PARALLEL VERSUS SEQUENTIAL PROCESSING OF STIMULUS-INDEPENDENT THOUGHT: A FOLLOWUP STUDY

by

Steven Goldstein

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July 29, 1975
date

John Antrobus
Chairman of Examining Committee

July 31, 1975
date

Florence L. Denmark
Executive Officer

John Antrobus

Ira Kaplan

Harold Wilensky

Supervisory Committee

The City University of New York

ABSTRACT

Eleven subjects participated in an error-free, self-paced visual signal detection task in which the independent variables were: (1) information density per visual signal (2) duration of time between a correct signal detection and the subsequent signal. The dependent variable was the relative frequency of stimulus-independent thought responses.

The purpose of the experiment was to determine whether the cognitive processes leading to mindwandering are carried out concurrently with the processing of external stimuli (parallel processing), or restricted to intervals between the processing of external stimuli (sequential processing) or perhaps, both.

Extensive analysis of the results supported a cognitive model that employs both parallel and sequential processing.

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CHAPTER I

INTRODUCTION AND HISTORY

Attention

Each of us has some power in creating our own world by choosing what we will attend to. William James (1890, pp. 403-04) described attention as follows:

> Every one knows what attention is. It is the taking posession by the mind, in clear and vivid form, of one out of what seems several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others.

James noted that there are several limitations on the number of things we can attend to (1890, p. 409). Two different types of processes that might, in part, be responsible for the limitations of attention have been described extensively in recent literature. One process is capable of doing but one thing at a time and requires some method of switching among the tasks it is attempting. Neisser (1967) labels this process "sequential" while Norman (1969) labels this process "serial." An alternative to sequential processing is "parallel" processing. A system capable of parallel processing can do a number of things simultaneously, and need not switch from one task to another, but there is some upper limit of capacity which competing tasks must share (Neisser, 1967; Norman, 1969).

Although the concepts of sequential and parallel processing can readily be applied to events external to our cognitive system (e.g., Norman, 1969 & 1975), or Moray, 1967 & 1974) it is also possible to apply the concepts to the integration of the processing of material from long term memory (i.e., mindwandering, imagery, fantasy, etc.) and/or external events (e.g., Antrobus, 1968; Goldstein, 1968; Antrobus, Singer, Goldstein, & Fortgang, 1970).

The experiment described in this paper is designed to determine whether the cognitive processes leading to mindwandering are carried out concurrently with the processing of external stimuli (parallel processing) or restricted to intervals between the processing of external stimuli (sequential processing).

To understand the application of parallel and sequential processing to mindwandering we need look no further than our everyday lives. It is a common experience for most of us to have stray thoughts intrude while we are trying to accomplish a task, such as driving a car, or listening to a lecture (Antrobus, 1968). At times we become so involved with our innerlives that daily routine becomes a monumental chore. Continuous preoccupation might even lead us to psychiatric treatment. The challenge for researchers is to transform our everyday experience of daydreaming into a meaningful experimental variable so that it is possible to gain a deeper understanding of the relationship between processing of external stimuli and material from long-term memory.

Antrobus-Singer Experimental Technique

Antrobus and Singer (e.g., 1964, 1966a, 1966b) have examined man's tendency to process material from long-term memory. These experiments have used a similar procecure. The subject is given an auditory or visual detection task (requiring task-directed thinking). The S is trained in defining stimulus-independent thought responses (mindwandering). The signal detection task (independent variable) is usually increased and/or decreased in difficulty over a variety of different time periods (trial lengths). Following each trial the subject is asked to make retrospective judgments of whether or not he had at least one stimulus-independent thought (dependent variable) during the just preceding trial. The persistence of high levels of stimulus-independent thoughts (mindwandering) was deminstrated during periods of active response to auditory signals. Reductions in stimulus-independent thoughts (SIT) could be brought about by task manipulations such as increasing the rate or complexity of stimulus presentation. Increases in SI thoughts could be brought about by arousing some area of interest or conflict. In these situations there was significant decrement in performance (Antrobus, Singer, Greenberg, 1966; Drucker, 1969). However, it appeared that material from long-term memory was persistent and demanding and the processing of this material bore some close relationship to sensory processing of external stimuli.

Mindwandering vs. Task Directed Thinking

We spend most of our lives in some sort of mental activity. However, our thinking is not always organized towards a goal. Man is also processing internal material in the form of memories, associations, daydreams, and night dreams (e.g., (e.g., Hebb, 1959 & 1963; Singer, 1966; Holt, 1964; Breger, 1967; Klinger, 1971).

Historically, psychology has long been interested in the existence of two different forms of mental organization. The distinction has been called "rational" vs. "intuitive," or "constrained" vs. "creative," or "logical" vs. "prelogical," or "realistic" vs. "autistic," or "secondary process" vs. "primary process" (Neisser, 1967). It is striking to list these side by side, because a very powerful, value laden judgment arises. One form of thinking is seen as efficient and purposeful while the other form of thinking is considered chaotic and inefficient, a mere self-indulgence.

However, as Klinger (1971) recognizes "in a species that has evolved through such an extended molding by natural selection, so prominent an activity as fantasy is likely to exercise important functions in the adaptation of the organism." Freud, of course, considers our unconscious (and fantasies as an expression of the unconscious) as the essence of the "real" self. Singer (1966) has suggested that daydreaming enables an individual to plan and anticipate his future.

Daydreaming can counteract boredom (Hebb, D. O., 1949; Wyatt, S. & J.A. Fraser, 1929; Wyatt,S. & J. N. Langdon, 1937; Antrobus, J. S. & Singer, J. 1964). Wheeler's dissertation (1969) supported Singer's (1966) notion of the value of daydreaming as a form of self-entertainment. Klinger (1971) examined evidence indicating that fantasy acts as a reminder for us, of pressing business other than that in which we are momentarily engaged. Klinger also takes the position that fantasy contributes to creative problem solving, intuition, interpersonal sensitivity, originality, and resourcefulness.

Whether we consider fantasy good or bad with respect to getting our work done, or our work as an interference in our fantasies, it is clear that these two forms of thinking compete for attention. What then are the characteristics of our cognitive subsystem that accomplishes an integration of fantasy and external stimuli?

Information Processing Model

In the past 20 years almost every aspect of perception and thinking has been conceptualized in terms of information theory, and mindwandering has not failed to join the group (e.g., Broadbent, 1958; Reitman, 1965; Kristofferson, 1965; Moray, 1974; Antrobus, 1968; Antrobus, et al 1970; Norman & Bobrow, 1965). Norman and Bobrow (1975) describe an information processing operator device which:

> . . . has programs and some mechanism for executing these programs. When a program is executed, it requires input data and it consumes resources. A set of programs that is being executed for a common purpose and for which resources are allocated as a unit is called a process. Resources are always limited. If several processes request a portion of the same available resource, this resource must be allocated among them. The results that the processes produce depend upon the nature of the data which they receive and the amount of resources that have been allocated to them.

Norman and Bobrow make the further assumption that operations that share limited capacity will not interfere with one another until the total processing resources required exceeds the fixed upper limit available. If it can be established that two processes interfere with one another it can be assumed that they share at least one common channel or operation in the total cognitive subsystem. The form of this sharing might be sequential, parallel, or both.

The sequential model would rapidly alternate use of components of the system so as to appear to simultaneously use the same components. The parallel model would share the components as computers do, which split memory into multiple parts to handle multiple jobs simultaneously (Neisser, 1967). Of course, it requires many components employed in sequence to handle the complex tasks of processing a signal or processing a stimulus independent thought. However, when a shared resource exceeds its limit, is the form of the sharing sequential, parallel, or both?

Our cognitive system not only receives, stores, and transforms information input from sensory data, but also operates on information stored in memory (Antrobus, 1968). As applied to our cognitive operations on sensory input and events stored in memory both types of thinking share a common limited capacity cognitive operator (Antrobus, et al, 1966; Antrobus, 1968). If the inputs from combined sensory and memory input exceed the capacity of the central operator the most efficient system would attempt to maximize the total pay-off of these operations based on some value associated with the sensory or memory material (Antrobus, 1968). As noted earlier, the maximization of these operations would be confined by the limitations of our cognitive system's ability to operate sequentially and/or in parallel.

An Experimental Approach to the Question of Shared Processing of Fantasy and Sensory Input

An experiment by Antrobus (1968) tested whether the process of making a perceptual response and the process of constructing stimulus-independent thoughts have any cognitive stages in common. The procedure varied signal presentation rate and the number of possible tones per signal, creating nine different information rates (.2-6 bits/sec.). The results showed that the relative frequency of stimulus-independent thought response was a negative linear function of the rate of presenting auditory information. The implication is that the process of making a perceptual response and the process of constructing stimulus-independent thoughts share a common cognitive operator of limited capacity, and that equal amounts of internally produced information are traded for equal amounts of task information. In this experiment, even in the highest information rate condition (6 bits/second) subjects produced an average of approximately 0.35 stimulus-independent thoughts per trial. This relatively high level of mindwandering despite the high information rate and despite the subjects being payed a bonus for efficiency of response to the signal detection task raises further the question of whether the cognitive processes leading to mindwandering are carried out concurrently with the processing of external stimuli (parallel processing) or restricted to intervals between the processing of external stimuli (sequential processing) (Antrobus, 1968; Antrobus, et al, 1970).

