This is to certify that the

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STIMULUS COMPLEXITY AND THE DURATION
OF VISIBLE PERSISTENCE

presented by

James Michael Yeomans

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of the requirements for

M.A. degree in Psychology

David E. Irwin
Major professor

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STIMULUS COMPLEXITY AND THE DURATION OF VISIBLE PERSISTENCE

By

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ABSTRACT

STIMULUS COMPLEXITY AND THE DURATION OF VISIBLE PERSISTENCE

By

James Michael Yeomans

Visible persistence refers to the phenomenal impression that a stimulus is still visibly present after its offset. A dispute exists whether visible persistence is under cognitive control ("process" hypothesis) or merely reflects temporal sluggishness in the visual pathway ("neural" hypothesis). This was investigated by manipulating cognitive load (stimulus complexity) in 10 experiments. These experiments used one of two techniques: (1) a temporal integration task, requiring subjects to integrate perceptually two temporally separated stimuli; and (2) an onset-offset method, requiring subjects to make subjective judgments about the onset and offset of stimuli. Complexity was found to have no effect on visible persistence duration, indicating that visible persistence is not under cognitive control; these results support the "neural" hypothesis. A set of complexity criteria was developed, and implications for models of visual processing were discussed.

THIS THESIS IS

DEDICATED

TO MY MOM AND DAD

CLAIRE AND JACK YEOMANS

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INTRODUCTION

Allen (1926) reported that the first reference to visual persistence can be seen in the writings of Aristotle (384-322 B.C.). Interest in this subject matter was renewed in the late 1800's by several researchers (e.g., Baxt, 1871; Cattell, 1886). Using tachistoscopes, and presenting stimuli (i.e., arrays of letters or numbers) at very short durations (usually 10-50 ms), these studies demonstrated the existence of a very short-term memory store. The general finding was that only a small subset of information (i.e., 3-5 items) could be reported. Subjects in these experiments insisted that they saw more than they actually reported, however, although nothing came of these introspective reports for nearly 70 years.

Sperling (1960) performed some replications and extensions of this pioneering work. In a typical experiment, a 3 row by 4 column array of letters was flashed tachistoscopically to subjects. As in the previously noted studies, the subject's task was to report as many letters as possible, and the finding was that 3-5 letters were correctly reported. This method of obtaining responses has come to be known as a full

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report. Sperling, having replicated the previous findings, then modified the procedure in the following way: (1) the 3 x 4 letter array was presented; (2) a variable length delay would occur; (3) a tone would be sounded that indicated which row of the array to report (i.e., a high frequency tone was used to cue the top row, a medium frequency tone corresponded to the middle row, and finally, a low frequency tone was used to cue the bottom row) If the tone occurred immediately at offset, subjects were able to report 3 out of 4 (on the average) of the letters in the cued row. This suggests that at least 9 of the letters were available for report (i.e., 3 letters from each of the 3 rows), since the subjects had no knowledge of which row would be cued on each trial. As the delay between the array offset and the cue onset was increased, performance declined until it reached the full report level (at about a 500 ms delay). This method has come to be known as partial report.

At the same time, Averbach and Coriell (1961) performed experiments using visual, rather than auditory cues. Employing a visual pointer and 2 x 8 letter arrays, they demonstrated that a partial report superiority exists until a cue delay of about 500 ms. This finding was important because it removed output interference as a possible explanation for the results. In other words, although it could be argued that

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Sperling's results were due to interference at the time of reporting the letters (i.e., you have several letters to report and they interfere with one another), Averbach and Coriell only required their subjects to report one letter per trial and found basically the same results. In other experiments, Averbach and Coriell used a different type of visual cue, an annulus that circled the letter to be reported. At stimulus onset asynchronies (i.e., the time from the onset of the array until the onset of the cue) of 100 ms, they discovered an unusual occurrence: circled letters seemed to be erased. This phenomenon is often referred to as metacontrast.

The finding that visual cues can create masking (i.e., erasures), as well as the introspective reports of subjects in full report conditions (i.e., that information faded before it could be reported) led to the development of a "visual" notion of sensory persistence. A great deal of evidence soon appeared that also seemed to be consistent with this visual conception. In general, it seemed that cueing by physical variables (e.g., brightness) led to partial report superiority. For example, color (Clark, 1969), brightness (von Wright, 1968), and shape (Turvey & Kravetz, 1970) have proved to be effective cues. Also, the failure of informational type cues (e.g., report only the letters that end in "ee," Coltheart et al., 1974) lent strength to the idea

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of a decaying visual trace. Thus, these results led to the consensual notion that visual information persists after stimulus offset in a pre-categorical, high capacity, quickly decaying memory store, which Neisser (1967) called "iconic memory." This view shall henceforth be referred to as the "traditional view" of iconic memory.

The partial report technique has been called an indirect measure of sensory persistence because it relies on the retrieval of visual information about a stimulus display, which does not necessarily have to be visible. Similar results have been found using more direct techniques. Direct methods are those that require more purely visual judgments. For example, Sperling (1967) invented a technique which measured the phenomenal duration of a stimulus, in which subjects adjusted the occurrence of a probe (tone) so that its onset and offset appeared to be synchronous with stimulus onset and offset. Another technique was introduced by Eriksen and Collins (1967, 1968), in which two random dot patterns were presented sequentially, separated by a variable interframe interval (i.e., the time from the offset of the first event to the onset of the second event). When superimposed, these patterns formed a nonsense syllable, and subjects were found to be able to integrate the two displays for interframe intervals up to 100-300 ms.

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Thus, the traditional view was further strengthened, since the direct methods (i.e., highly visual in nature) found evidence of a decaying trace lasting for time periods similar to those of the indirect partial report procedure.

There were some studies that seemed to conflict with the traditional view, however. Dick (1969) presented evidence which suggested that the physical aspects of the display (e.g., location information, brightness, etc.) seemed to decay faster than the stimulus identity information. Townsend (1973) found data that were consistent with Dick's results also. For example, most of the errors in Townsend's partial report task were mislocation errors (i.e., the incorrect letters in the subject's response were present in the stimulus array, but not at the cued locations), rather than intrusion errors (i.e., the incorrect letters in the subjects' report were nowhere in the array). This fact suggests that items in the array were identified and remembered quite well (provided the stimulus duration was not too short), but their locations are forgotten. Mewhort, Campbell, Marchetti, and Campbell (1981) found that familiarity with the stimulus array (i.e., different orders of approximation to English--arrays in which the letter combinations were varied as to how word-like they were) reduced the number of intrusion errors but not

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mislocation errors. These findings of differential decay of location and identity information suggest that perhaps the indirect measure (partial report) is tapping more than just raw stimulus information.

Recently, the unitary model of sensory persistence (i.e., the traditional view) has come under heavy attack. Coltheart (1980) has proposed a three component model to explain the preceding failures of the traditional model. Coltheart (1980) has stated that the "icon" should be subdivided into the following types of persistence: (1) neural persistence, due to residual activity in the visual pathway; (2) visible persistence, or the phenomenal impression that the stimulus is still visibly present; and (3) informational persistence, or knowledge about the visual properties of the stimulus. It is quite possible that visible persistence is due to neural persistence, since both processes are believed to last for about 100 ms. The main division in this model occurs between visible persistence and informational persistence (i.e., what partial report is claimed to measure). Evidence used to support this distinction is that the two types of persistence appear to be differentially affected by stimulus duration and intensity changes. Visible persistence duration (measured using direct methods) decreases as stimulus duration or stimulus intensity increases (e.g., Bowen, Pola, & Matin, 1974; DiLollo, 1977

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1977, 1980; Efron, 1970a, 1970b, 1970c; Haber & Standing, 1969, 1970), while in partial report tasks (i.e., measuring informational persistence) increasing stimulus intensity or stimulus duration results in no, or a positive effect on performance (e.g., Adelson & Jonides, 1980; DiLollo, 1978; Long & Beaton, 1982; Sperling, 1960; Yeomans & Irwin, 1985). Thus, to summarize, Coltheart (1980) states that visible persistence and informational persistence are separate phenomena, because they are differentially affected by changes in either stimulus duration or intensity.

This thesis will be concerned with exploring the nature of visible persistence. The first question that arises about visible persistence is "what exactly is it?" Coltheart (1980) suggested that it resulted from residual neural activity in the visual pathway. DiLollo (1980) has taken a similar view, although he named it the "recruiting phase" of stimulus processing. DiLollo claims that this stage is really just temporal sluggishness that is caused by the finite duration of a message sent to the brain at stimulus onset. In other words, neural messages do not travel at the speed of light, so they appear to persist phenomenologically for a period of time. DiLollo's main source of evidence comes from a temporal integration paradigm, in which subjects

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are required to integrate perceptually two temporally separated stimuli in order to arrive at the correct answer. A 5 x 5 array of dots was used, and the two frames each consisted of 12 of the 25 dots. The subject was required to determine which of the 25 locations had been unoccupied. Performance was found to deteriorate as the time from the onset of the first display was increased (either by increasing the first frame's duration or by increasing the delay between the 2 frames), up until an SOA of about 100-130 ms (where performance asymptoted). In fact, if the duration of the first stimulus exceeded 130 ms, subjects performed at about chance level even if there was no delay between the two frames.

There have been other studies which also seem to suggest that visible persistence is the result of a residual neural trace. For example, Phillips (1974) had subjects make same-different judgments on stimuli created by randomly filling cells in a square matrix. The first matrix varied in complexity, and this was manipulated by changing the size of the matrix (i.e., 4 x 4 matrices were the smallest used and 8 x 8 matrices were the largest employed). The first matrix was presented for 1 second, then there was a variable duration interval, after which the second matrix was presented until the subject responded same or different. It was found that pattern complexity had little effect when the intermatrix interval was short (i.e., up to about 100 ms). This suggested the presence of a complexity-independent neural process operating shortly after the offset of the first stimulus.

Finally, Long and his coworkers have provided a considerable amount of evidence that visual persistence is mediated by the photoreceptors (i.e., persistence results are due to peripheral neural mechanisms). For example, Long and Beaton (1982) employed a partial report task and found that increases in stimulus luminance resulted in a longer lasting icon. You will recall from the above discussion that this is directly opposite to the typical pattern found in visible persistence experiments (i.e., as stimulus luminance increases, visible persistence decreases), and also different from the results of other partial report experiments (e.g., Sperling, 1960; Adelson & Jonides, 1980). Furthermore, Long and McCarthy (1982b) had subjects respond to the last fading trace of a stimulus (i.e., the asynchrony judgment or probe matching task) and found increasing persistence duration with increases in stimulus luminance. Thus, Long demonstrated that both visible persistence and partial report tasks showed positive effects of stimulus luminance, which is entirely consistent with a photoreceptor or "neural" locus of persistence (i.e., persistence can be thought of as a photoreceptor afterimage that has resulted from bleaching (saturating) the rods or cones).

Although the evidence described above supports the view that visible persistence arises from residual neural activity in the visual pathway, other investigators have argued that visible persistence is really the manifestation of ongoing visual information processing. The reasoning behind this view is that the perceptual system may maintain information long enough to allow for various operations to be performed. According to this view, then, visible persistence is not just a lingering sensory trace of the stimulus, but is actually under cognitive control. Several studies have been performed in which complexity manipulations seemingly have had effects on the duration of visible persistence (e.g., Avant, Lyman, & Antes, 1975; Avant & Lyman, 1975; Briggs & Kinsbourne, 1972; Erwin, 1976). These studies have indicated that more complex stimuli, which presumably take longer to process, persist longer than less complex stimuli. The existence of complexity effects on visible persistence duration thus supports what might be called the "process" view of visible persistence. Now some of these aforementioned studies shall be considered in more detail.

Avant, Lyman, and Antes (1975), using a two alternative forced choice paradigm, showed an effect of stimulus familiarity upon early visual processing. A series of five experiments were performed in which two variable length presentations of stimuli, separated by a 1 second interval, were compared. The task of the subject was to say which of the two presentations was of a longer duration. The types of stimuli used were letters, words, and nonwords, and it was found that nonwords were judged to persist longer than words, which, in turn, were judged to persist longer than letters. When a word was inverted, it was found to persist as long as a nonword, thus suggesting that it was no longer a familiar stimulus. These judged duration differences were found to occur for stimulus durations ranging from 20-100 ms. Thus, these findings suggest that more complex stimuli (i.e., nonwords) persist longer than less complex stimuli (i.e., words or letters), and therefore support a "process" model of visible persistence. Complexity corresponds to familiarity in this study (i.e., the less familiar, the more complex), and it can be argued that the visual system tries to preserve information that is unfamiliar to it, so that it can perform more complete processing of its attributes.

The above findings led Avant and Lyman (1975) to explore further the early visual processing of stimuli of varying degrees of familiarity (complexity). The previous experiments had shown that the apparent duration differences were more substantial when a noise mask was presented during the interframe interval. It was claimed that the mask limited processing to its earliest stages (i.e., before conscious recognition). This procedure combined with their argument that more complex stimuli require longer time periods to process led them to expect a heightened effect of familiarity. In other words, the fact that simple (or more familiar) stimuli are processed faster leads to a shorter perceived persistence duration than complex (i.e., less familiar) stimuli, and masking serves to highlight these processing speed differences since highly familiar stimuli are more fully analyzed before the mask interferes. There is an assumption here that all processing is curtailed when the mask appears, however it has been argued extensively by many researchers (e.g., Long, 1980) that this assumption is not always true. Another interesting finding of Avant et al. (1975) was that the greatest apparent duration accompanied the least recognizable (i.e., to the subject) stimulus. So the first experiment of Avant and Lyman (1975) was an attempt to replicate the Avant et al. (1975) noise mask procedure, and in fact, the findings were quite comparable.

The second experiment attempted to increase familiarity by presenting repetitions of the same stimuli. It was found that the duration estimate differences decreased as familiarity was induced. Finally, experiment 3 compared duration judgments for upright and inverted three letter words at various exposure durations (i.e., 10, 20, and 30 ms). Judged duration was found to be greater for the inverted words.

Therefore, Avant and his colleagues, using a novel procedure, showed considerable support for the "process" hypothesis. The short exposure durations and the immediate masks that were employed make it conceivable that they were studying the earliest stages of visual processing. The number of experiments and the nature of their manipulations at least make a complexity effect tenable.

Another research project that showed evidence for an effect of complexity on visual processing is that of Briggs and Kinsbourne (1972). An onset-offset technique was used by these researchers in order to assess the nature and duration of visible persistence. This paradigm is based on Donder's method, and requires that the mean of a series of reaction times to the onset of a visual display be subtracted from the mean of a series of reaction times to the offset of the display. It was also necessary to subtract the exposure duration from these reaction time values, since the stimulus durations were not constant across blocks. These calculations led to an estimate of persistence duration of the stimulus in a particular condition, and these estimates were determined for each subject. Catch trials were also incorporated into the offset blocks to make sure subjects were responding to stimulus offset. Three types of stimulus presentations were used, namely letters presented monoptically (i.e., presented to the dominant eye), letters presented dichoptically (i.e., half of the total stimulus presentation was given to each eye, starting with the nondominant eye, on each trial), and squares presented monoptically. Also, the duration of presentation was varied (i.e., 100, 200, 300, 600, and 1000 ms).

The results showed that the persistence duration estimates decreased as duration of the stimulus was increased. It was also shown that dichoptic and monoptic presentations showed the same results, thus suggesting a central locus for these effects. More importantly, squares were judged to persist for a shorter time than letters at all exposure durations except 1000 ms. This differential persistence trend is suggestive of a complexity effect, although the differences were not quite significant. This method, therefore, seems worthy of further study, and in fact Erwin (1976; and Erwin &

Hershenson, 1974) has used this methodology in an attempt to isolate the effects of stimulus complexity on visual processing.

Erwin (1976) attempted to measure the phenomenal (i.e., stimulus appears to be visible) and functional (i.e., stimulus information is available for encoding) durations of visual stimuli differing in informational values, using a subtractive reaction time paradigm much like that of Briggs and Kinsbourne (1972). The complexity of stimuli was manipulated by using various approximations to English (AE's). The more redundant the letter string (7 letters in a row in these experiments), the more predictable the array, and thus, the lower the information content. A zero-order AE consists of 7 randomly sampled letters, and thus a letter at a certain point in the array would have a 1/26 probability of being a specific letter (e.g., a "B" in the second position). Increases in redundancy (i.e., raising the approximation to English), therefore make the stimuli more word-like.

