known that the STM function for a three-word message is approximately the same as for a three-consonant message (Murdock, 1961). It seems that the basic determinant of the memory span and the veridical memory span is the number of subjective units ("chunks") that man perceives in the message rather than the amount of information (in bits) in the message (Miller, 1956).

A higher-order organization in language communication is the sentence, and it becomes necessary to extend the investigation of message structure to STM for sentences if the generality of our findings is to be extended and supported. Using the Peterson-Peterson (1959) STM situation, we have shown that English sentences are forgotten over retention intervals up to 40 sec. in much the same manner as are more isolable verbal units (e.g., consonants, words) (Martin, Roberts, & Collins, In press). Moreover, in correspondence with the effect or STM of varying the number of independent units presented for recall, we have found that sentence length is a highly significant factor (Martin & Roberts, In press). Thus the independent variables of retention interval and string length have the same effects on the more structured messages of the English language as they have on strings of independent alphanumeric units.

What appears in sentences that is absent in the memory materials used in preceding sections of this report is redundancy, that is, sequential grammatical constraint. A measure of this constraint was first published by Martin and Roberts (1966). This measure indexes the amount of structural complexity that obtains among the words of a sentential message. Systematic manipulation of this measure as an independent

variable has revealed important characteristics about how messages are processed into memory.

First, it has been shown (Martin & Roberts, 1966; Martin, Roberts, & Collins, In press) that when sentence complexity and sentence length are controlled, the syntactic type (e.g., active, passive) of the to-be-remembered sentence is not a factor in retention. Studies outside our laboratory have confounded both of these variables with syntactic type, have accordingly observed significant effects on retention, and not surprisingly have therefore based much of their theorizing on the effects of syntactic type (e.g., Miller, 1962; Mehler, 1963).

A number of experiments and detailed analyses of error patterns have revealed that probably the major factor in erroneous recall of sentential information is that of differential word-class effects. Martin, Roberts, and Collins (In press) and Martin and Roberts (Unpublished) have shown that with lengthening retention interval, certain word classes (auxiliary verbs, adverbs, adjectives) are lost more rapidly than others (nouns, main verbs). Moreover, experimental judgments on the importance of the various words in sentences (Martin & Roberts, Unpublished) agrees completely with these differential forgetting rates. In addition, Roberts and Martin (Unpublished), by using the Cloze procedure both in its ordinary form and in a memory situation, have shown that uncertainty (predictability) is highest and uncertainty reduction greatest for those word classes most resistant to forgetting in the STM experiments. Throughout all of these experiments, the differential word-class effects just described are aggravated with greater structural complexity. What this means is that key word classes are more selectively attended to, and hence non-key word classes are more effectively ignored, the greater are the grammatical

constraints on the message.

In keeping with this picture of what structural organization does to the processing of sentential information, we were not surprised to find (Martin & Roberts, Unpublished) that recall errors are rated more similar or substitutable, meaning-wise, for their presented versions when those presented versions are of greater grammatical complexity. This result obtains in spite of the fact that verbatim recall of more complex sentences is poorer. Thus structural constraint serves to emphasize words that are key to the meaning of the sentence, to the memory detriment of less meaningful elements of the sentence. In short, the degree of selectivity for processing among sentence words follows directly the amount of grammatical complexity. Recall proper, then, consists of generating anew a proper English sentence around the key elements retained. Multiple routes of inference suggest that the reliably recurrent "soft spots" in processing messages in English are almost certainly encoding as opposed to retrieval phenomena.

Research on the role of intonative information in sentence retention has failed to implicate intonation is a significant factor. Apparently, intonative cues only weakly serve to signal grammatical redundancy (Martin, Roberts, and Hallahan, Unpublished) and only under irregular circumstances underlie resolution of syntactic ambiguity (Martin & Collins, Unpublished).