An examination of Figure 1 (taken from Antrobus, et al, 1970, p. 246) schematizes the two models, parallel and sequential. Three factors are significant in identifying a parallel model. First of all, an increase in the amount of information the central operator must process decreases the capacity available for the production of stimulus-independent thoughts. In Norman & Bobrow's (1975) terms, when several processes compete for the same limited resource, eventually the processes become overloaded and there is a smooth degradation of performance called "the principle of graceful degradation." Second, increasing the time available when the central operator is not processing external stimuli, should not significantly increase the probability of production of stimulus-independent thoughts. We assume that a system capable of parallel processing can at most times use some of the available resources for productions of SIT, and therefore, during those brief periods of nonresponding to external stimuli it is not necessary to increase production of fantasy.

Following along the same line of reasoning the diagram (Figure 1) also clarifies a sequential model. Increasing the information density per stimuli processed by the central operator, should not decrease the probability of producing stimulus-independent thoughts, since a sequential model can only process from one channel. The assumption is that all available resources are used for processing external stimuli, regardless of the effort required. Second, increasing the time when there is no processing of external stimuli should increase the probability of production from long term memory (i.e., all resources would be available for the production of stimulus-independent thoughts, which are assumed to be pressing for use of the necessary resources). Finally, when

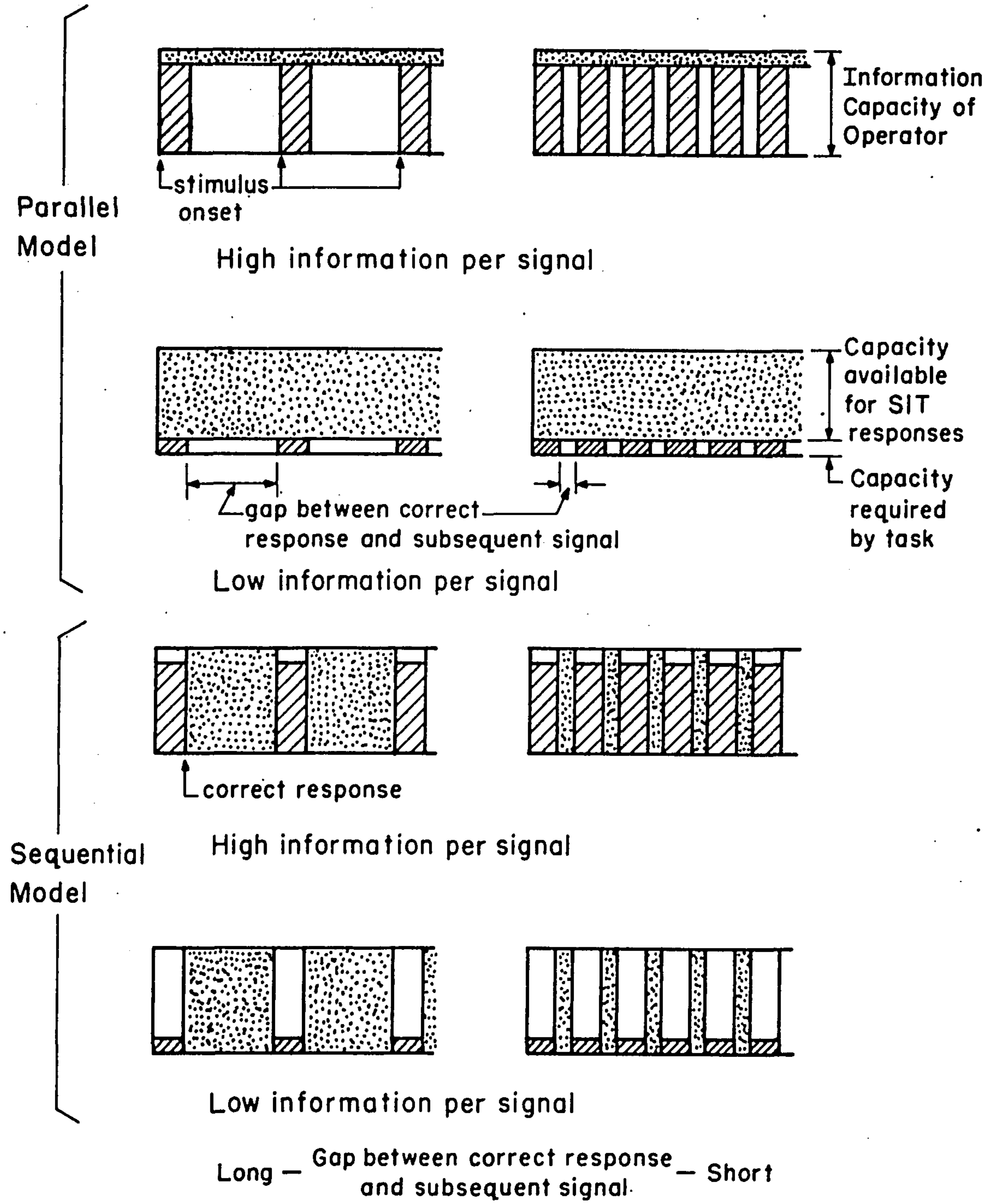

Fig. 1. Parallel and sequential models for the production of stimulus-independent thought and imagery during a simultaneous signal-detection task. (Antrobus, Singer, Goldstein, Fortgang, 1970)

increasing the time available when the central operator is _not_ processing external stimuli, should not significantly increase the probability of production of stimulus-independent thoughts. We assume that a system capable of parallel processing can at most times use some of the available resources for productions of SIT, and therefore, during those brief periods of nonresponding to external stimuli it is not necessary to increase production of fantasy. Finally, even when the central operator is continuously processing external stimuli there is still potential for productions from long term memory. (If there is a continuous press for the expression of fantasy this would necessitate parallel processing in this situation.)

Following along the same line of reasoning the diagram (Figure 1) also clarifies a sequential model. Increasing the information density per stimuli processed by the central operator, should _not_ decrease the probability of producing stimulis-independent thoughts, since a sequential model can only process from one channel. The assumption is that all available resources are used for processing external stimuli, regardless of the effort required. Second, increasing the time when there is no processing of external stimuli should increase the probability of productions from long term memory (i.e., all resources would be available for the production of stimulus-independent thoughts, which are assumed to be pressing for use of the necessary resources). Finally, when the central operator is continually processing external stimuli, there should be no processing of stimulus-independent thoughts (since the central operator can only process from one channel at a time).

Drucker (1969) found evidence compatible with a sequential model. His dissertation compared the effect of a regular versus irregular interstimulus interval on the production of stimulus-independent thoughts. The production of stimulus-independent thought was significantly reduced in the varied interval condition. If the process that produces the stimulus-independent thought response occurs only in parallel, or if the process is temporarily interrupted only after the signal has been presented, the productions from long term memory should be the same in both conditions.

Goldstein (1968) compared the parallel and sequential models directly. Eleven college students participated in an error-free, self-paced, auditory signal-detection task. The independent variables were: (1) amount of information per stimulus (1 Bit or 3 Bits); (2) the duration of the interval between the correct response and the subsequent signal (0.0, 0.1, 1.0, or 4.0 seconds). In the eight possible conditions each subject received one hundred 15-second trials. Following each trial the subject reported whether he had at least one stimulus-independent thought during the preceding trial. In order to enhance the motivation for responding to the stimuli a bonus of one-tenth of a cent was paid for each correct