Report of the presented array was required on some trials, and this requirement was found to affect the reaction times to offset, but the reaction times to onset were essentially unaffected. This result replicated Erwin and Hershenson (1974). Random consonants, 0-, and 1st-order AE's persisted for a significantly longer duration when a report was obtained, than when a report was not required, while 2nd-, and 3rd-order AE's did not show this pattern of results. Thus, it was claimed that "the phenomenal duration of a persisting representation of a visual stimulus is a function of the amount of encodable information in the stimulus if, and only if, utilization of the target information is required" (Erwin, 1976). Although Erwin claimed that the information content of the stimulus does not matter when encoding is not required, he stated that this variable does have importance when more elaborative processing must performed (i.e., the stimulus persistence is maintained for a longer period of time so that more processing operations can be performed).

The combined data from these experiments suggest that complexity may, in fact, have some effect on the duration of visible persistence, however, there are some problems with the preceding studies. For example, most of the positive complexity results have been found using relatively subjective methods. More specifically, the onset-offset technique relies upon judgments that are not independently verifiable by the experimenter. The forced-choice paradigm used by Avant and his colleagues has a different problem, namely that it incorporates a substantial memory component (i.e., there was a 1 second delay between the 2 stimulus presentations). Thus, it is unclear whether Avant is studying visible persistence per se.

There is even some evidence that both the "neural" and "process" models can be combined to explain the existing data. For example, Long and Wurst (1984) performed two experiments (in which subjects depressed a reaction time key when the stimulus had completely faded from view) that attempted to test between the "neural" and "process" models. Complexity was manipulated by varying the number of interior angles in each polygon shape, or by varying perimeter^2/area while maintaining either perimeter or area constant. Long and Wurst found an inverse complexity effect (i.e., estimated persistence duration decreased as complexity was increased) when solid black figures were used, but found a positive complexity effect (i.e., supporting the "process" account) when the identical shapes were presented in open, outline form. Thus, support was found for both the "process" and "neural" models. These results also suggest that stimulus attributes may conceivably have played a role in determining which particular model was correct in past experiments. It is, however, unclear whether too much consideration should be given to these experiments, since the task used is known to be highly susceptible to criterion shifts.

What is needed, therefore, is an objective methodology to determine whether the "process" model (i.e., processing demands determine persistence duration) or the "neural" model (i.e., persistence occurs due to temporal sluggishness in the visual system) is the correct explanation of visible persistence. Thus, the purpose of the following experiments will be to use an objective paradigm to assess the effect of complexity manipulations on visible persistence.

EXPERIMENTS

General Methods

The first five experiments used the same basic procedures, and these are illustrated in Figure 1. This section will highlight the general procedures used, and any deviations from this general framework will be noted within the individual experimental method sections.

Subjects

Subjects were drawn from the Michigan State University community, and included undergraduates, graduate students, and faculty. Most of these subjects had little or no knowledge of what was being studied. Subjects were paid for their participation. All subjects had normal or corrected-to-normal vision. Six to twelve subjects were used per experiment, and in several cases (which shall be noted), subjects participated in more than one experiment.

Stimuli

Half of all trials were designated as "high-complexity" trials and the other half were designated as "low-complexity" trials. The overall configuration on a trial was a 5 x 5 (or 4 x 4 in some of the later

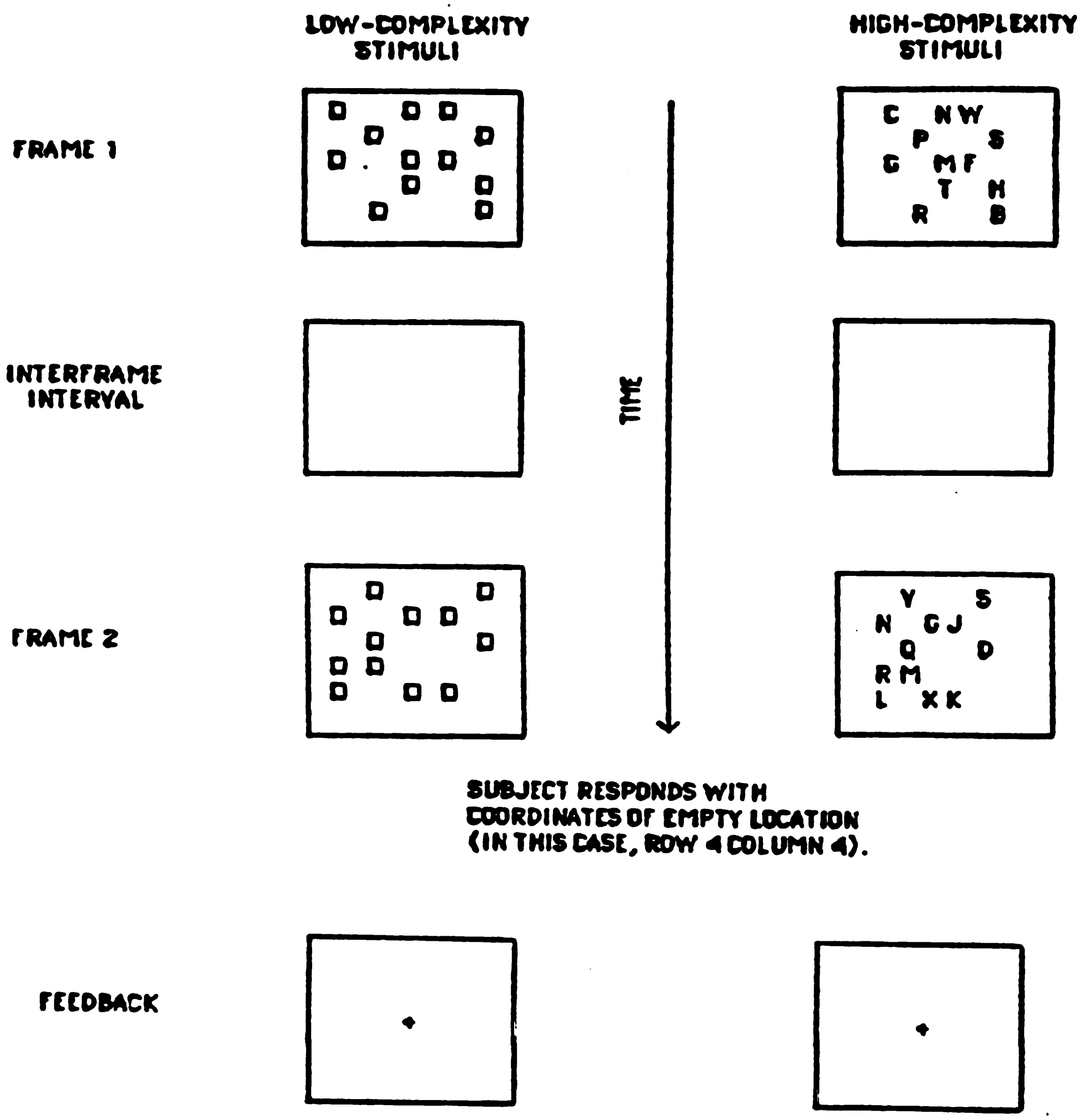


Figure 1. General procedure used in experiments 1-3.

experiments) array, which was exposed in two frames. These stimuli were always viewed as a distance of 13 inches. The visual angles for these experiments varied with stimulus types, as well as with array size. The first three experiments attempted to equate stimuli for relative brightness, by constructing individual stimulus elements out of approximately the same number of light points on the oscilloscopic display (16 on the average).

Equipment

Stimuli were displayed on a Hewlett Packard 1340A display oscilloscope, driven by a Digital Equipment Corporation Micro-11/23+ computer.

Preceding each of our experiments, the equipment (particularly the display oscilloscope) was allowed to run for 2 hours to warm up. It was previously discovered that this period of warm up is necessary to prevent intensity fluctuations. Also, just before each subject was run, a program was carried out that set the minimum intensity to the researcher's threshold value, to provide more consistency of intensities across subjects. Finally, in all of these experiments, the experimental chamber was kept illuminated, so as to prevent the subjects from detecting phosphor persistence.

Procedures

The paradigm used was a temporal integration task that was first employed by Hogben and DiLollo (1974; elaborating upon an idea by Eriksen & Collins, 1967), and later used by DiLollo (1980). On each experimental trial (after viewing a fixation point for 500 ms.), 24 of 25 elements from a 5 x 5 array were presented in two frames of time, 12 elements per frame. The subject's task was to identify the location in the 5 x 5 matrix (in row and column coordinates), at which no element had been presented. The subject triggered each trial by pressing the return key on a keyboard, and was allowed to proceed at his/her own rate. After entering the (row, column) response on the keyboard, the subject was given feedback (+ or -) as to the correctness of his/her response, and this feedback also served as the fixation point for the next trial.

Figure 1 summarizes the procedure that was employed. On each trial, subjects pressed the return key to initiate the trial, which led to the display of a fixation point; this was followed on a randomly determined basis, by either a frame of "high-complexity" stimuli or a frame of "low-complexity" stimuli for some duration; then an interframe interval of variable duration elapsed; then frame 2 was presented for some duration (always containing the same stimulus type as was presented in frame 1); and finally the subject entered his/her response and received feedback.

Conditions

Subjects generally performed these experiments over a time period of 2-4 days, depending upon the number of trials. Each of these blocks was constructed so that subjects received an equal number of trials from each complexity type (high and low) by timing parameter (either frame 1 duration or interframe interval) combination.

Experiment 1

In order to test between "neural" and "process" accounts of visible persistence, we varied the complexity of the stimulus elements to see whether more complex stimuli could be integrated over longer time periods than less complex stimuli. It is proposed that if persistence differences are found (i.e., a complexity effect), the "process" hypothesis will be supported.

Materials and Methods

Subjects. Six subjects with normal or corrected-to-normal vision were run in this experiment. Each subject was paid $3 for each of the 4 one-hour sessions. Each of these sessions included a block from experiment 1 and a block from experiment 2, and these blocks were run in a counterbalanced order.

Stimuli. Half of the trials were designated as "high-complexity" trials, and the stimuli in this case were randomly-chosen letters (i.e., all letters were used except a, e, i, o, u, and y). The overall configuration on a trial was a 5 x 5 array, which was exposed in two frames. At a 13 inch viewing distance, the array subtended 3.1 degrees of visual angle horizontally and 3.6 degrees vertically. Each letter within the array subtended .3 degrees horizontally and .4 degrees vertically, while each space between letters subtended .4 degrees both vertically and horizontally.

The other half of the trials were designated "low-complexity" trials, and the array elements were always rectangular shapes in these cases. These rectangles took up the same amount of visual angle as the letters and were constructed using 16 light points (i.e., the average number used for constructing letters). Random letters were assumed to be more complex than rectangles both cognitively and featurally. Since this experiment was exploratory, we decided to use a rather gross measure of complexity, keeping in mind that there were many confounds we could consider later if a complexity effect was found.

Equipment. See General Methods.

Procedures. See General Methods.

Conditions. Frame 1 and frame 2 both had durations of 20 ms. Interframe intervals were varied randomly from trial to trial. The values used were: 10, 30, 50, 70, 90, and 120 ms. Thus, this experiment was concerned with how interframe intervals (i.e., the time from the offset of frame 1 to the onset of frame 2) affect temporal integration with stimuli of varying degrees of complexity. Each subject completed 1200 trials over a 4-day period. There were thus 100 trials for each of the two complexity levels at each of the six interframe intervals. All of the conditions were randomly intermixed, such that each subject received 25 trials in each condition per session.

Results and Discussion

The results from experiment 1 are shown in Figure 2. All main effects were significant: block, $F(3,15) = 4.25$, $p = .0232$; stimulus type, $F(1,5) = 8.10$, $p = .0360$; and delay, $F(5,25) = 59.97$, $p < .0001$. The block x delay, $F(15,75) = 1.87$, $p = .0395$; and stimulus type x delay, $F(5,25) = 2.67$, $p = .0459$, interactions were also found to be significant. Due to the significance of the interactions, the main effects shall not be considered in

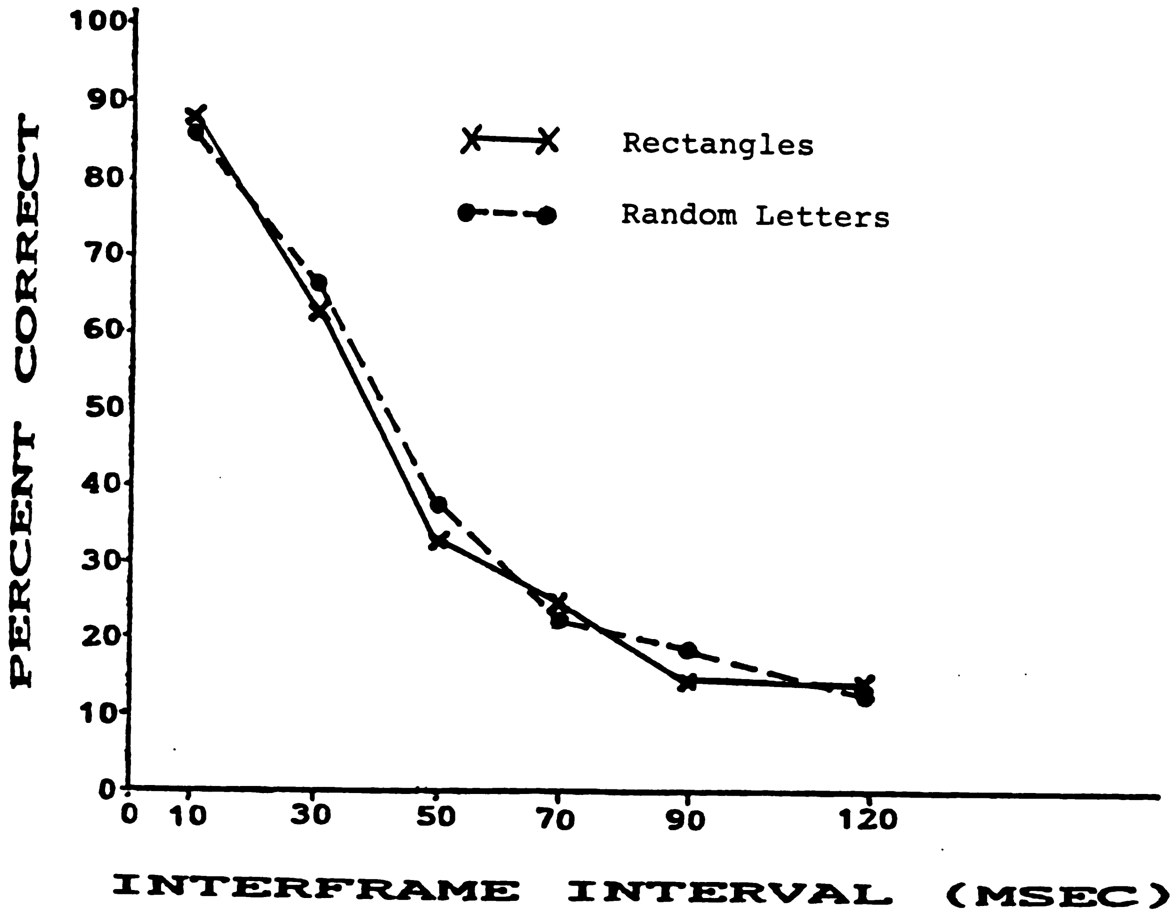


Figure 2. Percent correct for rectangles and random letters as a function of interframe interval in experiment 1.

further detail. Post-hoc comparisons on the block x delay interaction (Scheffe 95% confidence interval halfwidth = 17.38) showed that accuracy decreased as the delay was lengthened, but blocks 1-4 did not differ at any of the delays in any systematic manner.

The stimulus type x delay interaction was also examined with planned comparisons (Bonferroni 95% confidence interval halfwidth = 6.38). Table 1 shows the mean and individual results for the typestim x delay interaction. Within the rectangle condition, each increase in delay resulted in a significant decrement in accuracy through the 90 ms delay. For the letter condition, accuracy progressively decreased throughout the 120 ms delay, at which point it appeared to asymptote at a low level. All of the delays in the letter condition showed significant differences from each other, except that 70 ms was not significantly different from 90 ms. In sum, performance with random letters was significantly better than with rectangles overall, and the rectangles reached asymptote at an earlier interframe interval than did the random letters. Thus, random letters were found to persist longer than rectangles in experiment 1. It must be noted, however, that these differences are small at each of the delays. In fact, at no delay is the difference between random letters and

Table 1. Individual and mean results (% accuracy) from experiment 1, as a function of interframe interval

Stimuli: Rectangles						
	Interframe Interval					
Subject #	10	30	50	70	90	120
1	97	63	20	19	08	12
2	96	91	64	36	19	24
3	78	33	18	18	08	11
4	83	50	22	15	13	14
5	77	71	49.45	38	25	10.85
6	95	66	20	19	07	08
MEAN	87.67	62.33	32.24	24.17	13.33	13.31
Stimuli: Random Letters						
1	94	74	25	09	12	07
2	96	94	71	41	33	16
3	72	40	17	11	14	11
4	89	46	27	15	11	16
5	79	74	55.50	39.25	26.13	16
6	89	69	29	17	15	08
MEAN	86.50	66.17	37.42	22.04	18.52	12.33

rectangles significant. These findings are strong enough to promote further experimentation, however.