Time and Events Preceding Retrieval

From what has already been said about STM for messages of various kinds and length, it is clear that STM deteriorates very rapidly over a period of 30 sec. of rehearsal preventing activity. Other things being equal, this forgetting is greatest in the first few seconds after termination of presentation of the to-be-remembered unit and the rate of forgetting decreases progressively over the interval. The continuity of this decrement in recall over intervals up to 30 sec. has, however, been questioned by those (e.g., Waugh and Norman, 1965; Murdock, 1963) who believe that two distinct memory mechanisms are involved. They maintain that retrieval from a true STM, or "primary memory" is limited to a very short period following stimulus termination (usually specified in terms of the number of intervening perceptual events, with the limit at 6 to 8, which would be correlated with time periods of 2 to 4 sec.). Retrieval of message information during that short period is influenced by both primary memory and "secondary memory" (LTM), retrieval after that short period is influenced by secondary memory alone. The forgetting function for the latter memory has very little, if any, slope over considerable periods of time or numbers of intervening perceptual or irrelevant information-processing events. Formal conclusions on this question of a single continuum of STM and LTM or a 2-process interpretation of the observed forgetting curves over intervals up to 30 sec. would, in our opinion, be premature. However, it is quite clear that the first few seconds or intervening events following the storage of the message are the most damaging, and this damage is greater the greater the complexity and the less the degree of learning of the message (Melton and Fuchs, Unpublished).

It is also of considerable significance that the correlation is now considered to be between the forgetting and the number of intervening events, rather than between the forgetting and time per se. This suggests that the forgetting is related to the displacement of the message from a buffer-storage mechanism or its erasure by subsequent events, rather than to some autonomous decay process. However, buffer displacement theories have as yet specified no specific relationship between the probability of displacement and the similarity of the message elements and displacing events. Such theories, therefore, minimize implicitly what decay theories minimize explicitly; namely, the effect of similarity of interpolated activity on probability of retrieval. Rather, they lead to the expectation that the amount of forgetting would be correlated with the vigor or completeness of the description of message-initiated CNS activity. The effect of similarity under these circumstances is, of course, a basic principle of forgetting (Retroactive Interference) in the S-R associationistic interference theory of long-term forgetting. The application of LTM theory to STM, on the assumption that LTM and STM are regions on a continuum, leads to the expectation that STM would be markedly affected when the message and the activity interpolated between message reception and retrieval are highly similar but not identical. Data obtained within the project and elsewhere (e.g., Wickelgren, 1966) support both expectations and a well-developed theory that handles both expectations has yet to be formulated. In fact, much more detailed and parametric studies of both expectations will be required before a comprehensive theory is possible.

Similarity of interpolated activity.-- Several minor studies persuaded us early in the project that the amount of forgetting of

consonant trigrams and word triads was greater over all intervals up to 30 sec. when S engaged in rapid reading of elements of the same class than when the elements were of a different class, and that the interpolated reading of digits was the least interfering. Others (e.g., Wickelgren, 1966) have shown an effect of phonemic similarity on retroactive interference in STM.

In our view, the greatest need for data on the effects of similarity of the interpolated activity was in very-short-term memory. Ligon and Reicher (Unpublished) have shown very rapid forgetting of a consonant trigram over 1, 2, 4, and 8 intervening readings of consonants when all stimuli (to-be-remembered elements and interpolated elements) are read from a visual display at the maximum "shadowing" rate of the S (range 4/sec. to 3/sec.). Subsequent research by Ligon (Unpublished, part of a doctoral thesis to be submitted in 1967) with a similar method has shown that the amount of forgetting is a function of the similarity of the interpolated elements (consonants vs. digits following a 3-consonant message); and with a fixed number of interpolated elements, the forgetting is a function of the number, but not the location, of the similar elements. The method of testing for retrieval in this study was the "probe" method of Waugh and Norman (1965), which avoids many difficulties--especially those related to S's strategies and expectancies--associated with a method of complete recall of a designated message. Another study also in progress as a dissertation (Lively, Unpublished) has shown, by probe recall, that a unique element (e.g., a consonant in a string of 9 digits, or vice versa) is no better recalled than a same type element in the same serial positions when it is cued as a response by presenting the preceding element. However, when used as a stimulus

probe for the succeeding element, a unique element is a more effective cue. This suggests that heterogeneity of elements may favor stimulus recognition in recall, which fits other data from the project which will be described later.