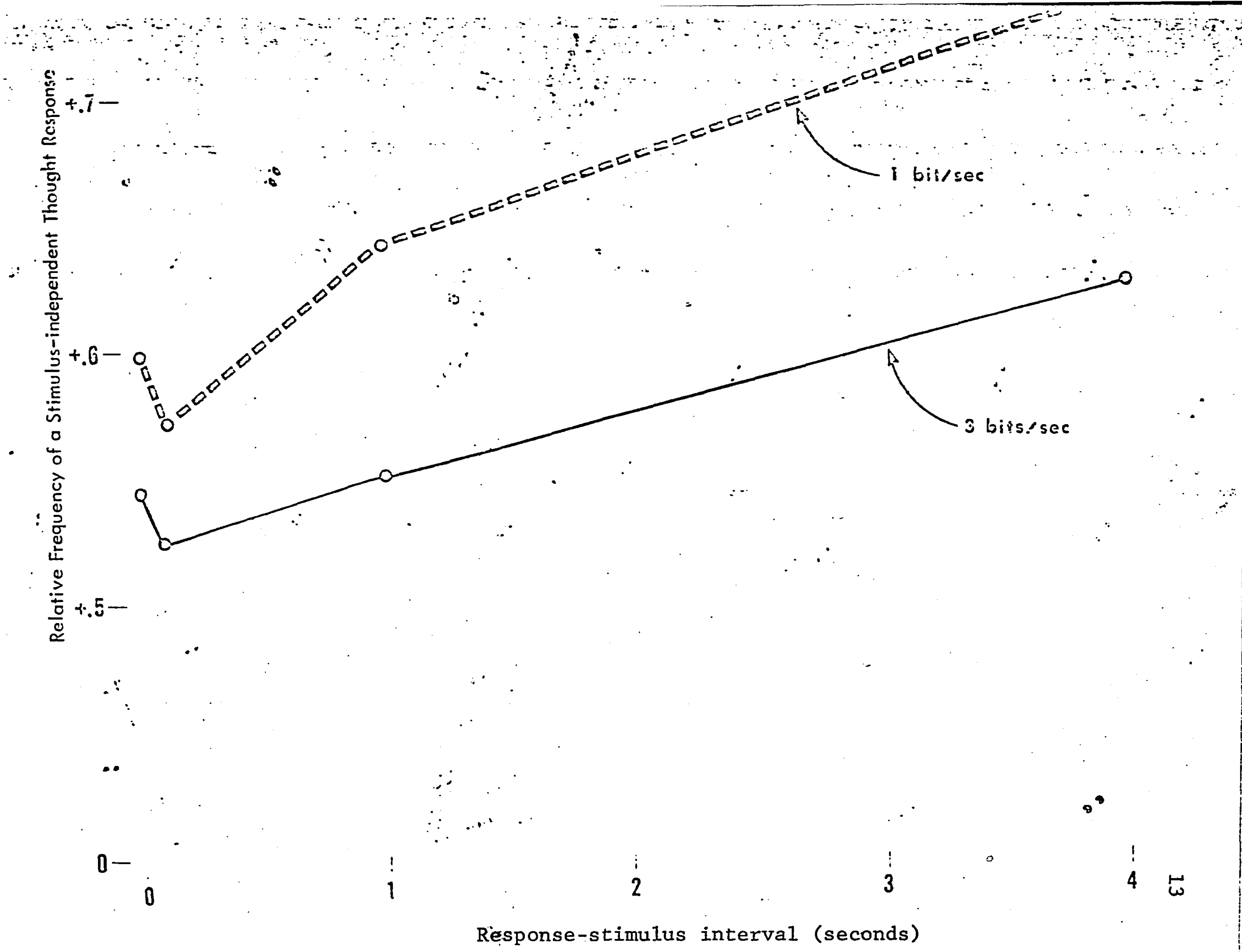

Fig. 2. Stimulus-independent thought responses as a function of number of bits per auditory signal and duration of interval.

response. In the experiment by Antrobus (1968) the two independent variables are confounded since subjects can take longer to detect or decode more complex stimuli, especially when longer interstimulus intervals were employed (Antrobus et al, 1970). The results of Goldstein's experiment, graphed in Figure 2, imply that both parallel and sequential models are involved in processing of information from perception and memory. The evidence for a parallel model is the decrease in production of stimulus-independent thought in relation to the increase of information per signal. Also, there was production of stimulus-independent thought in the no-gap condition. In this condition there is continual processing of external stimuli so a parallel processing is the only model that could incorporate the production of SIT. The evidence for a sequential model was the increased production of stimulus-independent thought as the inter-stimulus interval increased. Only the sequential effect was statistically significant; the parallel effect remains a trend rather than a significant effect. It is to obtain a more satisfactory test of the parallel model, in particular by examining the effect or increasing the range of information density per signal) as well as to replicate the sequential effect that the present experiment is designed.

Hypothesis

The present experiment proposes a procedure similar to Goldstein's (1968), but there will be a wider range of information density per signal (1.58

3.91, 5198, or 7.99 bits) and a greater number of inter-stimulus intervals (0.0, 0.1, 0.4, 1.0, 2.0, and 4.0 seconds).

If the production of stimulus-independent thought is only affected by the information density of the task signals, there would only be evidence for parallel processing. If the production of stimulus-independent-thought is only affected by the amount of gap size there would only be evidence for sequential processing. If both information density per signal and gap size affected production of stimulus-independent thoughts, there would be evidence for both parallel and sequential processing. Perhaps the most efficient system would use parallel processing when the need is for continuous attention to external stimuli (thus allowing production of fantasy), but switch to sequential processing when there is an increase in the time available for just producing fantasy (i.e., when there is no payoff for attention to external stimuli) or when the payoff for attention to external stimuli is so high that any interference from fantasy would be considered detrimental.

CHAPTER II

METHOD

General Design

Eleven subjects trained in defining stimulus independent thought responses (daydreaming) participated in an error-free, self-paced, visual signal detection task. The independent variables were: (1) the amount of information per stimulus and (2) the duration of interval between a correct response and the subsequent signal. The dependent variable was the relative frequency of stimulus independent thoughts.

The subject was presented with randomly ordered visual signals. The detection task included four different amounts of information per presentation (1.58 bits, or 3.91 bits, or 5.98 bits, or 7.99 bits per stimulus array). Each array was presented until correctly identified. There were six possible intervals (0 seconds, or .1 second, or .4 second or 1 second or 2 seconds or 4 seconds) between the correct response and the presentation of the next signal. During these intervals no stimuli were presented. Thus there were twenty-four different combinations (the four different amounts of information X the six different response-stimulus intervals). Conditions were counterbalanced across a four day period.

Each subject received 60 15-second trials in each of the 24 conditions. Each condition appeared for a total of 15 consecutive 15-second trials. Consequently, there were 360 trials each day (24 conditions x 15) for a total of 1440 trials. At the end of each 15-second trial Ss were required to make retrospective judgments of whether or not they had at least one stimulus-independent thought during the preceding trial.

The experimental design was thus a 4 x 6 x 11 analysis of variance (Amounts of Information x Interstimulus Intervals x Subjects).

Subjects

Eleven college students were recruited based on: (1) availability for a four day (5 hours each day) task and (2) ability to perform the visual signal detection task at some minimum standard and (3) ability to comprehend the operational definition of stimulus-independent thought at some minimum standard. An additional two subjects participated in pilot runs. Each subject was paid one dollar per hour plus a bonus of one-tenth of a cent for each correct response (a total of about 3-4 dollars per hour, depending on performance).

Equipment

(a) Environment. S was comfortably seated at a table in a sound-attenuated, light-free cubicle to minimize response to external cues other than the signals. An intercom system permitted S and E to communicate throughout the experiment. The subjects wore earphones throughout the experiment so E was able to monitor S both during the playing of the taped instructions and the actual participation in the task. On the table, facing the subject, was a metal cabinet with 2 adjacent screens, upon which the visual signals were presented. In between the two screens was a switch, that moves left or right, and was used to indicate stimulus independent thoughts at the end of each trial. On the table, were eight metal contacts used to respond to the signals. The contacts were placed on the table in a semi-circle that approximated the shape of the most comfortable placement of the fingers of both hands, excluding the thumbs.

During the experiment, background white noise was generated in the earphones, and there was no light except that given off by the signals.

(b) Apparatus and Stimuli. S was seated at a table. On the table, approximately two feet in front of the subject was a metal box (8" long x 7" wide) which contained a rear projection readout module (Industrial Electronics Engineers, Inc., Van Nuys Calif. One-plane readout Model 10-5512), which displayed the visual signals. For technical reasons, there were actually two screens upon which the signals were presented, but only one was employed at a time. The rear projection modules were set up to display four different background patterns and suitable stimulus lights for each. The background pattern was an illuminated circle of one inch diameter divided into 2, 4, 6, or 8 equal segments. In the center of each segment a small dot of light could be displayed. Each dot corresponded to one response button. These buttons were actually highly sensitive metal capacitance switches requiring only a light touch to indicate a response. This had the advantage (over the telegraph keys used in Goldstein's 1968 experiment) of minimizing fatigue, sore fingers, and kinaesthetic feedback. Since S was required to lift his fingers in order to indicate completion of a response there was no way of recording the difference between not responding and a response to a no-dot-signal. Therefore, the no-dot-of light signal was eliminated. This means that the number of possible alternatives in the 2 segment condition was 3, (2^2-1), and in the 4 segment condition was 15 (2^4-1) and in the 6 segment condition was 63 (2^6-1), and in the 8 segment condition is 225 (2^8-1). Therefore, the four possible amounts of information per presentation were 1.58 bits, or 3.91 bits, or 5198 bits, or 7.99 bits per stimulus array.[1]

Signal presentation was pre-programmed on 8 channel paper tape. The trial length of 15 seconds was pre-established. However, both independent variables had to be manipulated

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[1]Bits of information are computed by the formula 2^x = number of alternatives in which x = bits of information (see Miller, 1956).

during the experiment in order to change conditions. The combination of writing down scores and changing conditions could take up to a minute. Therefore, whenever a condition was changed the first two trials were not scored requiring approximately 17 trials in each condition, each day. Detection scores and stimulus-independent thought responses were recorded on a print-out counter. However, tabulation was done by hand so the results of bonus money accrued was not tabulated until after the subject finished,

Procedure

a. Pre-experiment. Prior to the actual participation in the experiment, subjects were told: (1) the experiment involved a visual discrimination task and, (2) the procedure would last four consecutive days of approximately four work hours each day, with a one hour break in the middle; (3) pay scale.

When S arrived the first day he was asked to fill out a payment form (see Appendix A) so that payment could be mailed to him.

b. Pre-testing and Instructions. After being seated in the test cubicle and placing the earphones on, S was started on the pre-recorded instructions (for verbatim transcript see Appendix B).