To summarize the results of experiment 1: (1) performance deteriorated as the interframe interval (or delay) was increased, for both types of stimuli; (2) performance for random letters was superior to that for rectangles; and (3) rectangles reached an asymptote earlier than random letters (i.e., the letters persisted longer).

These findings provide support for the "process" model of visible persistence, since the random letters were found to persist longer than the rectangles. The fact that the methodology used for these experiments was more objective than previous complexity studies strengthens the support for the "process" view. As described earlier, the stimuli that were used were equated for brightness (i.e., the number of light points used to construct them), so it is unlikely that differences in retinal excitation accounted for the results. This set of findings is in line with the results of other researchers (e.g., Erwin, 1976; Briggs and Kinsbourne, 1972). As expected, performance got worse the longer the interval between the two frames. This finding replicated the results of several researchers using variants of this technique (e.g., Eriksen & Collins, 1967; DiLollo, 1980). There was one concern with our findings, however, and that was the small absolute size of the differences. It was, therefore, necessary to perform additional experiments.

Experiment 2

In experiment 2, we examined the complexity question in a slightly different way. The interval between two frames can be varied in alternative ways. The purpose of this experiment was to rerun experiment 1, varying the stimulus onset asynchrony (i.e., the time from the onset of frame 1 to the onset of frame 2) to see what effect this manipulation has on persistence with stimuli of varying degrees of complexity. This experiment is not without precedent, since DiLollo (1980) has suggested (and provided some evidence showing) that visible persistence duration is actually dependent on stimulus onset asynchrony (SOA) rather than interframe interval (IFI). If complexity affects visible persistence duration, we would expect high complexity stimuli to persist over longer frame 1 durations.

Materials and Methods

Subjects. The same six subjects served in this experiment, as both of these studies were run concurrently, in a counterbalanced order.

Stimuli. The same stimuli were used in this experiment as were used in experiment 1.

Equipment. See General Methods.

Procedures. See General Methods.

Conditions. In this experiment, frame 2 and the interframe interval were maintained constant at 20 ms. The duration of the first frame was varied, and the values of this variable were: 20, 40, 60, 80, 100, and 150 ms. All of the conditions were randomly intermixed, such that each subject received 25 trials in each condition per session.

Results and Discussion

The results of this experiment are shown in Figure 3. All main effects were significant: block, $F(3,15) = 15.04$, $p = .0001$; stimulus type, $F(1,5) = 13.73$, $p = .0139$; and duration, $F(5,25) = 35.55$, $p < .0001$. No interactions were found to be significant in this experiment, however, as can be seen from the following F values and probabilities: block x stimulus type, $F(3,15) = .25$, $p = .8624$; block x duration, $F(15,75) = .99$, $p = .4724$; and block x stimulus type x duration, $F(15,75) = 1.36$, $p = .1925$.

Follow-up analyses were, therefore, performed on the main effects. For the block term, block 1 was found to have significantly lower accuracy than blocks 2, 3, and 4

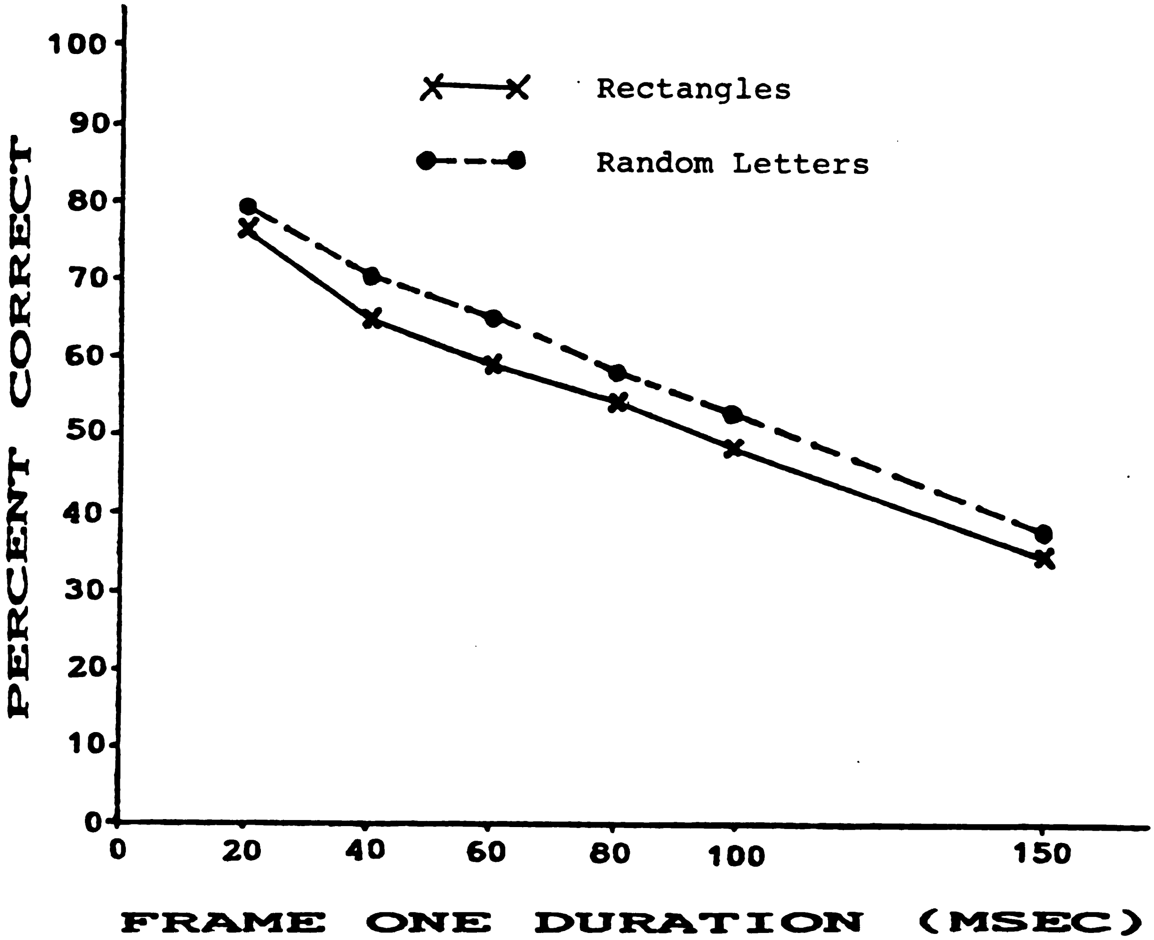


Figure 3. Percent correct for rectangles and random letters as a function of frame one duration in experiment 2.

(Scheffe 95% confidence interval halfwidth = 7.57), although these last three blocks were not significantly different from one another. For duration, 20 ms was found to have significantly higher accuracy than the 60-150 ms durations; 40 ms was significantly different from 80-150 ms; 60 ms was significantly different from 100-150 ms; 80 ms was significantly different from 150 ms; and finally 100 ms was significantly different from 150 ms (Bonferroni 95% confidence interval halfwidth = 10.61). For stimulus types, letters resulted in significantly higher accuracy than rectangles. Although the stimulus type x duration interaction was not significant, $F(5,25) = .51$, $p = .7665$; planned comparisons were performed to ascertain whether the letters persisted for a longer duration than the rectangles (Bonferroni halfwidth = 8.03), and no significant differences were found to be present. Mean and individual results for this interaction can be seen in Table 2.

In sum, performance was found to decline as the frame 1 duration was increased for both types of stimuli. Performance was found to improve slightly as the subject became more practiced. Finally, performance with random letters was found to be better than performance with rectangles, however, there were no significant interactions. It seems instead that performance with random letters was better than performance with

Table 2. Individual and mean results (% accuracy) from experiment 2, as a function of frame 1 duration

Stimuli: Rectangles						
	Frame One Duration					
Subject #	20	40	60	80	100	150
1	96	75	65	64	52	37
2	89	89	88	90	82	62
3	56	41	34	35	24	28
4	62	53	44	38	39	32
5	83.15	70.15	71.70	59.45	60.23	43
6	75	68	56	47	37	24
MEAN	76.86	66.03	59.78	55.58	49.04	37.67
Stimuli: Random Letters						
1	90	87	75	68	57	29
2	94	90	92	88	77	73
3	66	54	46	35	39	26
4	77	54	59	37	42	31
5	78	73	67.48	71	62	42.45
6	71	67	61	51	41	35
MEAN	79.33	70.83	66.75	58.33	53.00	39.41

rectangles at each frame 1 duration, and this suggests that there may be another process occurring. What might explain why random letters were successfully integrated significantly more often, but were not found to persist longer? As stated earlier, we did control for the number of light points in the display, but there may be some alternative explanation. Therefore, this experiment does not provide conclusive support for the "process" view, since only accuracy, and not persistence duration was higher for random letters.

In fact, the pattern of results does suggest an alternative explanation for our findings. Recently, DiLollo and Hogben (1985) have suggested that visible persistence duration is affected by suppressive interactions among array elements that are close together in space and/or time. Their experiments consisted of displays in which a point stepped around a circular path on an oscilloscope. Observers estimated the number of points seen simultaneously. Several variables were manipulated including spatial proximity of successive points and eccentricity in the visual field. It was found that the duration of visible persistence was highly dependent on interpoint separation, at least up to distances of about .5 degrees. Also, both visible persistence duration and the degree of suppression were found to increase with retinal eccentricity. These suppressive forces, therefore, act somewhat like the metacontrast effects that are seen throughout the visual masking literature. It was suggested by DiLollo and Hogben (1985; also Hogben & DiLollo, 1985) that suppression is an active inhibitory force that serves to reduce the smear that arises from objects in motion.

Thus, before we can conclude that more complex stimuli persist longer than less complex stimuli, the possibility of suppressive interactions must be ruled out, especially since our stimuli were separated by distances of less than .5 degrees in several cases. In other words, it could be that the results of the first two experiments were obtained due to intercontour suppression, since the contours of the rectangles are closer together than are the contours of the random letters.

Experiment 3

The purpose of experiment 3 was to compare random letters with stimuli which had intercontour distances more like those of the random letters. The suppression explanation predicts that with intercontour distance roughly equated, no complexity effect should be found.

Materials and Methods

Subjects. Six subjects were used in this experiment. Two of these subjects had taken part in experiments 1 and 2. Subjects all had normal or corrected-to-normal vision, and were each paid $1.50 for each of 4 half-hour sessions.

Stimuli. The same stimuli were employed, except that X's were used instead of rectangles. These X's were composed of 16 light points just as the previous stimuli had been (i.e., controlled for retinal excitation). Thus, the low complexity stimuli were X's in this case, and the high complexity stimuli were once again the random letters.

Equipment. See General Methods.

Procedures. See General Methods.

Conditions. As in experiment 1, frame 1 and frame 2 had durations of 20 ms. Interframe intervals were varied randomly on each trial. The values used were: 10, 30, 50, 70, 90, and 120 ms. Again, each subject received 1200 trials over the four sessions, comprised of 100 trials at each of the two complexity levels at each of the six interframe intervals.

Results and Discussion

The results for experiment 3 are shown in Figure 4. Block, $F(3,15) = 7.88$, $p = .0022$; and delay, $F(5,25) = 37.14$, $p < .0001$ were significant, but stimulus type, $F(1,5) = .10$, $p = .7654$ was far from significant. No

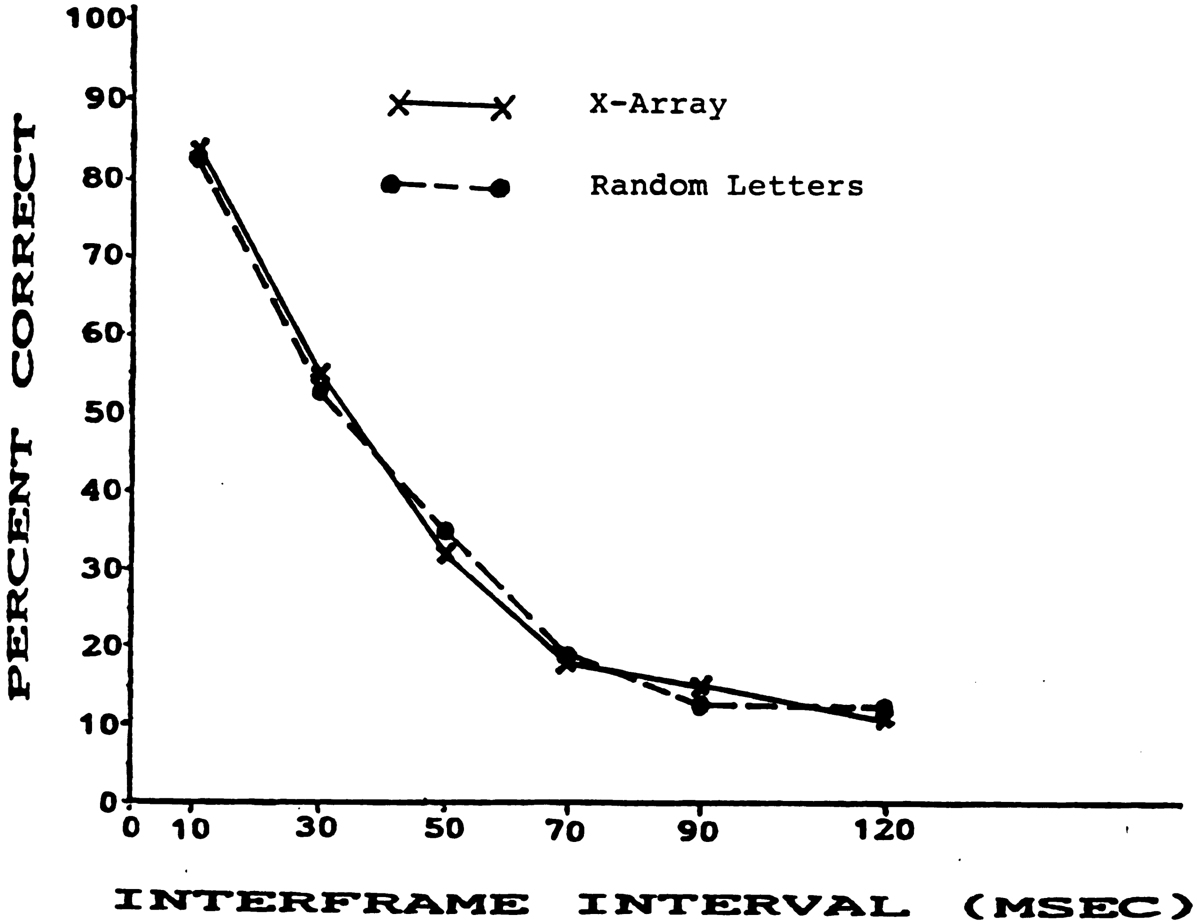


Figure 4. Percent correct for X-arrays and random letters as a function of interframe interval in experiment 3.

interactions were found to be significant, as can be seen by the following F values and probabilities: block x stimulus type, $F(3,125) = .31$, $p = .8192$; block x delay, $F(15,75) = 1.09$, $p = .3677$; stimulus type x delay, $F(5,25) = .74$, $p = .6036$; and block x stimulus type x delay, $F(15,65) = .69$, $p = .7873$.

Post-hoc comparisons were performed on the block term, and it was found that block 1 showed significantly lower accuracy than both blocks 3 and 4. No other comparisons among blocks were significant (Scheffe halfwidth = 4.49). Planned comparisons on the delay condition showed that 10 ms differed significantly from 30 ms which differed significantly from all of the other delays (i.e., 50,70, 90, and 120 ms), however these delays did not differ significantly from one another (Bonferroni halfwidth = 20.80).

In summary, performance deteriorated as the interframe interval was increased. Again, there was slight evidence of a practice effect, since block 1 was inferior to the other blocks. Finally, there was no difference in performance from the X's and random letters. Also, both types of stimuli reached asymptote at the same point, so neither stimulus type persisted longer than the other. Mean and individual results for the typestim x delay interaction can be seen in Table 3.