Much remains to be learned about the effects of similarity of interpolated activities on STM. However, it seems clear that several dimensions of similarity have marked effects on retrieval of a to-be-remembered unit. It also appears that these effects of similarity can be readily demonstrated within the range of very-short-term, or "primary" memory, as well as over filled intervals that are outside the range of "primary" memory. Perhaps the most interesting observation on this problem is Ligon's (Unpublished) dissertation that shows a relationship between the very-short-term forgetting and the number of interpolated similar elements, with total number of interpolated elements constant, but no relationship between the location of these similar items in the retention interval and the amount of forgetting.

Difficulty of interpolated activity.-- When similarity of the to-be-remembered message and the stimulus input during the interpolated retention interval is held constant, but the difficulty of the processing of the interpolated stimuli into appropriate responses is varied, the amount of forgetting is greater the greater the difficulty of the interpolated task. Posner and Rossman (1965) formulated this conclusion in a study in which they manipualted the difficulty of an interpolated task by requiring different amounts of information reduction (Posner, 1964) in a classification of 2-digit numbers. Later, Crowder (1965) demonstrated that more forgetting over short intervals of time occurred when the interval was filled with a serial choice reaction task when the display-

control relationships were incompatible than when they were compatible. He also showed that more forgetting occurred when S was in the early stages of learning a serial choice reaction task with incompatible display-control relationships than in the later stages. It would appear that information-processing load, whether it is made greater by the inherent difficulty of the task or by the activities involved in the early stages of learning the task, affect the retrievability of preceding message in STM. Of considerable interest is recent evidence (Reid, 1967) that the locus of a difficult information processing task in the retention interval is quite critical; it has its maximum effect when located immediately after storage of the message. This contrasts sharply with the evidence on the effects of similar interpolated events.

These findings regarding the effects of different kinds of interpolated tasks, and of different levels of similarity of the interpolated task or events and the to-be-remembered message, suggest that both factors may well be involved in producing the observed rapid short-term forgetting, although undoubtedly differentially involved in different situations involving information conservation. It is noteworthy that the standard situation for the measurement of the memory span is one that involves not only high similarity to the elements that follow each of the to-be-remembered elements in the message, but also similarity and complexity of processing of elements that follow each of the to-be-remembered elements, if the S is highly motivated in his intent to learn and retain. This also is consistent with data (Brown, 1954) that show the detrimental effect of interpolated activity to be greater in STM if there is intent to learn and recall the interpolated material than if the S merely makes discriminative responses to it.

Events Preceding Storage

Two types of effects of prior events on the storage and later retrieval of information from STM may be expected from the general framework of S-R Association theory. One is that earlier presentation and attempted recall of a message identical to the one currently presented will facilitate immediate or delayed recall of it. The other is that the prior presentation and attempted recall of a message that is similar but not identical with the one currently presented will interfere with delayed recall of it, but not with immediate recall. Both of these effects have been intensively studied in the contract program and elsewhere. The latter is, however, of greater practical and theoretical interest, perhaps because the former is expected from generally accepted theories of the relationship between repetitions, learning, and short-term and long-term retention, while the latter is a prediction from the S-R associative interference theory of forgetting in LTM. The practical interest in the proactive facilitation effects of prior learning of to-be-remembered messages has been discussed in the context of the structure of the message. The practical interest in proactive inhibition of STM by prior events derived from the need, and opportunity, to design tasks in ways that will minimize these deleterious influences on STM.