The first set of instructions described the placement of the fingers on the metal contacts (response buttons).

The subject was then shown the signals and told how to respond to them. The subject was then told about the bonus money and the importance of responding rapidly in order to increase payoff. There was then approximately 20-25 minutes of practice. In order to continue the S had to get at least an average of 10 correct detections per trial in the no gap/1.58 bits condition and at least an average of 2 correct in the 4 second gap/7.99 bits condition.

Following the practice the taped instructions were continued in order to describe the operational definition of stimulus independent thoughts. The instructions then described the requirement of making retrospective judgments of stimulus-independent thoughts following each trial. The definition of stimulus-independent thoughts was then tested against a list of items (see Appendix C), some of which were not be (by definition) stimulus-independent thoughts. Test items were stopped with the S correctly andwered at 80% accuracy in at least 10 consecutive items (all the subjects seemed to readily grasp the concept and all the subjects passed the test).

Finally, the lights were turned out, and 5 minutes of practice was given in responding to signals and indicating with the switch the presence or absence of stimulus independent thoughts. The E interrupted S on 5 yes and 5 no trials, asking S the basis for his yes/no response. If there were any discrepancies between E's and S's concept of stimulus-independent thought, they were resolved by E at this time.

The subject was then given a final summing up, with emphasis on the importance of speed in responding in order to increase bonus money.

c. Signal Detection Task. When a signal was presented, and the corresponding button touched, the light went out for the duration of the touch. When all stimulus lights were extinguished in this manner and no extra response buttons were being touched, the subject lifted his fingers and the signal went out. As soon as the S had removed all of his fingers from the response buttons (and the response was correct) there was a pause which could be set at 6 different intervals (0, .1, .4, 1, 2, or 4 seconds) until a new pattern of stimulus lights was presented. The subject could then begin a new response.

The instructions have emphasized the importance of responding rapidly in order to increase bonus money. This is significant, since in a self-paced task the S could choose to create huge periods in which to daydream if he were not given a strong incentive to respond. The end of the 15 second trial was indicated by the signals stopping and the background pattern dimming. This was a signal to the subject to push the switch between the screens, in order to indicate if he had at least one stimulus-independent thought during the preceding trial. As soon as he pushed the switch the next trial began.

CHAPTER III

RESULTS

All statistical tests involving the SIT response were carried out on 2 arcsin $\sqrt{\text{proportion SIT}}$, hereafter called "arcsin SIT". When the SIT raw data was scored in proportions and the proportions were cumulated as probability distributions over information conditions there were ceiling effects within the information condition. The transformation of proportion SIT to arcsin SIT tended to normalize the within-cell distributions.

Table 1 shows that both the linear and quadratic effects of gap size were significant at the .01 level. The relative frequency of an SIT response increased when gap size was small ($0 \rightarrow 0.1 \rightarrow 0.4 \rightarrow 1$ sec. gap conditions), but as gap size became larger (1 sec.$\rightarrow$2 sec.$\rightarrow$4 sec. gap conditions) the relative frequency of an SIT response leveled off.

The linear effect of information per signal was significant at the .01 level; the quadratic effect was not significant. This means that the relative frequency of an SIT response decreased with an increase in information density. No interaction effects were significant.

Were it not for the fact that results were contrary to any of the hypotheses of the present experiment or contrary to the results of Goldstein's (1968) previous experiment, the analysis

Table 1. ANALYSIS OF VARIANCE FOR ARCSIN SIT.
(information x gap x subjects, N=11)

Source	Sum of Squares	DF	Mean Square	F-Test
Information	2.513	3	0.838	4.997**
Information	5.029	30	0.168	
Inf. Linear	2.403	1	2.403	38.99***
Inf. Quadratic	.100	1	.100	1.62
Inf. Cubic	.010	1	.010	
Gaptime	7.629	5	1.527	24.752***
Gaptime x Subj.	3.092	50	0.062	
Gap Linear	5.279	1	5.279	31.42***
Gap Quadratic	2.096	1	2.096	12.48
Gap Cubic	.254	3	.095	.50
Information x Gaptime	0.901	15	0.060	1.702
Inf. x Gap x Subj.	5.297	150	0.035	
Subject	35.582	10	3.558	
Linear x Linear	.013	1	.013	.37
Quad x Quad	.059	1	.059	1.67
Res.	.829	13	.063	1.81
TOTAL	60.033	263	0.228	

** Significance=0.007

*** Significance=0.001

might have ended at this point. However, as Fig. 3 demonstrates, when the gap time was small (0→0.1→0.4→1 sec. gap conditions) sequential processing appears to take place, but when gap size increased (1 sec.→2 sec→4 sec. gap conditions) parallel processing appeared to take place.

Why should this be? Two features emerged from the data that altered the picture. It can be shown that the quadratic effect of gap time is simply an artifact of the design, and second, gap time is confounded by "free time" (i.e., the total time in a trial that the subject was not processing a signal).

The quadratic effect of gap time is actually a function of the number of "signal detection/gap" cycles per trial. The quadratic effect is actually a function of the following equation:

$$\#\text{ of cycles per trial} = \frac{15\text{ sec.}}{\text{RK sec.}}$$

15 sec. = trial length

RK = response & gap duration

= cycle time

Therefore, as cycle time increases from 0 to 4 sec., the opportunity to make a response decreases in the negatively decreasing, quadratic fashion demonstrated in Fig. 4. Thus SIT is far more a linear function of the gap time variable than was initially seen.

A review of the results of the detection task (Table 2) established that subjects generate unequal amounts of gap time in different conditions. For example, in the 7.99 bits per signal/1 sec. gap conditions Ss generate an average during 60 trials of approximately 316 gap seconds (316 correct

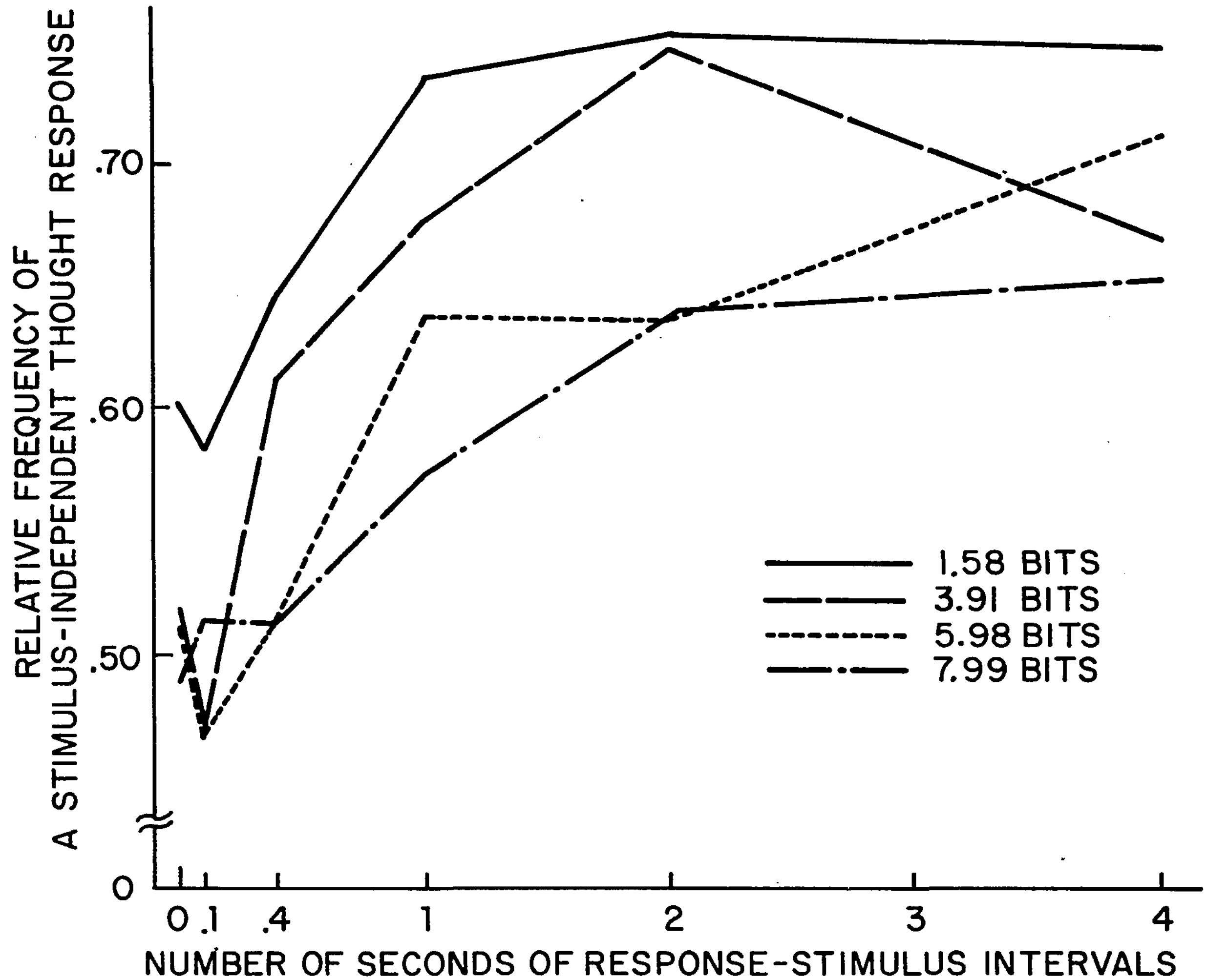

Fig. 3 Stimulus-independent thought responses as a function of number of bits per visual signal and duration of interval between correct detection and subsequent signal N = 11.