Table 3. Individual and mean results (% accuracy) from experiment 3, as a function of interframe interval

Stimuli: X-Array						
	Interframe Interval					
Subject #	10	30	50	70	90	120
1	98	96	79	40	28	18
2	59	35	13	13	11	12
3	94	83	41	22	20	16
4	94	56	27	11	10	10
5	74	42	22	11	17	09
6	81	23	10	15	10	09
MEAN	83.33	55.83	32.00	18.67	16.00	12.33
Stimuli: Random Letters						
1	98	90	73	43	22	30
2	58	26	25	12	16	09
3	94	84	45	21	15	12
4	92	59	28	13	08	13
5	80	44	22	15	10	07
6	74	22	16	11	13	12
MEAN	82.67	54.17	34.83	19.17	14.00	13.83

Thus experiment 3 suggests that stimulus complexity is not affecting the duration of visible persistence. Furthermore, the results of the first two experiments, which showed some evidence of a complexity effect, were shown to probably be due to an artifact, namely the operation of suppressive forces caused by the proximity of array elements. These results provide support for the "neural" hypothesis (i.e., visible persistence results from residual neural activity in the visual pathway and is unaffected by variations of stimulus complexity) rather than the "process" hypothesis (i.e., stimulus complexity affects the duration of visible persistence).

It is also possible, however, that we have simply not manipulated complexity effectively. The following two experiments will manipulate complexity in a different way, in the hope of generating some type of complexity finding. On the other hand, if no complexity effects are found, then substantial credence will be given to the "neural" hypothesis of visible persistence.

Experiment 4

In this experiment, instead of varying the complexity of the array elements, we varied the complexity of the overall pattern formed by the elements. In order to do this, we used a set of stimuli which had been independently rated for complexity. These ratings were reported in a recent study by Ichikawa (1985).

Ichikawa's subjects rated the complexity of various arrangements of 8 dots in 4 x 4 matrices. In our experiment, we used some of his rated stimuli as first frames in our temporal integration procedure (details to follow). If stimulus complexity affects visible persistence duration, then subjects should be able to integrate the high complexity patterns over longer interframe intervals than the low complexity patterns.

Materials and Methods

Subjects. Twelve subjects with normal or corrected-to-normal vision were run in this experiment. All but three of these subjects had participated in at least one of the previous experiments. Each subject was paid $3 for each of 2 one-hour sessions.

Stimuli. The stimuli used for this experiment were similar to those used previously, but they also differed in several respects, which should be elaborated upon. We used 40 patterns which had been rated low in complexity in the Ichikawa (1985) study (i.e., pattern numbers 26-65), and 40 patterns which had been rated high in complexity (i.e., pattern numbers 101-140). The complete set of stimuli is illustrated in Appendix A. Samples of these patterns are illustrated in Figures 5 and 6,

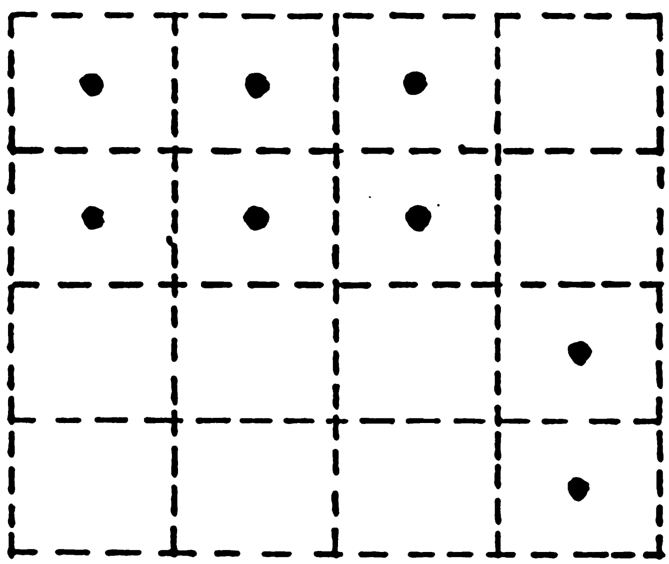


Figure 5. Sample of low complexity stimuli (Ichikawa, 1985) used in experiments 4 and 5.

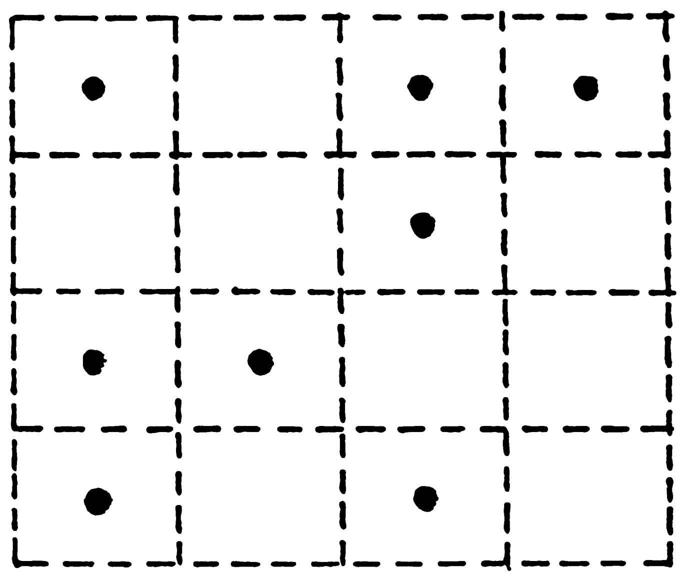


Figure 6. Sample of high complexity stimuli (Ichikawa, 1985) used in experiments 4 and 5.

respectively. The first frame consisted of one of the Ichikawa 8-dot patterns, either a simple or a complex one, and the second frame was formed by randomly filling in 7 of the 8 remaining locations. Thus, the two frames formed 4 x 4 arrays as opposed to the 5 x 5 arrays used in the preceding experiments. The stimuli in this experiment were solitary dots at each location, as opposed to rectangles or letters. The entire array of dots subtended 2.45 degrees of visual angle horizontally and 2.72 degrees of visual angle vertically. Each dot occupied .04 degrees of visual angle, and the spaces between dots occupied .79 degrees of visual angle horizontally and .88 degrees of visual angle vertically.

Equipment. See General Methods.

Procedures. The procedures used in this experiment were for the most part identical to those used in the previous experiments, except that 4 x 4 arrays were employed. Again, the task was to identify the unoccupied location.

Conditions. Both frames 1 and 2 were 10 ms in duration. The interframe interval was varied, but different values were used in this study, namely 10, 30, 50, 70, 85, and 100 ms (i.e., the longer intervals were excluded since performance dropped so low in the previous experiments). Each subject received 40 trials in each of the 2 complexity type by 6 interframe interval conditions. Although this experiment was run over two days, it was not broken into two blocks, since the two sessions were not identical in their trial composition (however, every subject did receive each of the patterns once for each of the six interframe intervals by the end of the experiment).

Results and Discussion

The results for experiment 4 are shown in Figure 7. The main effect for delay was significant, $F(5,55) = 52.62$, $p < .0001$, but stimulus type was not significant, $F(1,11) = .33$, $p = .575$. No interactions were found to be significant, since the stimulus type x delay term resulted in the following values: $F(5,55) = .81$, $p = .5442$.

Planned comparisons were performed on the delay condition (Bonferroni halfwidth = 15.91). Delays of 10, 30, and 50 ms were found to differ from 70, 85, and 100 ms significantly, but not from each other. Also, 70 ms differed significantly from 100 ms.

In summary, performance deteriorated as the interframe interval increased, but there was no effect of

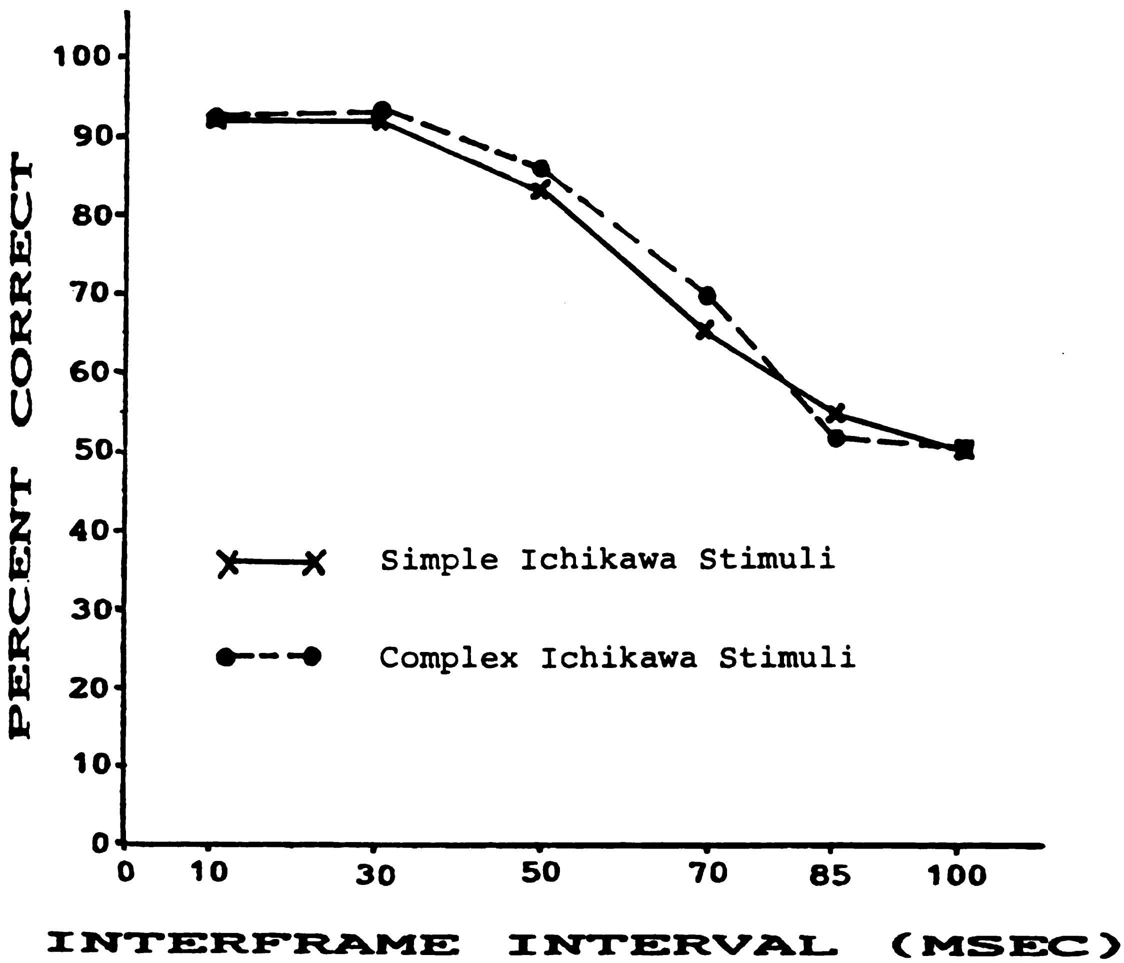


Figure 7. Percent correct for simple and complex Ichikawa stimuli as a function of interframe interval in experiment 4.

complexity on overall accuracy (or persistence duration, since neither curve dropped to asymptote before the other). This can be seen by looking at the mean and individual results for the typestim x delay interaction, which are given in Tables 4a and 4b. Thus, this experiment also suggests that the "neural" model, rather than the "process" model of visible persistence, is correct.

There may be a problem with experiment 4 though. The results suggest that no complexity effect is operating, however, the accuracy of subjects was quite high, even at the 100 ms delay (probably due to the fact that 4 x 4 (smaller) arrays were used).

This raises an important issue: How might one determine the level of subject's performance expected if persistence was not operating (e.g., at very long delays)? In other words, what is the best performance that a subject could achieve relying solely on chance performance? In the case of a 5 x 5 array, the best performance allowable (at long delays) by chance is probably about 16.7%. This is determined in the following way: When the first frame of 12 elements is presented, some of these elements may enter into short-term memory; we will assume that 7 (see Miller, 1956) are held in short-term memory. When the second frame is presented, all 12 elements will be available. Thus, at

Table 4a. Individual and mean results (% accuracy) from experiment 4, with simple Ichikawa patterns, as a function of interframe interval

Stimuli: Simple Ichikawa Patterns						
	Interframe Interval					
Subject #	10	30	50	70	85	100
1	100	95	92.5	57.5	40	25
2	97.5	97.5	97.5	82.5	77.5	82.5
3	95	100	97.5	100	95	90
4	92.5	95	82 5	72.5	50	47.5
5	82.5	90	77.5	70	47.5	55
6	100	92.5	72.5	50	40	42.5
7	92.5	92.5	92.5	67.5	75	67.5
8	90	90	78.5	50.0	50.0	27.5
9	95	90	77.5	67.5	47.5	45
10	95	87.5	82.5	77.5	60	45
11	82.5	90	67.5	50	45	27.5
12	90	87.5	80	47.5	52.5	65
MEAN	92.7	92.3	83.8	66.0	56.7	51.7

Table 4b. Individual and mean results (% accuracy) from experiment 4, with complex Ichikawa patterns, as a function of interframe interval

Stimuli: Complex Ichikawa Patterns						
	Interframe Interval					
Subject #	10	30	50	70	85	100
1	97.5	100	92.5	67.5	30	35
2	95	97.5	97.5	92.5	85	65
3	95	100	97.5	97.5	90	85
4	95	97.5	87.5	80	65	52.5
5	97.5	92.5	87.5	67.5	35	45
6	95	100	82.5	55	45	57.5
7	90	85	87.5	82.5	60	60
8	87.5	95	75	52.5	37.5	45
9	92.5	92.5	95	72.5	62.5	47.5
10	100	95	87.5	67.5	35	37.5
11	87.5	85	60	42.5	52.5	37.5
12	82.5	80	80	60	45	52.5
MEAN	92.9	93.3	85.8	69.8	53.5	51.7

best (with long delays), the subject should have 7 elements from the first frame (in STM), and 12 elements from the second frame on which to base his/her answer. Therefore, chances become 1 out of 6 (i.e., 16.7%) since there are 25 total locations.

Similar computations can be performed for the 4 x 4 array, and chance performance turns out to be about 50%, since the subject has 7 elements from frame 1 available in short-term memory, and 7 elements from frame 2 still visible. There are 16 possible locations in this case.

Inspection of Figures 2, 3, 4, and 7 shows that these are approximately the baselines reached when long interframe intervals are considered. Thus, it seems likely that we used long enough delays.

However, it still seems possible that we might have found a complexity effect in experiment 4 if we had looked at longer interframe intervals, as predicted by the "process" hypothesis. Experiment 5 considered this possibility.

Experiment 5

The present experiment is an attempt to replicate and extend the results of experiment 4. Interframe intervals were varied over a wider range, and fewer subjects with more trials per subject were run (i.e., to decrease the high between-subjects variance that occurred in experiment 4).

Materials and Methods

Subjects. Four subjects (who had participated in at least one of the previous experiments) were run in this experiment. Subjects were paid $3 for each of 2 one-hour sessions.

Stimuli. The same stimuli that had been employed in experiment 4 were used in this experiment.

Equipment. See General Methods.

Procedures. See General Methods.

Conditions. Frames 1 and 2 were again 10 ms in duration. The interframe intervals that were used were 10, 40, 70, 100, 130, and 160 ms. Also, each subject received 80 trials in each of the 2 complexity level by 6 interframe interval conditions, and these 80 trials were split into 40 trials per session.