Proactive facilitation.-- Our work on this problem centers around an issue raised by Hebb in connection with his two-process view of STM and LTM. He considered "immediate" recall of a message, as represented in memory-span measurements, to be reflective of "activity traces" in the CNS, and not productive of permanent, "irreversible," structural traces that are the basis of LTM. He tested this notion (Hebb, 1961) by presenting strings of 9 random digits to subjects as a series of immediate

memory tests. However, every third 9-digit number was the same number, all others being different. The immediate recall of the repeated number improved as the number of repetitions increased, and this was interpreted as contradicting the assumption that "immediate" memory (or STM) was mediated by a unique mechanism or process. Prior to this contract, Melton (1963) confirmed Hebb's finding and showed that the effect of repetitions of a 9-digit number on immediate recall of it was a decreasing function of the number of other 9-digit numbers that were presented and recalled between each occurrence of the repeated number. In the project work this was followed by three studies, all of which used two 9-consonant vocabularies to construct 8- or 9-consonant messages, in which it was shown that (a) the effect of repetition, with fixed intervals between repetitions, was greater when the messages presented and recalled between repetitions used the same set of 9 consonants than when they used the different set of 9 consonants, (b) the effect of repetition was not dependent on the regularity of the occurrence of the repeated message within the sequence of messages, and (c) the effect of repetition did not depend on the location of the similar non-repeated messages in the interval between occurrences of the repeated message (Melton, Unpublished). The general conclusion from these studies is merely that presentation and recall of information from STM, even under conditions that should interfere greatly with consolidation of activity traces into structural traces, does not leave the CNS unaffected in a permanent way. The data do not necessarily deny a two-process theory of memory, since two-process theories now assume that traces may be simultaneously present in the transient activity form and in the relatively permanent, structural form.

Proactive inhibition.-- Initial results on the retention of sub-span messages after short intervals filled with rehearsal-preventing activity failed to demonstrate an interference in the recall of the message as a function of the number of similar messages previously presented and recalled (Brown, 1958; Peterson and Peterson, 1959). S-R interference theory of LTM makes the strong prediction for STM, as well as LTM, that prior learning of a similar but non-identical message should inhibit the retrieval of the last message, with greater inhibition the longer the retention interval for the last message. Therefore, new tests were made of this prediction (Keppel and Underwood, 1962), and the prediction was confirmed. Since that time the phenomenon has been repeatedly demonstrated and there is clear confirmation of the expectation that the amount of proactive interference (PI) in STM is correlated with the similarity of the prior and presently to-be-remembered messages.

Noyd (Unpublished) made the first comprehensive investigation of PI in the project. After preliminary training in the STM task which was explicitly designed to avoid PI effects on the first to-be-remembered message, different groups of 27 Ss had as their first test the recall of 2-, 3-, or 5-noun stimuli after 4, 8, or 24 sec. filled with fast digit reading. All Ss then proceeded to receive all 9 conditions in the experiment with complete counterbalancing of first-order sequence effects (i.e., every condition was preceded in the experiment equally often by itself and every other condition). The major findings were: (a) An increase in PI (decrease in recall) occurred over the first 5 tests in the experiment. At its maximum, PI reduced recall about 50%. (b) There was greater forgetting after 4 sec., the longer the message, on the first test of the experiment (when PI is minimal), but no further forgetting up to 24 sec.

By the fourth or fifth test of the experiment, when PI had reached a maximum, forgetting of all lengths of message was greater the greater the retention interval. Clearly, the differences in retention after 4 sec. are a function of what we have called intrastimulus interference, differences in retention from 4 sec. to 24 sec. are a function of the PI in the situation. (c) Within the entire experiment, the probability of correct recall of a message is least when the length of the to-be-remembered message and the preceding message is the same. The length of a message is a common characteristic of successive messages that produces added PI. (d) The effect of PI on recall are traceable in large part to overt intrusions of words from previous messages into the recall of the last message. Such intrusion errors come most frequently from the most recent messages, but some come from messages as far back as 10 in the sequence.