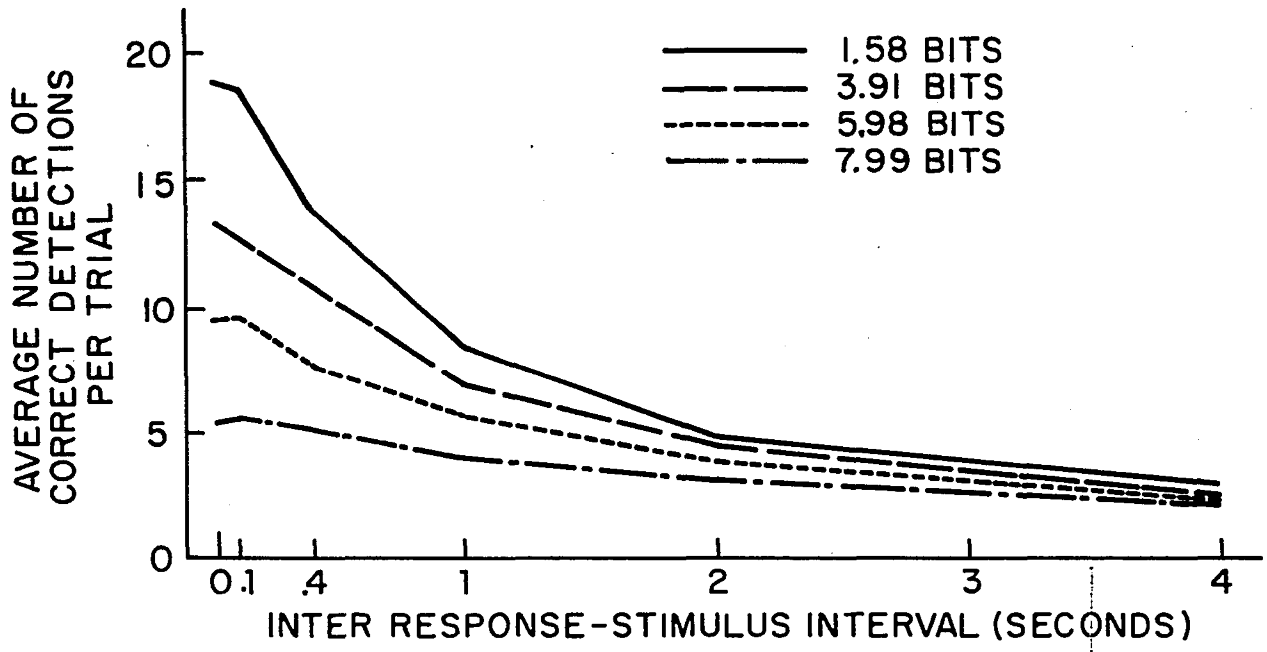

Fig. 4 Average number of correct responses in a trial as a function of number of bits per visual signal and the interresponse-stimulus interval (N = 11)

responses x 1 second gap; while in the 7.99 bits per signal/ 2 sec. gap condition Ss generate an average during 60 trials of approximately 476 gap seconds [238 correct responses x 2 second gaps]).

Table 2. AVERAGE NUMBER OF CORRECT RESPONSES PER TRIAL

Information Density	Gap Size					
	No	.1	.4	1 sec	2 sec	4 sec
1.58 bits	25.45	24.98	18.53	10.52	6.23	3.63
3.91 bits	18.2	17.18	14.68	9.2	5.55	3.32
5.98 bits	12.53	12.85	10.53	7.43	5.12	3.1
7.99 bits	7.17	7.22	6.87	5.27	3.97	2.72

Thus, the confounding of the gap size condition is demonstrated since as the gap size increases the total free time per condition is unequal across gap times. Since the significant effect of gap size on arcsin SIT seems to support a sequential model, the possibility existed that the gap size effect might be attributed largely to total free time. Therefore, it was necessary to establish a means of accurately measuring total free time.

By total free time is meant the total time during the trial the subject was not processing a signal. The following formula for total free time was devised:

Total free time = 15- [(SRT) (R)]   SRT = average response time per signal

R = average # of correct responses per signal

Average response time may be estimated from trials with negligible gap size. The results of the signal detection task (Table 2) revealed the same number of responses in the 0 second gap condition as in the .1 second gap condition, which implied some interference from the preceding signal, in processing or responding to a subsequent signal, when one stimulus followed another without any gap. Thus the best estimate of response time per signal for a given information condition is the following equation:

$$SRT = \frac{15 \text{ sec.}}{\frac{\#R \text{ in } 0 \text{ sec. gap} + \#R \text{ in } 1 \text{ sec. gap}}{2}}$$

The total free time generated in each condition (Table 3) clearly indicated the wide range of free time in the various conditions.

Table 3. AVERAGE NUMBER OF SECONDS OF TOTAL FREE TIME PER 15 SECOND TRIAL

Information Density	Gap Size					
	No	.1	.4	1 sec	2 sec	4 sec
1.58 bits	0	0	3.98	8.74	11.24	12.84
3.91 bits	0	0	2.55	7.20	10.28	12.19
5.98 bits	0	0	2.55	6.21	8.95	11.34
7.99 bits	0	0	.68	4.01	6.73	9.33

An analysis of covariance on arcsin SIT covarying out total free time, was attempted. The variances of total free time, however, were not homogeneous (a requirement for Ancova).

In addition there appeared to be floor and ceiling effects on the raw free time data. Therefore, the total free time scores were converted into proportions based on the maximum possible free time, and then free time was transformed to "arcsin free time" which tended to normalize within-cell distribution and achieved better homogeneity of variance (F max=10.78).

However, Ancova was not a viable solution. T he within-cell distributions of the covariate showed almost no overlap, and there was a negative regression coefficient (b=-.19), both indications that Ancova was not the solution to analyzing the effects on arcsin SIT. Parenthetically, the Ancova effect of gap time and information density with total free time as a co-variate were insignificant, but since Ancova was not appropriate no interpretation of the loss of significance was made.

Thus, another route to analyzing the results was necessary. Fig. 5 showed that SIT was a linear function of free time. The correlation between arcsin SIT and arcsin free time, averaged over all conditions and all subjects was .37 (r^2=.14). A linear contrast between gap time and arcsin free time was used to estimate the correlation between the two variables: p^2=.58, p=.76. The strength of association between gap time and free time was high enough to provide presumptive evidence for the proposition that the effects of gap size on arcsin SIT was largely determined by total free time. The linear trend for the gap time effect on arcsin SIT was significant at the .001 level. The strong association between gap size (free time) and arcsin SIT was considered support for a sequential model.

When stimulus-independent thought was plotted as a function of information density and free time, (Fig. 5) a linear relationship emerged. However, when arcsin free time was plotted as a function of information density and gap size interval (Fig. 6) a curvilinear relationship appeared as in the plotting of the original data, Fig. 3. If number of cycles decreased in a nonlinear fashion as a function of gap size and signal response time (a constant), then as the number of cycles decreased, total free time increased, and in a "mirror image" quadratic fashion. Therefore, SIT (whether arcsin SIT or percentage SIT) would be a linear relationship of information density and total free time.

In summary, the results had the following significant features:

(1) SIT increased as a linear function of total free time, supporting a sequential model.

(2) The gap size effect was via its strong association with free time.

(3) SIT decreased as a linear function of the information density of presented visual signals, supporting a parallel model.

(4) In the conditions with "no gap" intervals (0.0, & 0.1 second gap conditions) the probability of a stimulus-independent thought was well above zero (.50 in the 3.91,