Results and Discussion

The results for experiment 5 are shown in Figure 8. Only the main effect of delay was significant, $F(5,15) = 26.95$, $p < .0001$. The main effects of block, $F(1,3) = .03$, $p = .8806$; and stimulus type, $F(1,3) = 1.19$, $p = .3546$ did not approach significance. No interactions

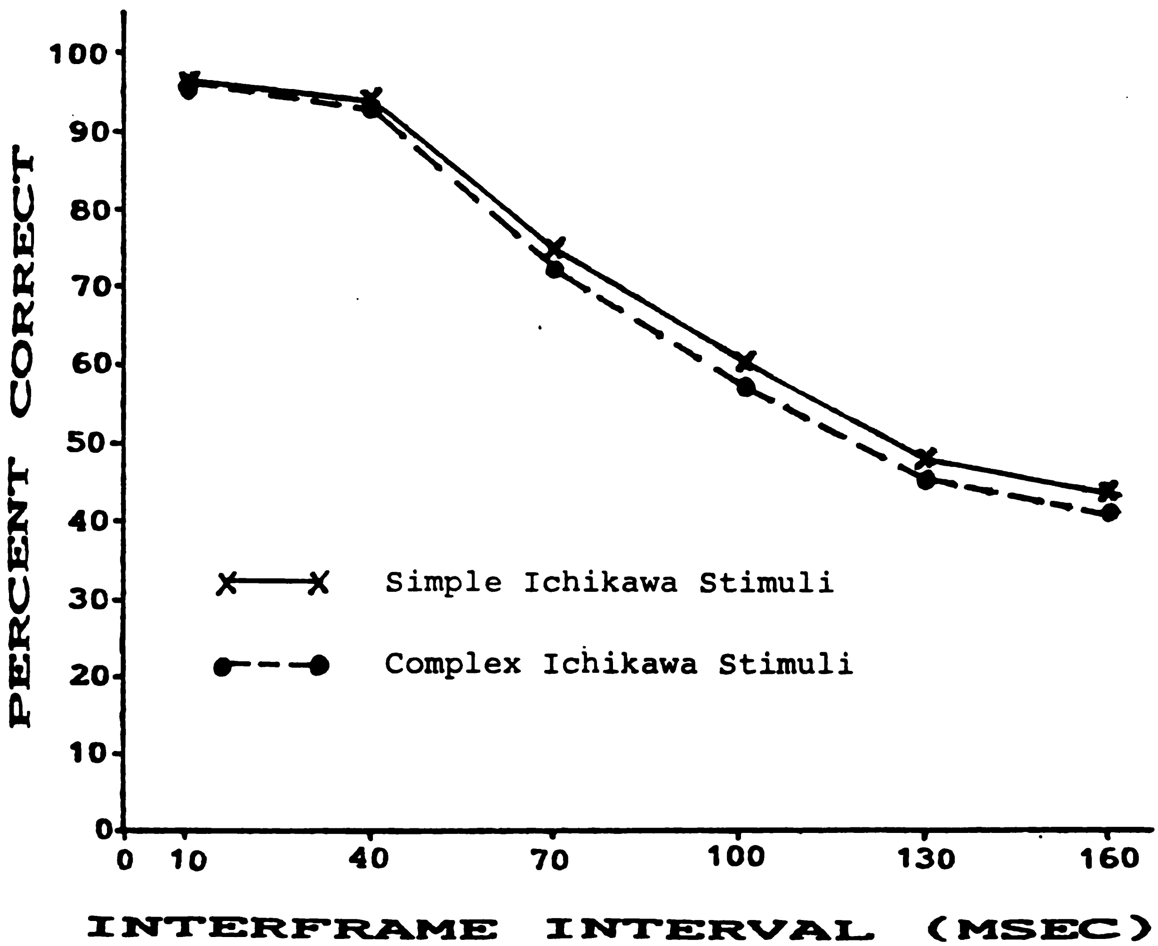


Figure 8. Percent correct for simple and complex Ichikawa stimuli as a function of extended interframe intervals in experiment 5.

were found to be significant either, as can be seen by the following F values and probabilities: block x stimulus type, $F(1,3) = 2.70$, $p = .1987$; block x delay, $F(5,15) = .38$, $p = .8559$; stimulus type x delay, $F(5,15) = .16$, $p = .9725$; and block x stimulus type x delay, $F(5,15) = .69$, $p = .642$.

Planned comparisons were then performed on the delay data (Bonferroni halfwidth = 21.32). 10 ms was found to differ significantly from 70, 100, 130, and 160 ms; 40 ms differed significantly from 100, 130, and 160 ms; 70 ms differed significantly from 130 and 160 ms; and finally 100, 130, and 160 ms did not differ significantly from one another.

In summary, performance deteriorated as the interframe interval increased, but once again, there was no effect of stimulus complexity on accuracy or persistence duration. The mean and individual results for the typestim x delay interaction are shown in Table 5. In fact, there was some suggestion that performance on the simple patterns was better than performance with the complex patterns. It is conceivable that the simple patterns aided performance due to their gestalt-like quality; with simple patterns, subjects may have been able to use short-term memory to remember some dot locations, rather than having to rely just on visible persistence. This is not without precedent, since

Table 5. Individual and mean results (% accuracy) from experiment 5, as a function of interframe interval

	Stimuli: Simple Ichikawa Patterns					
	Interframe Interval					
Subject #	10	40	70	100	130	160
1	98.75	98.75	88.75	76.25	67.50	57.50
2	98.75	100	96.25	85	63.75	57.50
3	97.50	90	52.50	36.25	32.50	38.75
4	91.25	87.50	62.50	46.25	32.50	27.50
MEAN	96.56	94.06	75.00	60.94	49.06	45.31
	Stimuli: Complex Ichikawa Patterns					
1	97.50	97.50	85	67.50	55	50
2	98.75	98.75	98.75	85	60	63.75
3	95	91.25	55	38.75	43.75	32.50
4	93.75	85	51.25	41.25	28.75	23.75
MEAN	96.25	93.13	72.50	58.13	46.88	42.50

Phillips (1974) showed evidence for persistence in short-term visual memory for durations up to 9 seconds, using a same-different judgment and square matrices with randomly filled cells. Furthermore, performance was better for less complex (as defined by the size of the square arrays [i.e., number of cells]) arrays than for more complex arrays when the interval between the two patterns exceeded about 100 ms. Thus, it is important that one recognizes the possibility of short-term memory influencing performance on these types of visual tasks. Regardless of these cautions, there was no support found for the "process" hypothesis of visible persistence. Also, there was no indication of a practice effect in this experiment, which is not really surprising since experienced subjects were run.

Thus far, most of the evidence we have found has suggested that complexity does not affect visible persistence duration. Some researchers have shown effective complexity manipulations however (e.g., Erwin, 1976), so our next step was to try to discover the reason for the discrepant findings. The following experiments were performed with two goals in mind: (1) to determine the effectiveness of our complexity manipulations; and (2) to investigate the effect of forced identification on performance. It is possible that the preceding experiments have not manipulated complexity effectively. Our failures to find a complexity effect may simply be due to the fact that we have not changed or measured the correct attributes of the stimuli. Thus, it is important that we demonstrate a complexity effect with our stimuli, using a different (perhaps more subjective) paradigm. The paradigm that we employed, namely the onset-offset subtractive reaction time technique, has been used by Erwin (1976) to provide some of the most compelling positive complexity effects that have been found. Thus, the overall aim of the next set of experiments was to demonstrate a complexity effect with a subjective technique, and then try to find a complexity effect using the same stimuli with our objective temporal integration paradigm. Our second goal, investigating the effect of forced identification, will be elaborated upon later.

Experiment 6

Experiments 4 and 5 found no complexity effect (using a temporal integration technique), with stimuli that had previously been rated as varying in complexity (Ichikawa, 1985). The technique used was objective since it required visible traces from both frames to be used. Erwin's (1976) task is more subjective, so if we can find a complexity effect using the Ichikawa stimuli, then it is quite likely that our objective technique will point out the failings of the onset-offset reaction time paradigm and show why a complexity effect is obtained when Erwin's task is employed. Thus, our prediction is that the onset-offset technique will show a complexity effect with the Ichikawa (1985) stimuli.

Materials and Methods

Subjects. Seven subjects were used in this experiment. All subjects had normal or corrected-to-normal vision. Subjects were paid $5 for one session which lasted about 1 1/2 hours.

Stimuli. The stimuli employed were the same dot patterns that were used in experiments 4 and 5, although only the first frame was used. In other words, on each trial one of the Ichikawa patterns was presented, but the other 7 of 8 locations in the 4 x 4 matrix were not filled in by a second frame. The dots and the arrays subtended the same visual angle as in the previous experiments (i.e., 4 and 5), since the same viewing distance (13") was used.

Equipment. The same equipment was employed in this experiment.

Procedures. Subjects initiated each trial by pressing the return key on a computer keyboard. A fixation point was then exposed for a period of 500 ms.

There was then a variable length delay (500-1300 ms) between the offset of the fixation point and the onset of the stimulus. Stimuli were presented for 10 ms (to allow more accurate comparisons with experiments 4 and 5) for regular trials, and 500 ms on catch trials. Subjects were given the task of indicating the onset of stimuli on some blocks, and the offset of stimuli on other blocks. In each offset block, one third of the trials were designated as catch trials to insure that subjects really were responding to the offset of the stimulus. On half of all trials, the subjects were asked to write out, on a response sheet, a full report of the stimuli observed, and this factor was also blocked. This report served the same function that it did in the Erwin (1976) experiment, namely that it forced the subjects to process the stimuli to a greater degree. Thus, there were four types of trials: (a) respond to onset with no report; (b) respond to onset with a report; (c) respond to offset with no report; and (d) respond to offset with a report. Figure 9 shows the general procedure that was employed.

Conditions. There were two levels of complexity in this experiment (i.e., the low complexity Ichikawa stimuli and the high complexity Ichikawa stimuli). There were two levels of report (i.e., no report and full report). In addition, we incorporated 5 levels of delay

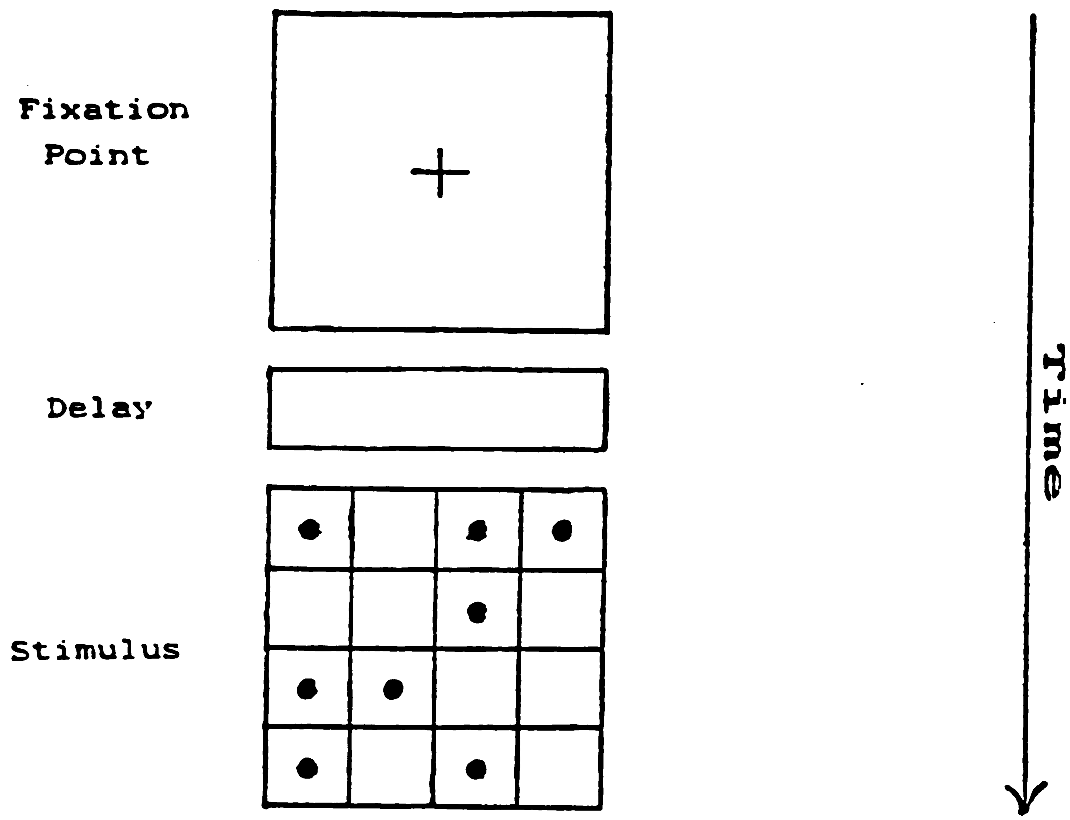


Figure 9. General procedure used for the onset-offset experiments (i.e., 6, 7, and 8). Subjects responded to the onset of the stimulus on half of the blocks, and to the offset of the stimulus for the other half of the blocks.

between the fixation spot and the stimulus. The purpose of this manipulation was to prevent subjects from anticipating the onset of the stimulus. The five levels used were: 500, 700, 900, 1100, and 1300 ms, however, the catch trials only incorporated the 500 and 700 ms delays due to a programming error. Finally, two types of reaction times (RT's) were collected: RT's to onset and RT's to offset. For each subject, an average RT was calculated for each of these two measures, and the RT (avg) to onset was subtracted from the RT (avg) to offset. It was not necessary to subtract out stimulus duration, since the program running the experiment did this while collecting the RT's. This resulted in an estimate of persistence duration (see Briggs & Kinsbourne, 1972; Erwin, 1976). These persistence duration estimates were determined for each of the two complexity levels at each of the two report levels.

Subjects completed four blocks of experimental trials. A counterbalanced order of blocks was randomly assigned to each subject. Onset blocks consisted of 80 trials, while offset blocks consisted of 120 trials (i.e., there were 40 catch trials). Before each block, subjects were run in a practice session that consisted of 20 trials for onset and 30 trials for offset (i.e., 10 catch trials included). Before beginning each practice session and accompanying block, subjects were advised as to whether they should respond to the onset or the offset of the stimulus, and also whether or not they would have to give a report on each trial. Each of the stimuli (i.e., 40 simple and 40 complex) were randomly intermixed to construct the experimental trials for both onset and offset blocks. On the catch trials (for the offset blocks), the stimuli were randomly created on each trial, so that complexity would have no systematic effect. Subjects were not advised of the complexity manipulation that had been implemented on the experimental trials.

Results and Discussion

The results from experiment 6 are shown in Figure 10. There were no significant main effects or interactions in this experiment: condition, $F(1,6) = .17$, $p = .6906$; report, $F(1,6) = .07$, $p = .8053$; condition x delay, $F(4,24) = .34$, $p = .8511$; however, some of the analyses showed marginally significant results: delay $F(4,24) = 2.14$, $p = .1072$; report x delay, $F(4,24) = 2.26$; $p = .0925$; condition x report, $F(1,6) = 2.31$, $p = .1797$; and condition x report x delay, $F(4,24) = 2.21$, $p = .0979$.

Although none of the above analyses showed significance, further analyses were done on several of the effects and interactions that showed marginal

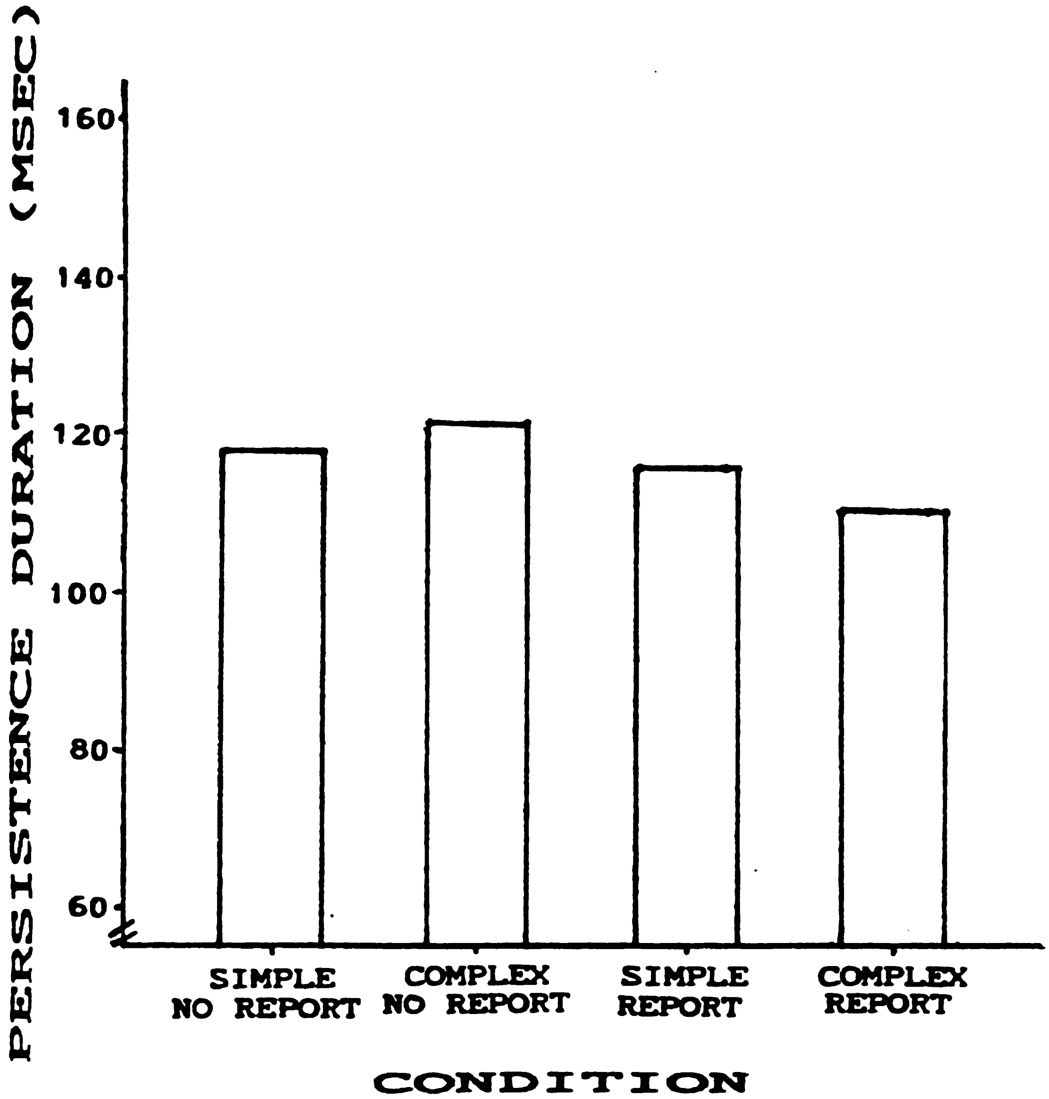


Figure 10. Onset-offset persistence duration as a function of complexity (simple versus complex Ichikawa patterns) and report conditions for experiment 6.

significance. Post-hoc comparison on delay (Scheffe halfwidth = 31.46) showed no significant differences. Furthermore, planned comparisons on the condition x report interaction (Bonferroni halfwidth = 14.71) and post-hoc comparisons on the condition x report x delay interaction (Scheffe halfwidth = 38.02) showed no differences to be significant. Finally, a t-test for correlated means was performed on the two types of stimuli (i.e., condition) and it was found that the difference was not significant ($t(6) = .418$, n.s.).