Other studies have shown, using the 3- and 5-noun stimuli used by Noyd, that (a) the probability of erroneous intrusions from previous messages is greater, the greater the frequency of correct recall of the last message, whether for reason of its frequency of repetition or its short retention interval (Melton and Fuchs, Unpublished). (b) The amount of PI decreases as the rest interval between the recall of one message and the presentation of the next is increased from 5 sec. to 25 sec. (Melton and Bronstad, Unpublished). This observation has been confirmed and extended by Loess and Waugh (Unpublished), who also show that a rest period of approximately 5 min. must occur if PI is to be eliminated altogether. (c) PI is increased in the recall of consonant quadrigrams when the consonants in the preceding message are acoustically confusible with those in the to-be-remembered quadrigram (Melton and Hauenstein, Unpublished). (d) Several experiments from the project have demonstrated

that intrusions from immediately preceding messages occur in the recall in the same serial position that they had in their source message, thus demonstrating that serial position coding of message elements may be one source of similarity between messages that produce PI.

These data relate principally to the conditions that produce PI, and the inference is that PI builds up because of similar characteristics of successive messages. This inference has been confirmed by the studies of others which show complete release of STM from high levels of PI when (a) the category of elements in the message changes from 3-digit numbers to consonant trigrams (Wickens, Born, and Allen, 1963), and (b) the concept category of words used in messages changes, e.g., from "metal" words to "furniture" words (Loess, 1966). A study just completed as a doctoral dissertation in the project (Rubin, Unpublished) has shown complete release of STM for 3-word messages from a high level of PI when the mode of presentation is changed from visual to auditory or vice versa.

In summary, proactive interference is present in STM in large amounts, and seriously reduces man's information retrieval capacity, when successive messages have similar elements, the same semantic category labels, the same lengths, and the same input modality. However, the PI, even though substantial in amount can be eliminated by changing the elements of the message, the semantic category of the words in the message, and the channel of input of the message. Partial release from PI can be gained by varying the lengths of successive messages and the introduction of rest intervals between messages. It is possible, although not yet tested, that a shift activity between messages, not rest alone, can release STM from PI. It seems very probable that many subtle

dimensions of the memory task may, if changed, produce a release from PI. These findings are considered to be of considerable potential significance for the human engineering of information transmission tasks.

Recogniton Memory

Substantial progress has been made in the analysis of short-term recognition memory. Throughout these studies, the "continuous recognition memory" method of Shepard and Teghtsoonian (1961) has been employed. In this method, the S sees a long list of items (3-digit numbers, trigrams, words, nonsense forms, objects) in which some or all items occur two or more times. The spacing of the occurrences of an item is a standard variable of interest. As each item is seen, the S is required to designate it (by vocal or key-press response) as "new" or "old" (within the list). The rate of presentation of the items has been from 3 to 6 sec. per item, and all recent studies require S not only to designate the items as "new" or "old" as they occur, but also to indicate his level of confidence in the judgment (on a 3- to 5-point scale). Decision times have been recorded in some studies.

Melton, Sameroff and Schubot (1961) confirmed and extended the observations of Shepard and Teghtsoonian (1961) on recognition memory for 3-digit numbers. False positives (saying "old" to new items) increase rapidly over the first 40 new items, but remain relatively constant thereafter; correct recognition of old items as "old" shows a rapid decline as the number of other items between the first and second occurrence of an item increases, but remains very much higher than the false positive rate even when those occurrences are separated by 20 other items. When an item is falsely called "old" on its first occurrence it has a higher probability of being called "old" on all further occurrences, whatever

the interval, than an item correctly called "new" on its first occurrence.