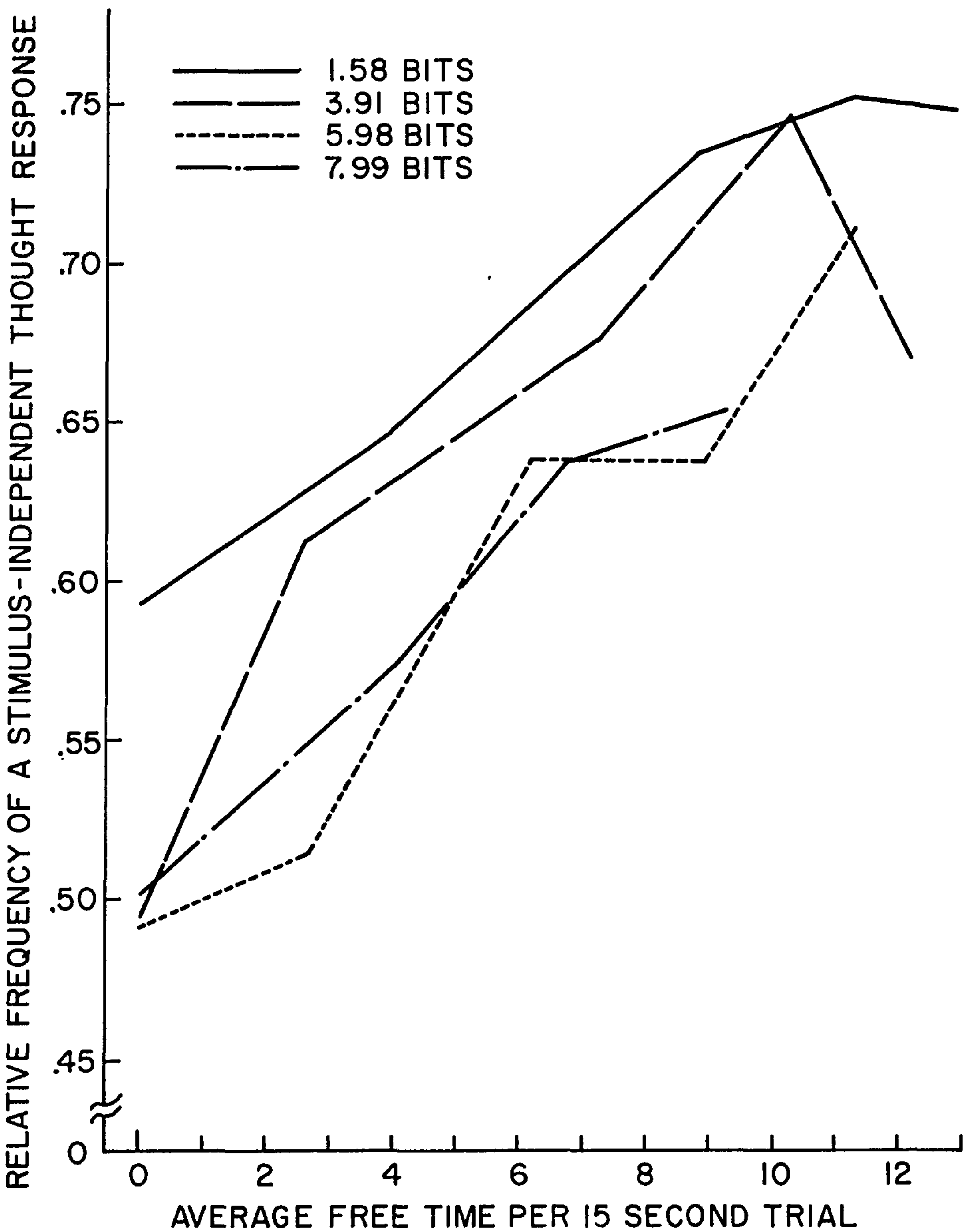

Fig. 5 Stimulus-independent thought responses as a function of number of bits per visual signal and free time per trial N = 11.

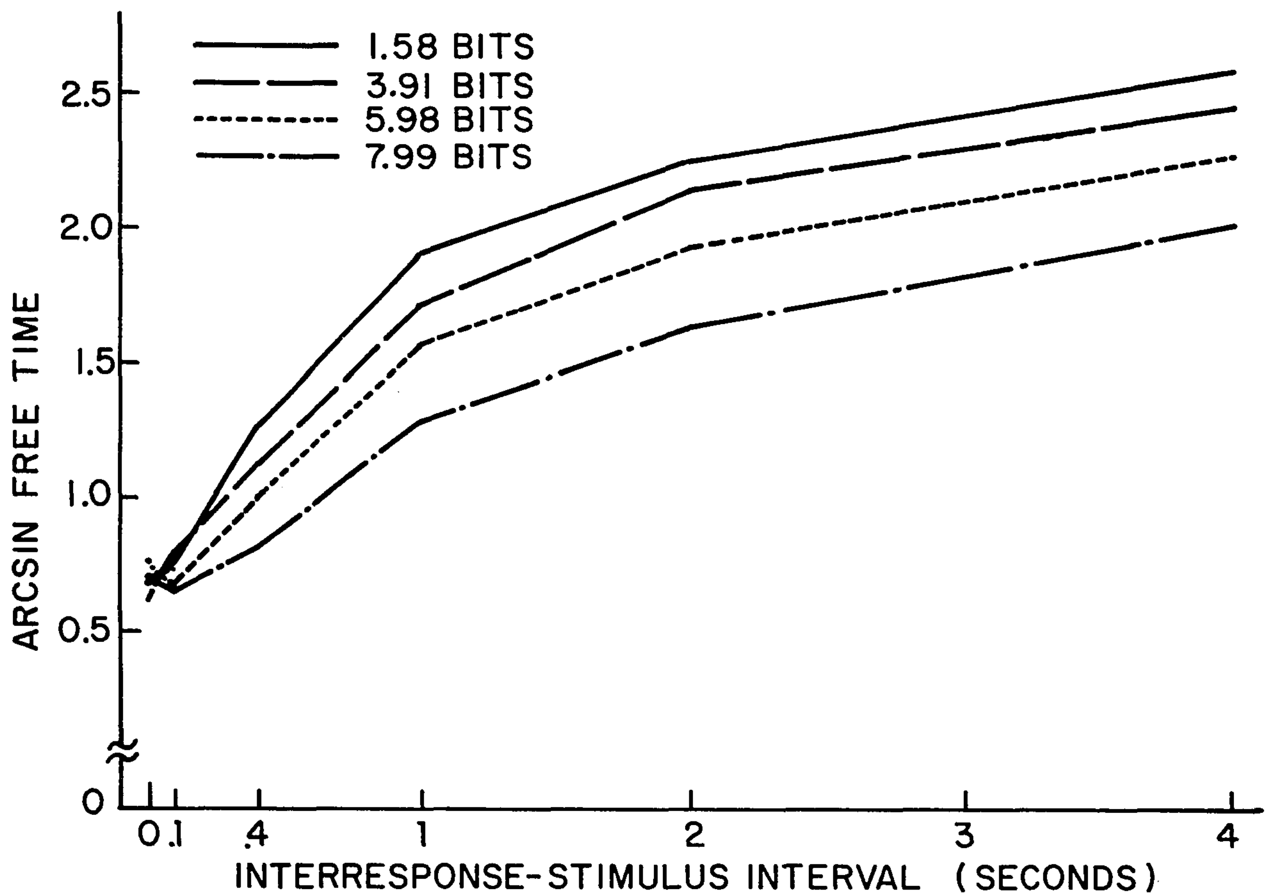

Fig. 6 Free time as a function of information per visual signal and interresponse-stimulus interval N = 11.

5.98, and 7.99 bits per signal condition; .60 in the 1.58 bits per signal condition), which could be constratd as support for either a parallel or a sequential model, depending on the interpretation.

Therefore, the analysis of the data thus far supported a model that integrates sequential and parallel processing. In its broad outlines the combination of sequential and parallel processing. In its broad outlines the combination of sequential and parallel processing suported the findings of earlier research (Goldstein, 1968). However, in the discussion, major modifications of these conclusions will be made.

CHAPTER IV

DISCUSSION

This study was designed to find out whether the cognitive processes leading to production of a stimulus-independent thought are carried out in parallel or sequentially with respect to the processing of external signals. Gap size, one of the two independent variables designed to contrast the implications of parallel and sequential processing, was confounded by total free time per trial in this experiment, thus requiring very cautious analysis of the results.

The experiment used a self-paced signal detection task in which the independent variables were: (1) the amount of information per visual signal and, (2) the interval between the correct response and the subsequent signal.

The intended purpose of varying information density per signal was to increase the task load of the shared cognitive capacity. It was proposed that in a parellel model an increase in information would decrease the available resource and consequently decrease the probability of an SIT response (see Fig. 1). There would be no effect of varying signal density in a sequential model, since all mindwandering occurs between the presentation of signals.

The intended purpose of varying interresponse-stimulus intervals (gap times) was to test another contrasting assumption of the two models. Namely, if the cognitive operator is restricted to producing stimulus-independent thought during intervals between responding to signals (sequential model), an increase in gap time would increase the probability of production of an SIT response. There would be no effect of varying gap size in a parallel model, since production of a stimulus-independent thought could occur during the processing of a signal.

Although gap size and total gap time or free time are necessarily confounded in this design, the extent of the confounding was not realized until total stimulus-response time was estimated. Total stimulus-response time is the product of: (1) response time per signal and, (2) the number of signals per trial. Total free time is, obviously, the complement of total stimulus-response time. As Table 3 illustrates, the wide range of free time generated in the different conditions confounds the analysis of gap time.

If no effect of gap time were to exist there would be no reason to correct for total free time. Since a gap size effect does exist, however, it is necessary to determine whether the obtained gap size effect, or any portion of it, is independent of total free time. The most obvious way to partial out any confounding effect of free time is by means of analysis of covariance. Analysis of covariance is, however, not a viable solution because of the reasons discussed in the

Results section. Since Fig. 5 indicated that SIT was a linear function of free time (r=.37, r^2=.14), an analysis of variance of arcsin free time was carried out, which indicated that gap size shared 58% of its variance with arcsin free time. The strength of association between gap time and arcsin free time constituted strong evidence for the proposition that the effects of arcsin free time on SIT are mediated by gap time. The point here is that "total free time" is actually made up of the sum of chunks of "gap time", and the analysis of sequential and parallel models proceeds from the link between total free time and gap time.