Figure 10 illustrates that performance was virtually identical in each of the condition x report levels when collapsed across subjects, however, the results for individual subjects show that at least two different styles of responding were present. These results are shown in Table 6. Subjects 3 and 5 showed much shorter persistence durations in both of the report conditions, suggesting that they may have sped up their responses so as to improve their reports. The other five subjects showed either flat results or a tendency for persistence duration to increase when a report was required. These results also make it clear that there was little effect of complexity upon persistence duration.

It was thought that some people might not respond appropriately on the offset trials, and this was the reason for the inclusion of catch trials. The results of

Table 6. Individual and mean persistence durations (in ms) from experiment 6, as a function of complexity and report condition

Subject #	Simple Ichikawa No Report	Complex Ichikawa No Report	Simple Ichikawa Report	Complex Ichikawa Report
1	129.98	118.72	133.32	107.16
2	133.26	131.50	130.43	126.01
3	115.88	122.90	56.74	46.14
4	105.57	126.81	157.58	147.74
5	157.07	153.96	77.84	65.87
6	118.38	123.95	170.71	186.36
7	69.67	70.28	95.95	103.51
MEAN	118.54	121.16	117.51	111.83

the performance on catch trials for each of the subjects in experiment 6 are listed in Table 7, as well as the results of incorrect responding on the experimental trials. A criterion of fewer than 10% (or less than 4) errors on catch trials was set as acceptable performance. Table 7 shows that subject 2 failed to meet this criterion. The data were reanalyzed with this subject's data excluded, however, there was no appreciable change in the results, so these data shall not be described in any more detail. Thus, incorrect performance on the task was probably not the explanation for failure to achieve a significant complexity effect.

Finally, the mean persistence duration in this experiment was 117.26 ms, which is in line with various estimates of persistence that have been obtained previously (e.g., DiLollo, 1980; Erwin, 1976).

To summarize the results of experiment 6: (1) no main effects or interactions were significant; (2) results showed at least two different subjective styles of responding; (3) persistence durations were roughly equivalent to values that have been obtained previously; and (4) an analysis of the catch trials ruled out incorrect responding as the reason for the lack of a complexity effect.

Thus, these findings failed to support Erwin (1976), since no complexity effect was obtained. This is

Table 7. Number and associated proportion of trials in which subjects responded too quickly, as a function of condition and type of trial (i.e., experimental or catch) for experiment 6

Subject Number	Trial Type	Condition							
		Onset-No Report		Onset-Report		Offset-No Report		Offset-Report	
		Count	Propor.	Count	Propor.	Count	Propor.	Count	Propor.
1	Catch	--	--	--	--	0	0%	0	0%
	Exptal.	3	3.75%	0	0%	0	0%	0	0%
2	Catch	--	--	--	--	9	22.5%	0	0%
	Exptal.	3	3.75%	9	11.25%	0	0%	1	1.25%
3	Catch	--	--	--	--	1	2.5%	0	0%
	Exptal.	0	0%	0	0%	0	0%	0	0%
4	Catch	--	--	--	--	2	5%	0	0%
	Exptal.	0	0%	0	0%	0	0%	0	0%
5	Catch	--	--	--	--	2	5%	0	0%
	Exptal.	1	1.25%	0	0%	0	0%	0	0%
6	Catch	--	--	--	--	2	5%	1	2.5%
	Exptal.	0	0%	0	0%	0	0%	0	0%
7	Catch	--	--	--	--	0	0%	0	0%
	Exptal.	4	5%	4	5%	0	0%	0	0%

somewhat unsatisfying, since we had hoped to replicate Erwin with his paradigm, and then test the complexity effect using our more objective temporal integration task (although in fact, we already did this in experiments 4 and 5).

Experiment 7

The preceding experiment failed to demonstrate a complexity effect, even when full report was required, but perhaps the preceding Ichikawa complexity manipulation was too subtle, especially with 10 ms exposures (e.g., Erwin, 1976; used 50 ms presentations). It might be possible to demonstrate a complexity effect with a different type of stimulus. Experiment 3 showed that performance with X's and random letters in a temporal integration task was virtually identical. Will these stimuli show a difference in the Erwin task? Again, it was thought that these stimuli might show differential persistence durations due to the subjective nature of the task. Thus, our hypothesis was that random letters would persist longer than X's.

Materials and Methods

Subjects. Six subjects were used in this experiment. All subjects had normal or corrected-to-normal vision, and each was paid $5 for a single session lasting about 1 1/2 hours.

Stimuli. The same stimuli that were employed in experiment 3 were used in this experiment (i.e., random letters arrays and arrays of X's). These arrays were formed by randomly filling in 8 locations in a 4 x 4 matrix with one of these two stimulus types. Thus, the stimuli consisted of random frames of 8 elements that were presented for a constant duration (for all trials).

Equipment. The same equipment was used for this experiment.

Procedures. The same procedures that were used in experiment 6 were employed again, except that exposure durations were 20 ms in length. The general procedure shown in Figure 9 once again applied, except for the different exposure durations that were used.

Conditions. The same conditions were used in this experiment as in experiment 6, except that complexity was manipulated by using letters and X's instead of high and low complexity Ichikawa stimuli. Also, the programming error that resulted in only two delays (between fixation and stimulus) being used for catch trials in experiment 6, was corrected for in this experiment.

Results and Discussion

The results for experiment 7 are shown in Figure 11. The only main effect that was significant was delay,

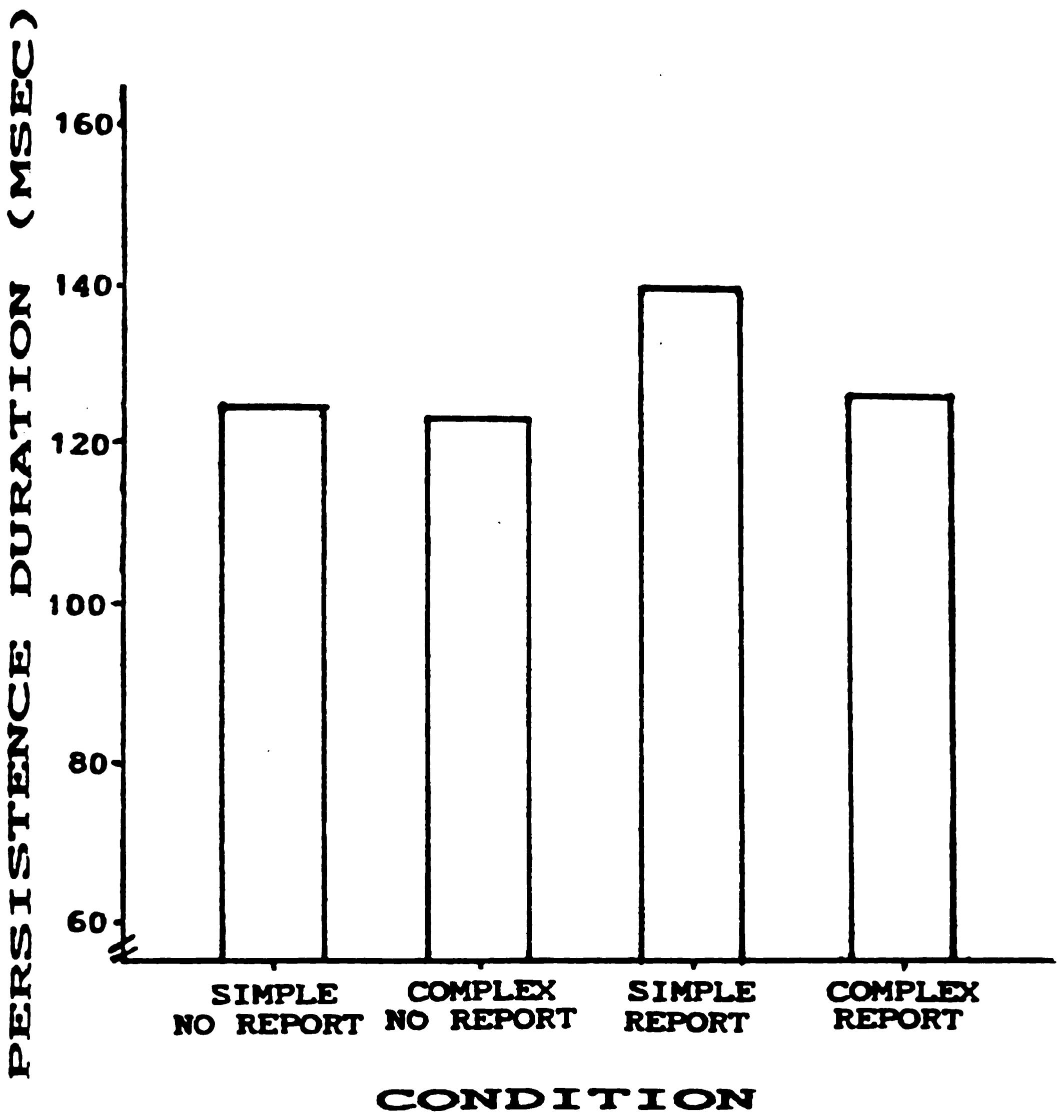


Figure 11. Onset-offset persistence duration as a function of complexity (X-array versus random letters) and report conditons for experiment 7.

$F(4,20) = 4.39$, $p = .0104$. The report x delay interaction was also found to be significant, $F(4,20) = 3.11$, $p = .0384$; and the condition x delay interaction was marginally significant, $F(4,20) = 1.86$, $p = .1571$. All other main effects and interactions failed to show significance: condition, $F(1,5) = .65$, $p = .4568$; report, $F(1,5) = .33$, $p = .5898$; condition x report, $F(1,5) = 1.24$, $p = .3153$; and condition x report x delay, $F(4,20) = 1.08$, $p = .3923$.

Post-hoc comparisons on the report x delay interaction (Scheffe halfwidth = 32.66) showed that the 1100 ms delay resulted in significantly longer persistence durations than the 500 to 700 ms delays for the report condition. When post-hoc comparisons were done on the delay term (Scheffe halfwidth = 26.85), it was found that only the 500 ms and 1100 ms delays differed, with greater persistence being exhibited at the 1100 ms delay. Thus, longer persistence for the 1100 ms delay term is the likely cause of the one significant post-hoc comparison in the report x delay interaction. Post-hoc comparisons on the condition x delay interaction (Scheffe halfwidth = 35.41) showed nothing to be significant. Planned comparisons on the condition x report term (Bonferroni halfwidth = 30.63) showed no significant differences. A t test for correlated means was also performed on the condition term, and the difference was found to be not significant ($t(5) = .806$, n.s.).

Once again, performance in each of the condition x report levels was similar, as seen in Figure 11. Report conditions showed slightly longer persistence durations, but this was not significant. Part of the reason for this result was that at least two different types of responding styles were adopted by individual subjects. These results can be seen in Table 8. Subjects 1 and 2 showed much shorter persistence durations in both of the report conditions. This was analogous to the finding in experiment 6, and in fact subject 2 was one of the two subjects from experiment 6 who adopted this responding style. It was suggested previously that this quick responding may have been used as a means to improve report accuracy (i.e., perhaps subjects did not wait for complete fading of the visible trace). The other four subjects showed either flat results, or a tendency for persistence duration to increase when a report was required.

The type of stimulus (i.e., complexity condition) seemed to have little effect, although simple stimuli appeared to have slightly longer persistence durations (albeit a nonsignificant difference). It is unclear why this difference might occur in this direction, except perhaps that it is easier to group figures that are

Table 8. Individual and mean persistence durations (in ms) from experiment 7, as a function of complexity and report condition

Subject #	Simple (X-Array) No Report	Complex (Rand Lets) No Report	Simple (X-Array) Report	Complex (Rand Lets) Report
1	133.50	124.28	98.99	81.46
2	153.63	160.24	132.58	125.74
3	97.09	103.91	95.73	105.51
4	142.95	124.95	211.48	129.31
5	108.13	91.18	111.10	112.51
6	110.15	132.72	194.40	205.43
MEAN	124.24	122.88	140.71	126.66

identical than those that differ. Thus, the X's might serve as placemarkers in the same way that the Ichikawa dot patterns may have, and short-term memory might be more readily applied to these stimuli. Random letters, on the other hand, would make the task more difficult because each stimulus element is different from its neighboring elements, and thus the individual identities might interfere with its functioning purely as a placeholder.

Again, the data from catch trials were considered. Table 9 shows the number (and percentage) of trials on which subjects performed incorrectly. The same criterion was applied (i.e., fewer than 10% errors on catch trials), and in this experiment subjects 3 and 4 failed to perform at an acceptable level. A reanalysis excluding these subjects failed to reveal any different findings, so these results shall not be described in any more detail. Thus, once again, incorrect performance of the task is unlikely to be the cause of nonsignificant complexity effects.

The mean persistence duration in this experiment was 128.62 ms, which is once again similar to several results reported in the literature (e.g., Erwin, 1976).

To summarize the results of experiment 7: (1) no main effects were significant except for the delay term; however, this was simply a control factor inserted to

Table 9. Number and associated proportion of trials in which subjects responded too quickly, as a function of condition and type of trial (i.e., experimental or catch) for experiment 7

Subject Number	Trial Type	Onset-No Report		Onset-Report		Offset-No Report		Offset-Report	
		Count	Propor.	Count	Propor.	Count	Propor.	Count	Propor.
1	Catch	--	--	--	--	0	0%	0	0%
	Exptal.	0	0%	0	0%	0	0%	0	0%
2	Catch	--	--	--	--	1	2.5%	0	0%
	Exptal.	2	2.5%	0	0%	0	0%	0	0%
3	Catch	--	--	--	--	1	2.5%	4	10%
	Exptal.	0	0%	0	0%	0	0%	0	0%
4	Catch	--	--	--	--	4	10%	0	0%
	Exptal.	11	13.75%	12	15.0%	0	0%	1	1.25%
5	Catch	--	--	--	--	3	7.5%	0	0%
	Exptal.	5	6.25%	1	1.25%	0	0%	0	0%
6	Catch	--	--	--	--	0	0%	0	0%
	Exptal.	0	0%	1	1.25%	0	0%	0	0%

prevent subjects from anticipating the onset of stimuli; (2) the report x delay interaction was significant; however, this result seemed mainly to be due to the effect of the delay term; (3) subjects once again showed at least two different styles of performing the task, thus demonstrating the subjectivity of the task; (4) persistence durations were comparable to those of experiment 6, and previous reports in the literature; and (5) an analysis of catch trials ruled out incorrect responding as the reason for the lack of a complexity effect.

In conclusion, the findings from this experiment also represent a failed replication of the Erwin (1976) results. Our complexity manipulation was less subtle in this experiment (i.e., X's versus random letters), than in experiment 6, where complexity was formed by the overall configuration of dots rather than the individual stimulus elements. Once again, our results would have been more satisfying if we could have found support for Erwin (1976), and then used the same stimuli in a temporal integration task, and fail to find a complexity effect (as we did in experiment 3).