Subsequent studies with the same basic design as the one described above have shown the following to be true: (a) Items originally called "new" with high confidence have a greater probability of being correctly recognized later as "old" than those called "new" with lower confidence (Melton, Bernbach and Reicher, Unpublished). (b) The frequency of occurrence of an item is correlated with the probability of correct recognition of it, at all intervals up to 20 intervening items (Bernbach, 1965). (c) The recognition memory for consonant trigrams does not reflect the acoustic confusability of the consonants from which the trigrams are made, but is markedly affected (both false positive rates and correct recognitions as "old") by the size of the consonant vocabulary (6, 9, or 18) from which the trigrams are made (Melton and Reicher, Unpublished). (d) Recognition memory for both consonant-vowel-consonant and 3-consonant trigrams is related to the association-value (M) of the trigram. The higher the association-value the lower the false positive rate and the higher the correct recognition rate (Melton and Martin, Unpublished). (e) Recognition memory for high-frequency, 4-letter nouns is truly exceptional. In a study involving the presentation of 320 different words, the false positive rate increased linearly to a final value of 18 per cent, and correct recognition of an old word as "old" was 86 per cent even when 80 other items intervened between the first and second occurrences of a word (Melton and Hauenstein, Unpublished). (f) Payoff for accuracy of judgments of "old" and "new" and of estimates of confidence in those judgments has a significant effect on recognition memory, but training in making such estimates of confidence does not (Phillips and

Melton, Unpublished).

Our basic data on recognition memory in this continuous processing task have had an important role in the development of a theory about the relation between recognition memory and recall which appears to be applicable to a wide variety of learning and short-term memory situations. Martin (1967) has developed this theory in some detail. The basic idea is that stimulus recognition is a necessary condition for the elicitation of a response associated with it, and that stimulus recognition is mediated by the recurrence of a subjective coding response. This subjective coding response is more variable the lower the association-value (M) of the stimulus. The prediction that stimulus recognition is a necessary condition for associative response elicitation has been confirmed by Bernbach (1965) and Martin (In press (2)). Further tests of the theory are in progress in the contexts of short-term free learning, paired-associate learning, and transfer and interference in the learning of successive sets of S-R relationships.

Theoretical Issues

A quantitative model of STM.-- One of our stated objectives was to construct a quantitative empirical description of human STM for discrete alphanumeric and verbal messages. The major findings of the research have been reviewed under headings which identify the principal independent variables (characteristics of the message, of the period of delay before recall or recognition, and of the activities prior to storage in STM) and dependent variables (recall and recognition). These data have not yet been encompassed by a quantitative model of STM. Although it is clear that the probability of recall (or recognition) of a message at time X can be related, at least for certain specific classes of messages, to the

appropriately weighted values of the independent variables, this is not yet considered to be a profitable formal exercise. There are many unresolved empirical questions about the operation of these variables when the others are held at some arbitrary constant value. Furthermore, it is clear from the data at hand that these independent variables have complex and important interactions which have been detected but not fully described at this point in time. A formal quantitative model of an appropriate scc[illegible]pears to be a reasonable expectation only after these independent variables and their interactions have been specified more exactly by direct empirical studies and theories of the sub-phenomena of STM.

S-R assciation theory.-- The S-R interference theory of forgetting, as developed in the context of experiments on the forgetting of verbal habits and skills that have been carried to a relatively high level of strength through repetition, is widely accepted as a gross description of the principal factors in human forgetting (Postman, 1961). But it is admittedly incomplete in certain respects and these deficiencies have been the targets of opponents of the application of this theory to STM. As presently formulated, the key process concept in this theory is the concept of "unlearning", i.e., a process whereby a previously learned response (R_1 of S_1-R_1) is made unavailable, or less readily available, in recall even though the competition of the second learned response (R_2 of S_1-R_2) is removed from the recall process. The effects of this unlearning factor are thought to be transitory. Thus, the very rapid forgetting of R_2, which is attributed to PI, is viewed as a consequence of "spontaneous recovery" of R_1 from "unlearning" during the acquisition of R_2.