<u>Sequential Processing</u>

The major evidence for sequential processing is the increased probability of a stimulus-independent thought response as a function of increased free time (Fig. 5). Although, when the original data is plotted (Fig. 3) it appears that the effect of gap time on percentage SIT asymptotes, this asymptote was shown to be simply an artifact of the design, since as the number of response time and gap time cycles decreases in a nonlinear fashion, total free time increases in a quadratic fashion. Therefore, SIT would be a linear function of information density and free time. The increased probability of an SIT response, when information density is constant and free time increases, supports a sequential model, since the cognitive operator can only produce a stimulus-independent thought when the operator is not processing a signal. If a

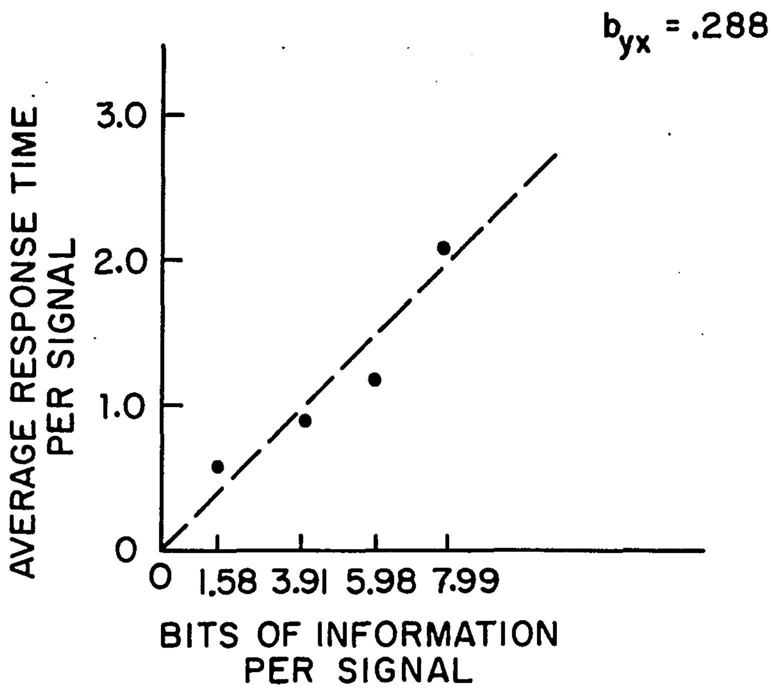

Fig. 7 Linear regression of average response time per signal on bits of information per signal (N = 11)

parallel model held, and simultaneous processing of SIT and the visual stimuli was possible, there would in effect be 15 seconds of free time in every trial and the size of the gap would have no effect on the probability of an SIT response.

Furthermore, it can be shown, that increasingly complex stimuli are encoded over increasing increments of time, and in this respect do not impinge on a greater portion of operator capacity. The average response time per bit of information was approximately .25 seconds (Table 4).

TABLE 4

AVERAGE RESPONSE TIME PER BIT OF INFORMATION

Bits of Information	Average Response Time
1.58	.5948 sec.
3.91	.8478 sec.
5.98	1.1819 sec.
7.99	2.086 sec.

When this data was graphed as a regression function (Fig. 7) the evidence suggested that increasingly complex stimuli are encoded over increasing increments of time and that at least a portion of the decreased probability of an SIT response, when information is increased (Fig. 3 & Fig. 5) is due to a decrease in available free time.

Parallel Processing

Without considering free time there is no way to reliably estimate the effect of information density on percentage SIT.

In order to portray the effect of free time the graph of percentage stimulus-independent thought as a function of information density and free time per trial (Fig. 5) is essential. Support for the parallel model came from the decreased probability of an SIT response with increased information per signal. The decreased probability of a stimulus-independent thought implies that as information density increases there is a decrease of operator capacity available for production from long term memory. The minor reversal of slope in the 3.91 bits per signal condition is considered to be a chance phenomena, since it did not coincide with any of the remainder of the data.

Further evidence for parallel processing was suggested by the fact that the probability of an SIT response was well above zero in those conditions in which theoretically no free time was generated (0.0 and 0.1 sec. gap conditions), since cognitive operations that produced a stimulus-independent thought would have been generated during the interval between the presentation of the stimulus and the correct response. Thus, in the "no" gap condition, the subject may be able to generate an SIT response by creating an additional small gap of his own. Such a possibility would be consistent with the sequential model.

Combined Parallel and Sequential Models

A comparison of the present experiment with Goldstein's 1968 experiment revealed many similarities and suggested some changes. Of course, any comparison is tenuous because of the differences of the experiment. The earlier experiment used auditory signals (versus visual signals in the present experiment), had information densities of 1 and 3 bits per signal (versus 1.58, 3.91, 5.98 and 7.99 bits per signal in the present experiment), and had only 4 gap conditions of 0.0, 0.1, 1, and 4 seconds (versus 0.0, 0.1, 0.4, 1, 2, and 4 seconds). However, the basic designs of the two experiments were very similar and the trends are similar. Without adjustments for free time it was not possible to examine the effect of information density in any condition except for no gap.

In Fig. 2 it can be seen that again there is at least a .50 probability of an SIT response. The fact that in both experiments there is a .50 probability of producing a stimulus-independent thought in the no-gap condition suggests a cognitive model that allows a baseline amount of fantasy production regardless of conditions (parallel processing). This was an impressive finding since it implied that the press to fantasize has found accommodation in modern man.

The most important difference between the two experiments is that the first experiment was not adjusted for free time. It can be seen in Fig. 2 that as gap time increased it appeared that the probability of SIT increased. The first experiment, however, lacked a 2 second gap condition, which is the point in time where SIT begins to asymptote in the second experiment (Fig. 3).

The effect of plotting the results of the first experiment (Fig. 2) led to what seemed to be consistent conclusions.

It is possible to illustrate the implications of the contrasting findings (Fig. 8). The first experiment (Goldstein, 1968) suggests a combined model (Fig. 8, Model A) in which increased information per signal decreases the operator capacity, but the search from long term memory was accomplished by sequential operations. The new analysis (Fig. 8, Model B), which is on much firmer ground, suggests that increased information per signal uses more operator capacity and increased operator time. That portion of the operator used for processing external stimuli is only interfered with by fantasy if there is a switch to long term memory. Both models allow for some baseline amount of fantasy.

In summer, this experiment supports a cognitive model:

(1) that sequentially processes material from long term memory with respect to processing of external stimuli.

(2) that uses increased operator capacity and increased operator time in processing increasingly complex external stimuli; which decreases the operator capacity and operator time for processing fantasy.

(3) in which a baseline level of fantasy occurs regardless of the complexity of the task of processing sensory material. It does not distinguish whether the baseline level of fantasy is generated in parallel with the processing of the task stimuli or whether it is created in brief subject-generated gaps which cannot be identified by the experimenter.

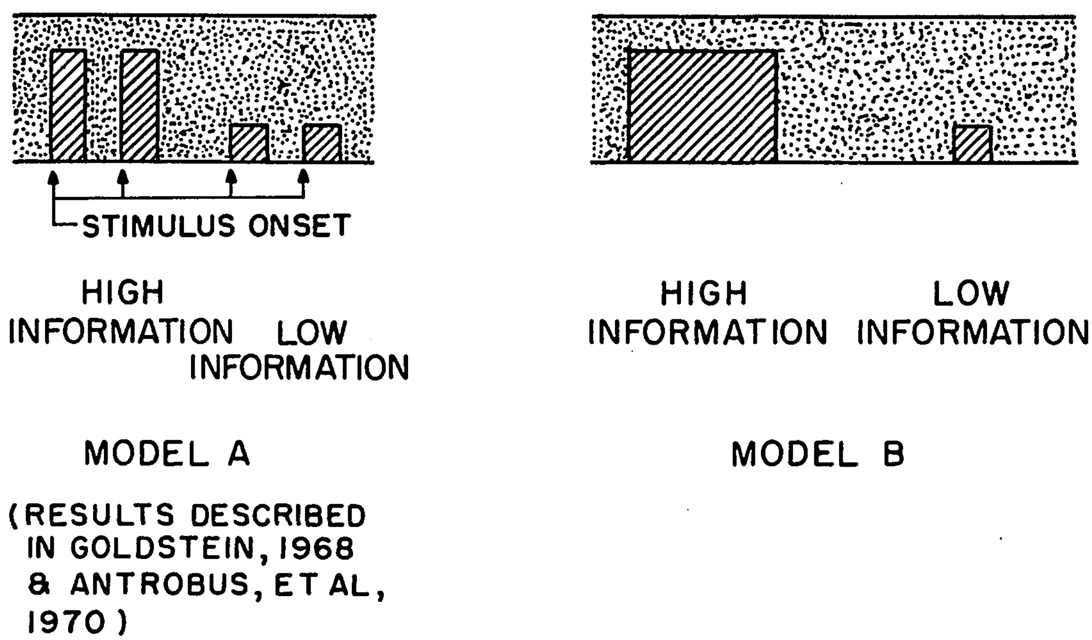

Fig. 8 Combined parallel and sequential models for the production of stimulus-independent thought and imagery during a simultaneous signal-detection task.