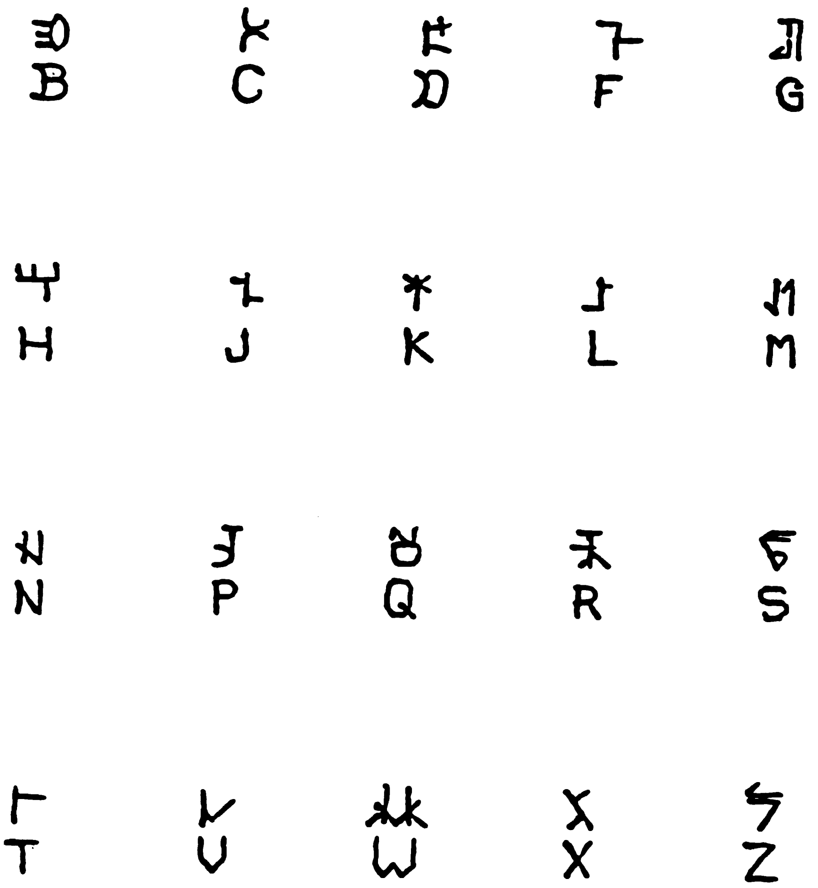
Experiment 8

Thus far, we have failed to obtain the same results as Erwin (1976), since we have been unable to obtain a complexity effect, even when a report of the information has been required. Perhaps it will be possible to get a complexity effect with stimuli that are particularly complex (i.e., they do not have name codes attached to them, and should be unfamiliar to the subjects). To meet this demand, a set of pseudo-letters was created and pitted against the random letters. It was hypothesized that pseudo-letters would persist longer than random letters, particularly when a report was required.

Materials and Methods

Subjects. Six subjects were run in this experiment. All subjects had normal or corrected-to-normal vision, and were paid $5 for a single session lasting for about 1 1/2 hours.

Stimuli. Arrays of random letters (all of the consonants except y) and arrays of random pseudo-letters (created by the author by interchanging the line segments of each of the 20 letters used), were presented. Figure 12 illustrates the pseudo-letters that were used, as well as the letter that each was derived from. These arrays consisted of 8 letters (or pseudo-letters), placed randomly in a 4 x 4 matrix like that used in several of the preceding experiments. Again, the viewing distance was 13", so the letters subtended .3 degrees vertically and .4 degrees horizontally, while each space between the



<u>Figure 12</u>. Pseudo-letters employed in experiments 8, 9, and 10. These pseudo-letters were created by interchanging the line segments of all the consonants with the exception of y.

letters occupied .4 degrees of visual angle in both the vertical and horizontal directions. Letters and pseudo-letters were equated for the number of light points making them up, and both sets averaged 16 points per letter. The entire array subtended 2.8 degrees of visual angle vertically, and 2.4 degrees of visual angle horizontally. Pseudo-letters were assumed to be cognitively more complex than letters, but equivalent featurally (i.e., they were constructed with this in mind).

Equipment. The same equipment was used in this experiment.

Procedures. 20 ms exposures were used for both types of stimuli in this experiment, since the letter arrays used in the previous experiments had this exposure duration. All other procedures were identical to those employed in experiment 6. Again, answer grids were provided to subjects for their full report blocks. Once again, the general procedure sketched in Figure 9 applied, except that exposure durations were 20 ms rather than 10 ms. Also, due to the difficult nature of the report with these stimuli, subjects were asked to report as many of the array elements as they could without relying completely on guesses.

Conditions. The same conditions were used in this experiment, except that complexity was manipulated by using letters and pseudo-letters rather than the rated low and high complexity Ichikawa stimuli (experiment 6), or X's versus random letters (experiment 7).

Results and Discussion

The results for experiment 8 are shown in Figure 13. The only main effect that was significant was delay, $F(4,20) = 11.7$, $p < .0001$. No other main effects or interactions were significant as can be seen by the following results: condition, $F(1,5) = 1.28$, $p = .3089$; report, $F(1,5) = .33$, $p = .59$; condition x report, $F(1,5) = 1.27$, $p = .3106$; condition x delay, $F(4,20) = .13$, $p = .97$; report x delay, $F(4,20) = 1.69$, $p = .1911$; and condition x report x delay, $F(4,20) = .41$, $p = .7959$.

Post-hoc comparisons on delay (Scheffe halfwidth = 27.46) showed that 500 ms differed significantly from both 1100 ms and 1300 ms, and that 700 ms differed significantly from 1300 ms. The shorter delays showed shorter persistence durations in these cases. Planned comparisons were performed on the condition x report interaction (Bonferroni halfwidth = 13.22), and it was found that no report trials led to significantly longer persistence durations than report trials for pseudo-letters, and with random letters, the same trend was

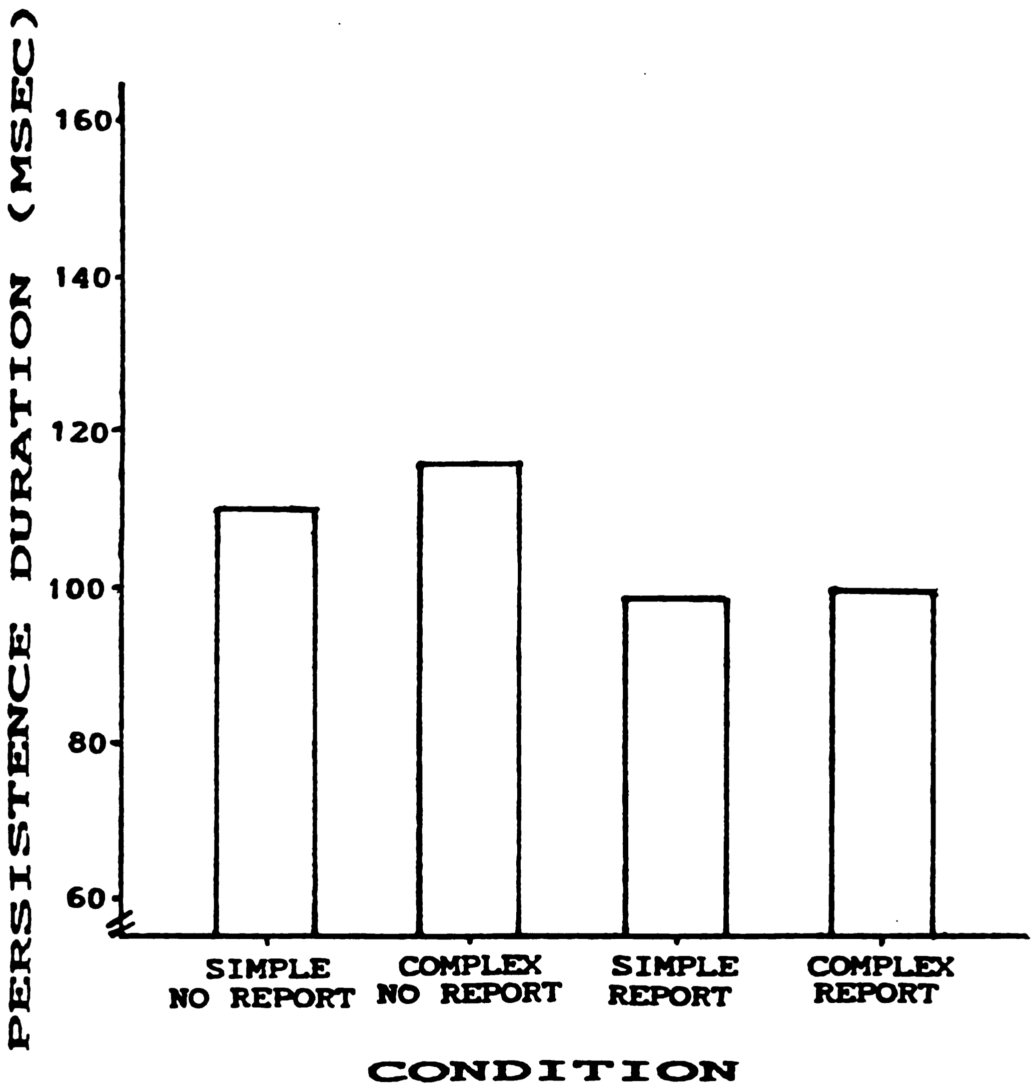


Figure 13. Onset-offset persistence durations as a function of complexity (random letters versus pseudo-letters) and report conditions for experiment 8.

observed, although the difference was not quite significant. Within each of these report conditions, however, complexity did not vary significantly. A t test for correlated means showed that the two types of stimuli did not lead to significantly different persistence durations ($t(5) = 1.132$, n.s.).

In this experiment, the various condition x report levels showed slightly different results, since the report conditions actually resulted in shorter persistence durations than the no report conditions, as can be seen in Figure 13. This is probably due to the fact that 3 subjects (numbers 1, 5, and 6) showed a pattern of results in which report conditions led to shorter persistence durations. These three subjects were the same ones that had responded this way in at least one of the previous onset-offset experiments (6 and 7). Thus, there seem to be subjective styles of responding that fall out when using this technique. The other three subjects in this experiment showed either flat results or the opposite pattern (i.e., report conditions lead to longer persistence durations). These trends can be seen in Table 10.

Once again, the catch trial data were considered in more detail. Table 11 shows the number (and percentage of trials on which subjects performed incorrectly. The same criterion for adequate performance was used (i.e.,

Table 10. Individual and mean persistence durations (in ms) from experiment 8, as a function of complexity and report condition

Subject #	Simple (Rand Lets) No Report	Complex (Pseudo-Lets) No Report	Simple (Rand Lets) Report	Complex (Pseudo-Lets) Report
1	102.83	101.16	50.95	55.21
2	103.18	122.19	107.68	106.17
3	76.80	78.50	90.49	82.47
4	121.25	123.10	216.72	201.65
5	135.22	139.26	84.18	96.37
6	119.95	132.19	43.64	55.83
MEAN	109.87	116.07	98.94	99.62

Table 11. Number and associated proportion of trials in which subjects responded too quickly, as a function of condition and type of trial (i.e., experimental or catch) for experiment 8

Subject Number	Trial Type	Condition							
		Onset-No Report		Onset-Report		Offset-No Report		Offset-Report	
		Count	Propor.	Count	Propor.	Count	Propor.	Count	Propor.
1	Catch	--	--	--	--	1	2.5%	1	2.5%
	Exptal.	1	1.25%	0	0%	0	0%	1	1.25%
2	Catch	--	--	--	--	3	7.5%	1	2.5%
	Exptal.	11	13.75%	7	8.75%	0	0%	0	0%
3	Catch	--	--	--	--	6	15%	1	2.5%
	Exptal.	1	1.25%	0	0%	0	0%	0	0%
4	Catch	--	--	--	--	3	7.5%	0	0%
	Exptal.	1	1.25%	0	0%	0	0%	0	0%
5	Catch	--	--	--	--	1	2.5%	0	0%
	Exptal.	0	0%	0	0%	1	1.25%	0	0%
6	Catch	--	--	--	--	1	2.5%	1	2.5%
	Exptal.	2	2.5%	0	0%	0	0%	1	1.25%

fewer than 10% errors on catch trials), and only subject 3 failed to perform at this level. A reanalysis with the data from this subject excluded did not change the results in any way, so they shall not be discussed in any more detail. Thus, quick responding is unlikely to be the cause of failure to find significant complexity effects with this paradigm.

The mean persistence duration in this experiment was 106.13 ms; which is shorter than it was in the previous two experiments, although still comparable to results found in the persistence literature.

To summarize the results of experiment 8: (1) the only significant main effect was delay, which was not a variable of interest, and there were no significant interactions either; (2) half of the subjects showed one style of responding in which the report conditions resulted in longer persistence durations, while the other half of the subjects responded in the opposite manner; (3) the persistence durations were similar to those of experiments 6 and 7 and previous reports in the literature; and (4) the catch trial analysis once again showed that the failure to achieve a complexity effect was not due to incorrect responding.

In conclusion, this experiment failed to obtain results comparable to those of Erwin (1976), even when a seemingly strong complexity manipulation was employed (i.e., random letters versus pseudo-letters). It was hoped that this experiment would show a complexity effect, and that we could eliminate the effect, using the same stimuli in a temporal integration task. Overall, the Erwin onset-offset paradigm seemed less satisfactory than the temporal integration task, since several responding styles could be adopted by subjects. Also, these three onset-offset experiments suggest that the "neural" hypothesis is the more tenable of the two, since there was no evidence of a complexity effect throughout any of our stimulus manipulations.

It could be argued, however, that the complexity manipulations used in the present set of experiments simply did not work. In other words, perhaps a different complexity manipulation would be more successful with the Erwin paradigm. The experiments had originally been designed in such a way that it was taken for granted that the Erwin results were reliable. We planned to obtain complexity effects with this technique, and then show them to be artifacts of this subjective method, by removing them with the very objective temporal integration technique. It seems likely that the Erwin paradigm is untrustworthy, since the stimuli used for experiment 6 were independently rated as varying in complexity. It could very well be the case that a more "forceful" experimenter could obtain complexity effects using the onset-offset technique with the very same stimuli. Also, it seems likely that the pseudo-letters provided a true complexity manipulation due to their unfamiliarity and lack of name codes.

Experiment 9

The purpose of this experiment was originally to try to eliminate the complexity effect found in experiment 8 using the more objective temporal integration paradigm. The problem encountered was that we could not obtain a complexity effect with the Erwin paradigm (although some subjects showed a tendency toward this pattern of results). It is still of interest, however, to see what results will be obtained using the same stimuli (i.e., random letters and pseudo-letters) in the temporal integration task. The "neural" hypothesis predicts that there will be no difference in performance between the letters and pseudo-letters, especially since they have been equated for the number of light points used, and the features (line segments) used in constructing them. The "process" hypothesis predicts that subjects will show a complexity effect, especially under the report conditions (see experiment 10). The preceding experiments lead us to the prediction that no persistence difference will be found for the two types of stimuli.

Materials and Methods

Subjects. Six subjects were run in this experiment. All had normal or corrected-to-normal vision, and each was paid $5 for a single session lasting approximately 1 1/2 hours.

Stimuli. The same stimuli were used in this experiment as were employed in experiment 8. The only difference was that the stimuli once again consisted of two frames which filled in 15 of 16 possible locations in a 4 x 4 matrix when perceptually integrated. The first frame consisted of either letters or pseudo-letters in 8 positions within the 4 x 4 matrix. The second frame was formed by filling in 7 of the 8 remaining locations with letters (or pseudo-letters, if the first frame consisted of pseudo-letters).

Equipment. The same equipment was employed in this experiment, as had been used in each of the preceding experiments.

Procedures. This experiment was analogous to experiments 4 and 5, except that letters and pseudo-letters were used rather than Ichikawa stimuli. The subject's task was to report the location in the 4 x 4 matrix where no letter (or pseudo-letter) was presented. Subjects were once again required to type this location into the computer. Each subject was run in 2 blocks of 300 trials, thus receiving 50 trials in each of the 2 complexity by 6 interframe interval conditions.

Conditions. Frame 1 and frame 2 were both presented for 20 ms. There was a variable length interframe interval (IFI) separating these two frames, and the IFI values that were used in this experiment were the following: 10, 40, 70, 100, 130, and 160 ms. Random letter trials and random pseudo-letter trials were randomly intermixed. Subjects were given 30 practice trials before their first block of 300 experimental trials, and 20 more practice trials before their second block of 300 experimental trials.

Results and Discussion

The mean results from experiment 9 are shown in Figure 14. The only main effect that was significant was delay (interframe interval), $F(5,30) = 74.03$; $p < .0001$. No other main effects or interactions were found to be significant as can be seen by the following: block, $F(1,6) = .24$, $p = .6429$; typestim, $F(1,6) = 1.57$, $p = .2571$; block x typestim, $F(1,6) = 1.29$, $p = .2990$; block x delay, $F(5,30) = .68$, $p = .6405$; typestim x delay, $F(5,30) = .76$, $p = .5750$; and block x typestim x delay, $F(5,30) = .94$, $p = 4702$.