The concepts of "unlearning" and "recovery" have received

substantial support from studies involving the memorization of lists of verbal elements, but there is still great uncertainty about the processes involved in "unlearning" and recovery therefrom. One hypothesis about "unlearning" is that it occurs to the extent that previously learned responses occur as non-reinforced overt or covert intrusion errors during new learning. However, it is not obvious how this process hypothesis applies to STM for a string of three words that are read off in 2 sec. and then show marked and increasing forgetting over periods up to 30 sec. when the conditions for PI are present. Also, very little is now known about the process of recovery from such unlearning, except that it occurs and is time-limited.

We have performed experimental and theoretical analyses in an effort to refine the process specifications of the S-R interference theory in order to encompass not only forgetting after multiple repetitions (LTM) but also STM after single presentations that have little likelihood of allowing unreinforced occurrences of covert or overt alternative responses. This has involved several studies of memory following multiple repetitions in the retroactive inhibition and proactive inhibition paradigms of S-R interference theory.

Goggin (In press, a) has examined the hypothesis that the amount of unlearning of first-list responses is correlated with the opportunity for their occurrence as errors during second-list learning. A correlation was observed, but there was substantial unlearning even when the opportunity for such errors was minimized. In another study Melton and Kammann (Unpublished) replicated Postman's (Unpublished) finding that recovery from unlearning is complete within 20 min. following termination of practice on the first list. Other studies (Goggin, In

press, b; Garskof (In press) continue to support the notion that some form of inhibitory influence (suppression, unlearning, reciprocal inhibition) is associated with the perception and storage of new information which is in some way conflictful with information previously stored in LTM or just recently stored in STM. An explicit theory of how these processes are involved in STM has not yet been formulated, although one form of a theory about some aspects of the problem has been formulated by Martin (1967).

D. Publications and Other Public Communications That Are Products of Contract No. AF 49(638)-1235

A major index of the research productivity of the program is the number of communications to the scientific community. These communications have been of two types: (a) published papers that report specific experimental findings, theoretical integrations of our findings and those of other scientists, or reviews of the literature, and (b) oral presentations at scientific meetings or topical symposia and conferences that report specific experimental findings or theoretical integrations of our findings and those of other sicentists. These two types of products are listed separately in the following pages.

The productivity of the contract work over the period 1 June 1963 through 31 May 1967, as measured by this index, is summarized in Table 4.

Table 4

Number of Published and Oral Communications Based on Contract No. AF 49(638)-1235 During the 4-Year Period

Year	Number of Published Articles	Number of Oral Presentations
1963 (From 1 June)	0	3
1964	2	3
1965	14	2
1966	9	10
1967 (To 31 May)	9	5
1967 (In Press)	10	--
Total	44	23

There is excessive publication lag (from 12 to 24 months) in the major psychological journals that carry reports of experimental and theoretical work of the type performed on the contract. Also, such journals frequently exclude detailed analyses and tables of data that are useful to ourselves and others working in the same areas. Therefore,

we publish some reports, in advance of journal publication and in a limited edition, as Technical Reports or Memorandum Reports. Prior to 1 January 1966, such technical reports were published as University of Michiagn Technical Reports in a series identified only by the internal project number (e.g., 05823-3-T). Subsequent to 1 January 1966, such technical reports have been published in the Human Performance Center Technical Report series. All doctoral dissertations performed as part of the project work are published as technical reports. Other project work, such as oral presentations at scientific meetings and symposia, and also reports of materials, methods, and equipment of methodological value (not normally published in journals), has been published in the Human Performance Center Memorandum Report series subsequent to 1 January 1966. Before that date there was no formal publication of such materials.

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PART IV

REFERENCES TO REPORTS OTHER THAN PRODUCTS OF CONTRACT NO. AF 49(638)-1235

The following list includes only those references that are not listed as products of Contract No AF 49(638)-1235 in Part III, Section D, Sub-section a, which lists by year all published or "in press" articles that are products of that contract.

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