APPENDIX A

SINGLE SESSION EXPERIMENTS

SUBJECT CONSENT FOR PARTICIPATION IN PSYCHOLOGICAL RESEARCH

I hereby, voluntarily offer my services as a subject for psychological research.

I have been informed that many subjects have previously taken part in experiments which have employed procedures similar to those of the experiments for which I am volunteering. On the basis of this past experience, the experimenter has assured me that, in his judgment, none of the procedures employed should cause physical harm to my person.

The above assurance not withstanding, I reserve the right to leave the experiment at any time, with or without any justification of my action.

The name of the experimenter is Steven Goldstein. I understand that he/she is working under the supervision of Professor Antrobus who is a faculty member of the Department of Psychology of the City College of the City University of New York.

________ 1. I understand that I will be paid at the rate of $1 per hr. plus a bonus (where applicable) of .1 cent/ correct response.

________ 2. I am volunteering my service as a subject without financial remuneration.

(Subject: Please initial either #1 or #2)

Signed ______________________________ (Subject Volunteer)

Address ______________________________ Telephone # __________

____

______________________________ Date ______________

APPENDIX B

TAPED INSTRUCTIONS

Each subject was seated in the experimental booth, fitted with earphones, shown the equipment and microphone, and given the following taped instructions:

> Listen carefully while I give you the instructions for the task you are about to perform. You will be given a series of visual signals in the form of segments of a pie. Your task is to determine which signal is presented to you. There are eight metal circles, that I will refer to as buttons, on the table in front of you, separated by two foam guards. The buttons are placed on the table in a form that should best fit the placement of your fingers. Now, place the fingers of your left hand, other than the thumb, on the four metal buttons on the left side. Your index finger should be next to the foam guard and your pinky should be on the outside. (There is a pause.) Now place the fingers right hand other than the thumb on the four metal buttons on the right side. Your index finger should be facing inward and be next to the guard. Your right pinky should be on the outside. Is this understood? (There is a pause.) The foam guards have been placed there as an indicator for you of the separation between your left hand and right hand. In addition, when the lights are turned out they will allow you to place your fingers back on the buttons in the minimum amount of time, since your index fingers will have a guide or reference and the remaining fingers can fa-l into place. Is this understood? (There is a pause.)

The subjects were then shown the signals and told how to respond to them in the following way.

> Now if you look at the apparatus in front of you, you can see a verticle line that appears down the center of the square. You can conceive of this as a pie cut in half. (Pie is shown on left screen.) You you will see a four part pie (pie is shown on right screen), now a six part pie to the right, and finally an eight part pie to the left.
>
> The metal buttons on the table correspond to different segments of the pie. When the pie has two segments

(experimenter puts on 2 part pie) your left index finger corresponds to the left segment of the pie, your right index finger corresponds to the right segment of the pie. The remainder of your fingers should be removed from the buttons when you respond to a 2 segment pie. When you are responding to a four segment pie (experimenter puts on 4 part pie) use four fingers. You should use the index and middle fingers of both your hands. Your left index finger and your right index finger correspond to the upper half of the pie and your middle fingers to the bottom half of the pie. No other fingers should be touching the buttons. For a 6 part pie (E puts on 6 part pie), i.e., all the fingers except the pinkies. Your index fingers correspond to the upper segments of the pie, your middle to the middle segments of the pie. No other fingers should be touching a button.

For an 8 part pie use all eight fingers. Your index fingers correspond to the upper segments. Your middle fingers correspond to the segments just below. Your ring fingers to the next segments and your pinkies to the bottom segments.

Are there any questions so far?

A signal will be indicated to you by a dot in the segments. Your task is to press the appropriate button or buttons with your fingers. The buttons are very sensitive so you need not press hard. When you press the appropriate buttons the dot will go out in the corresponding segment. When you have pressed all the appropriate buttons you must lift your fingers. If you have made the correct response that signal will go out and the next signal will appear. There are two important things to remember. If you are pressing any button corresponding to a segment that does not have a dot you cannot get the correct response. You must only be pressing the appropriate buttons. And second, when you feel you have made the correct response lift your fingers just off the buttons so the next signal can appear.

The subject was then told about the bonus money and the importance of responding rapidly in order to increase payoff. The S was then given approximately 15 minutes of practice. In order to continue the S should manage at least an average of 10 correct discriminations per trial in the no gap/1.58 bits condition and at least 2 correct in the 4 second gap/7.99 bits condition. Following the practice the taped instructions were continued in order to describe the stimulus-independent thoughts.

> Now I am ready to continue. After you have been detecting signals for a period of time, you may find that you begin to think about other kinds of things, entirely unrelated to the experiment. You may think of what you were doing last night, or what you were doing last weekend, or you may think of something you would like to do next weekend or something, perhaps, that you should be doing on your way home. Again, you may be thinking about something having to do with your courses at school, or your job. All of these things have in common the property of being unrelated or irrelevant to the task of detecting the signals. Now every once in a while, you will find that the signals will stop, and the light dims. This means the end of a trial. There will be about 180 such trials while you are here today. When the light dims indicating the end of a trial, it will be a signal for you to let me know whether you have had any outside or irrelevant thoughts while the signals were being presented to you. Now, you will notice a switch in the center of the apparatus where the signals are presented. Pushing this switch to the right means yes--that you have had at least one outside thought during the last trial; pushing the switch to the left means no--that you have not had any outside thoughts during the last trial. You will use this switch to signal to me if you have had any ouside or irrelevant thoughts during each trial. Remember, when the light dims, it is a signal to you that the trial is over, and that you are to signal to me whether you have had any outside or irrelevant thoughts during the immediately preceding trial. In other words, push the switch to the right, meaning yes, if any outside thoughts went through your mind during the last trial; whether the thought lasted for a second, a minute or five minutes. If there were no outside thoughts during the preceding trial, then push the switch to the left--meaning no.
>
> Now, I would like to return to the definition of an outside thought. An outside thought will be a thought about anything that occurred either before the trial started, or anything that you expect might happen after the trial is over. That is, if you were just thinking about what occurred before the experiment started, or about anything that happened in the trials preceding the trial which you have just completed, that would be an outside thought. At the end of such a trial, you would push the switch to the right, meaning yes. By contrast, if you were just thinking about something that happened during the trial which you have just completed, that is not an outside thought, and you will push the switch to

> the left, meaning no. In other words, whether something is an outside thought or not will be defined in terms of the duration of the trial just completed. Now, for example, if you were thinking only of the signals and how to discriminate them during the trial, you will push the switch to the left at the end of that trial, because all of your toughts were related to the task of detecting the signals. Also, you might hear an airplane overhead, or a fire engine going by, or someone walking down the hall during a trial. Then again, you should answer no at the end of the trial, because these were not outside thoughts, inasmuch as they are events that occurred during the trial. Of course you may hear a fire engine, and also have an outside thought in addition. For example, something relating to your experiences with fire engines or fires, or something completely unrelated. In this case, you are to push the switch to the right, meaning yes--because at least one irrelevant thought occurred during the trial. Another somewhat ambiguous case might be that during the trial you felt hungry, or tired, or that your muscles were getting sore from sitting too long. Again, at the end of such a trial, you would push the switch to the left--meaning no. Yet another ambiguous case is when you find yourself thinking about the instructions, the purposes of the experiment, or about the experimenter. Since these are not thoughts about events occurring during the actual trial, you push the switch to the right, meaning yes, because these are otside thoughts, although they are related to the experiment as a whole. You may also find the same thought occurs again and again in a number of trials. For example, if you were hungry enough, you may imagine yourself eating dinner for several trials in succession. Even though this is the same thought which occurs each time, push the switch to the right, meaning yes, at the end of each trial during which these thoughts occurred.

The concept is then tested against the list of items in Appendix C. If the subject passes the test (80% accuracy in at least 10 items) the final instructions are given.

> A final reminder: in the middle of a trial, the number of segments in the pie might change. You should adjust as quickly as possible by adding or removing the appropriate fingers and then continue. (In the experiment in order to allow for the experimenter's changing conditions, and the subject's own mental and physical preparation the first two trials in any condition will not be scored.)

APPENDIX C

TEST OF STIMULUS-INDEPENDENT THOUGHTS

Now I would like to see how well your judgment of an outside thought corresponds with that of other people. I am going to read you a list of prepared thoughts. As I read each thought please tell me whether you think it is an outside thought or not:

I thought about a girl/boy (opposite sex) I had been seeing.	YES
I thought about the signals and how much I earned on this last trial.	NO
I thought about the uses for this experiment.	YES
I thought about whether I had differentiated the tones in this trial correctly.	NO
I thought about what the experimenter was doing.	YES
I thought about how badly I had done on the trial preceding this one.	YES
I thought about the signals and how much I would earn altogether.	YES
I thought about talking to a friend about the experiment.	YES
I tried to guess the next signals.	NO
I thought about the instructions.	YES
I thought about how I missed the previous tone.	NO
I thought about how I just pressed the wrong button.	NO
I felt hungry.	NO

I thought about an exam I have tomorrow.	YES
I thought about how soon this would be over.	YES
I thought that my chair wasn't comfortable.	NO
I thought that the signals were too loud.	NO
I felt hot.	NO
I thought about my job.	YES
I thought about how fast I could get the tones.	NO

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