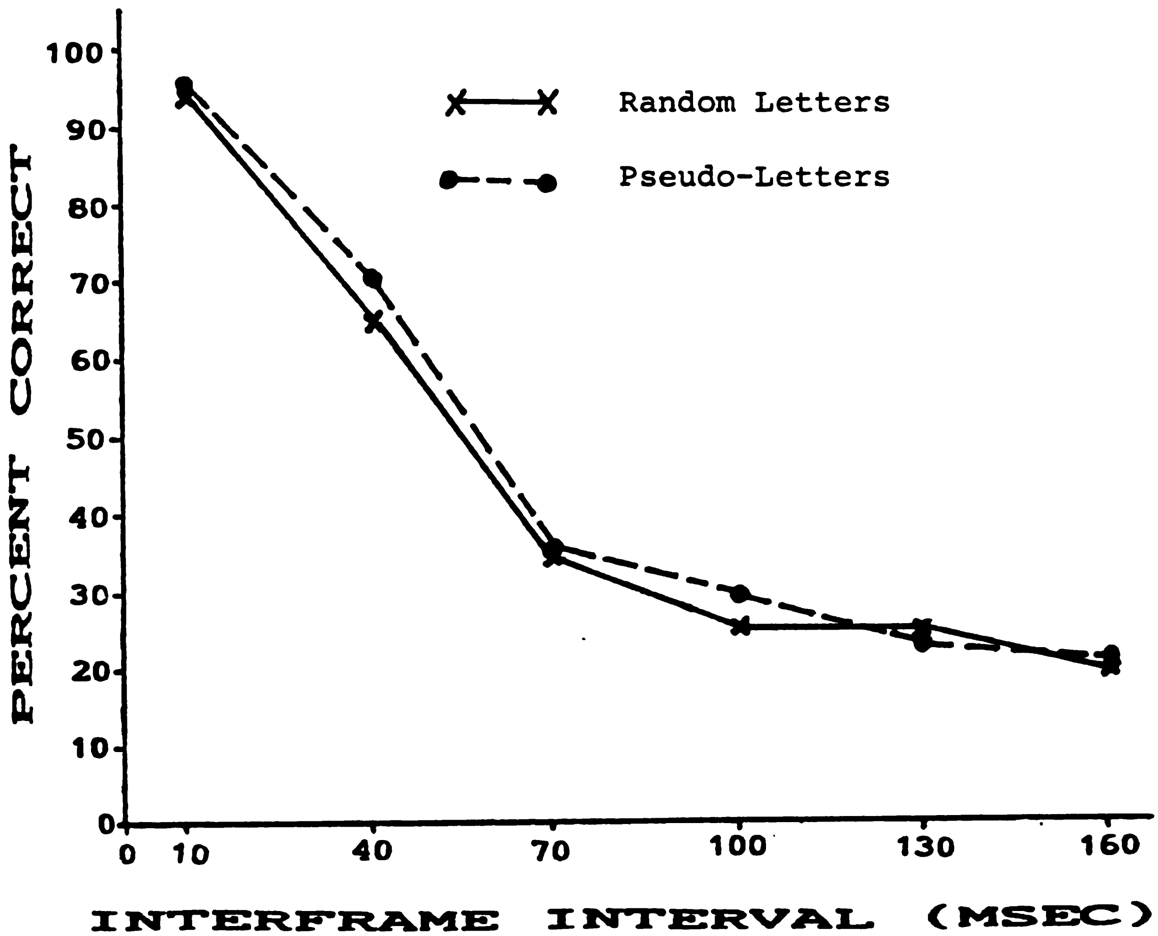


Figure 14. Percent correct for random letters and pseudo-letters as a function of interstimulus interval in experiment 9.

Planned comparisons were performed (Bonferroni halfwidth = 15.31) on the delay term. 10 ms was found to differ significantly from 40, 70, 100, 130, and 160 ms. 40 ms differed from all other delays. Finally, 70, 100, 130, and 160 ms were found not to differ significantly from one another. Performance was found to decrease as the interframe interval (delay) was increased. To determine whether there were any persistence differences, planned comparisons were performed on the typestim x delay interaction (Bonferroni halfwidth = 6.71), however no significant differences were found.

Table 12 shows that individual subjects displayed basically the same pattern of results, as were found by the overall mean. There were no radically different styles of performing, as there had been when using the Erwin (1976) paradigm (especially considering the fact that the same subjects were used).

To summarize the results of experiment 9: (1) performance decreased as the interframe interval was increased; (2) there was no effect of complexity, since pseudo-letters did not persist significantly longer than random letters; and (3) there was no evidence of a practice effect, as shown by the lack of significance for the block factor.

Table 12. Individual and mean results (% accuracy) from experiment 9, as a function of interframe interval

Stimuli: Random Letters						
	Interframe Interval					
Subject #	10	40	70	100	130	160
1	100	96	82	56	50	42
2	98	54	14	10	14	16
3	96	58	30	28	22	12
4	92	54	16	18	14	16
5	92	76	44	24	32	28
6	100	94	58	44	36	32
7	86	26	10	08	12	08
MEAN	94.8	65.4	36.3	26.9	25.7	22.0
Stimuli: Pseudo-Letters						
1	100	98	80	66	42	54
2	100	52	12	22	16	16
3	94	68	24	16	20	12
4	88	56	22	28	20	20
5	100	80	48	36	40	30
6	100	96	60	32	32	24
7	86	42	10	10	04	08
MEAN	95.4	70.3	36.6	30.0	24.9	23.4

Experiment 10

The temporal integration experiments that have been run thus far suggest that the "neural" hypothesis is correct. The slight complexity effect that was obtained in experiment 1 was ruled out as being due to suppressive forces acting among array elements near each other in space and/or time. Furthermore, although several replications of Erwin (1976) were attempted (using three different complexity manipulations), no complexity effect was obtained. A "process" advocate could argue that the temporal integration experiments fail to show a complexity effect because they do not require identification of the stimuli. In fact, Erwin (1976) stresses that these complexity effects only occur when complex processing of the stimuli is required (e.g., if a report must be made). Thus, the purpose of this experiment was to force identification of the stimuli while still maintaining the task of detecting the missing location in the array (i.e., the temporal integration paradigm). The "neural" hypothesis suggests that this deeper processing requirement will not result in a complexity effect.

Materials and Methods

Subjects. Six subjects were run in this experiment. All had normal or corrected-to-normal vision. Subjects were paid $5 for each of two 1 1/2 hour sessions.

Stimuli. Stimuli were identical to those used in experiment 9.

Equipment. The same equipment was employed in this experiment, as had been used in each of the preceding experiments.

Procedures. In addition to typing their row-column coordinate for every trial, subjects also had to record the letters (or pseudo-letters) that were in the same row as the unoccupied location. These are designated as partial report trials, since this method is analogous to the partial report technique seen throughout the persistence literature (e.g., Sperling, 1960). To aid the subjects on these partial report trials, a diagram was provided of all of the pseudo-letters, so as to improve drawing accuracy. Subjects were run in the same number of practice and experimental trials as they had been in experiment 9.

Conditions. The conditions for this experiment were the same as those used in experiment 9, except that a partial report was required on every trial.

Results and Discussion

The mean results for experiment 10 are shown in Figure 15. The only main effect that was significant was delay, $F(5,30) = 52.48$, $p < .0001$. Also, the typestim factor was marginally significant, $F(1,6) = 5.90$, $p = .0512$. Pseudo-letters were found to result in better performance than random letters. The other main effect (block) was not significant, $F(1,6) = .10$, $p = .7616$. One interaction showed a trend toward significance: namely the block x typestim x delay, $F(5,30) = 1.66$, $p = .1751$. The other interactions were not significant as shown by: block x typestim, $F(1,6) = .00$, $p = .9536$; block x delay, $F(5,30) = .80$, $p = .5573$; and typestim x delay, $F(5,30) = 1.38$, $p = .2591$.

Planned comparisons on delay (Bonferroni halfwidth = 17.71) showed 10 ms to be significantly different from 40, 70, 100, 130, and 160 ms. 40 ms was significantly different from 70, 100, 130, and 160 ms. 70 ms was significantly different from 160 ms. Finally, 100, 130, and 160 ms did not differ significantly from one another. Thus, as the interframe interval increased, performance was found to decrease.

The typestim factor showed results very near significance, with pseudo-letters resulting in higher accuracy than random letters (when a report was required), and it also appears that the pseudo-letters

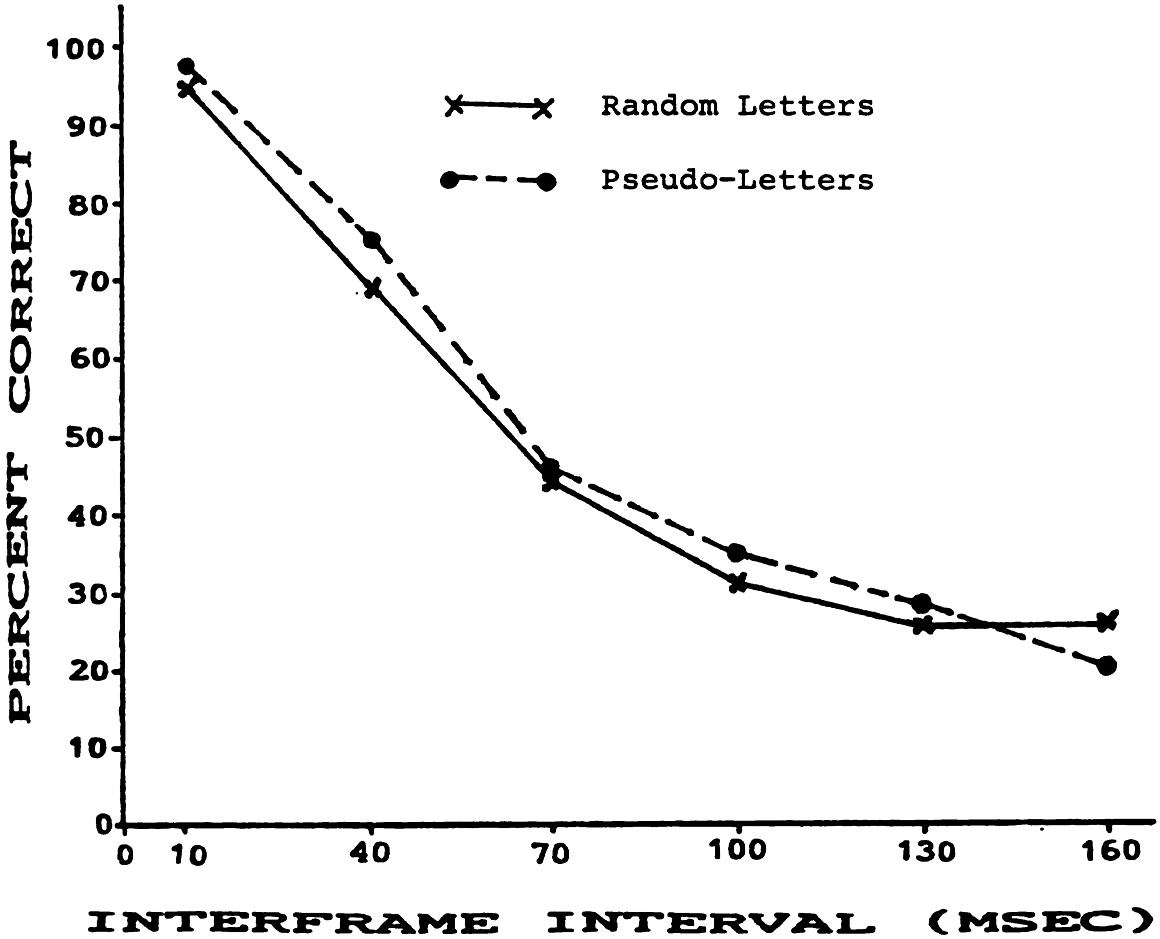


Figure 15. Percent correct for random letters and pseudo-letters when report was required as a function of interframe interval in experiment 10.

asymptote later than the random letters. This supports the "process" account. Why might this state of affairs have occurred? One possibility is that a complexity effect was obtained. Another is that subjects experienced some sort of "frustration effect" when the pseudo-letters were presented. In other words, when the first frame consisted of pseudo-letters, subjects decided that they would at least get the location correct, since the pseudo-letters were so difficult to report. Subjects continually complained of the difficulty of reporting the pseudo-letters, and they generally felt as if they were guessing on these reports. Since the random letter trials were somewhat easier, subjects may have more evenly divided their efforts on these trials. In any event, the differences between stimulus types were quite small.

The typestim x delay interaction was also analyzed with planned comparisons (Bonferroni halfwidth = 10.47). No significant differences were obtained, however, as the 10-130 ms delays, pseudo-letters resulted in better performance than the random letters at near significant levels. Individual subjects showed slightly different patterns of results, as can be seen in Table 13. This result can be contrasted with the individual results from experiment 9 (i.e., listed in Table 12), where responding styles were remarkably consistent across subjects.

Table 13. Individual and mean results (% accuracy) from experiment 10, as a function of interframe interval

Stimuli: Random Letters with Report						
	Interframe Interval					
Subject #	10	40	70	100	130	160
1	100	98	84	60	42	48
2	92	50	20	12	14	18
3	92	52	24	20	16	24
4	90	44	24	18	26	26
5	94	70	52	38	38	20
6	96	94	70	50	42	44
7	98	78	36	24	10	14
MEAN	94.6	69.4	44.3	31.7	26.9	27.7
Stimuli: Pseudo-Letters with Report						
1	100	100	88	64	54	40
2	94	50	30	20	14	08
3	98	76	24	22	12	18
4	96	42	20	28	16	18
5	100	72	44	42	44	34
6	98	98	86	58	42	16
7	96	88	30	14	18	18
MEAN	97.4	75.1	46.0	35.4	28.9	21.7

There was another trend that is troublesome for the "neural" hypothesis to account for however, as subjects appeared to perform better in this experiment than in experiment 9, even though the task was substantially more difficult (i.e., a report of the stimuli was required). If performance was superior when a report was required, then this is consistent with the "process" hypothesis. In fact, this result is very much like that of Erwin (1976). It should also be pointed out that subjects always performed experiment 10 after experiment 9, so it is of interest to see whether the observed effect was due to practice or to a true positive complexity effect.

In order to ascertain this information, the data from experiments 9 and 10 were pooled for those subjects who had taken part in both studies (i.e., six of the seven subjects in each experiment had participated in both). When the data were pooled, most of the main effects and interactions were not significant, as can be seen by the following: experiment, $F(1,5) = .98$, $p = .3680$; block, $F(1,5) = .11$, $p = .7561$; experiment x block, $F(1,5) = .02$, $p = .8911$; experiment x typestim, $F(1,5) = .04$, $p = .8516$; block x typestim, $F(1,5) = .45$, $p = .5334$; block x delay, $F(5,25) = 1.00$, $p = .4369$; experiment x block x typestim, $F(1,5) = .00$, $p = .9534$; experiment x block x delay, $F(5,25) = .43$, $p = .8227$;

experiment x typestim x delay, $F(5,25) = .98$, $p = .4509$; and block x typestim x delay, $F(5,25) = .67$, $p = .6465$.

Only one main effect was significant, namely delay, $F(5,25) = 56.09$, $p < .0001$. There was a trend toward significance for typestim however, $F(1,5) = 3.41$, $p = .1368$. The typestim x delay interaction also showed a trend toward significance, $F(5,25) = 1.89$, $p = .1316$. Finally, two other interactions were marginally significant, experiment x delay, $F(5,25) = 2.25$, $p = .0810$; and experiment x block x typestim x delay, $F(5,25) = 2.13$, $p = .0954$.

Further analyses were performed on the theoretically interesting data as well as those factors and interactions that approached significance. Planned comparisons were performed on the delay term (Bonferroni halfwidth = 15.29), and it was found that 10 ms differed from all other delays, as did 40 ms; 70 ms differed from 160 ms, and all other delays were not significantly different. As has been found for all of the temporal integration experiments, accuracy decreased as the delay was increased.

A t test for correlated means was performed on the typestim main effect ($t(5) = 1.771$, n.s.), and it was found that the two types of stimuli were not significantly different, although 4 of the 6 subjects showed a tendency for pseudo-letters to lead to higher accuracy than random letters.

Planned comparisons were also performed on the typestim x delay interaction (Bonferroni halfwidth = 5.73), and it was found that there were no significant differences between the stimulus types at any of the delays, although the difference was close to significant at the 100 ms delay. Figure 16 illustrates the results of this interaction, and Table 14 lists the mean and individual results. The pseudo-letters led to higher accuracy at all delays except 160 ms, however the differences were extremely small in all cases. Furthermore, both types of stimuli appeared to asymptote at the same point, so there is little evidence that one stimulus type persists longer than the other.

Since the pseudo-letters appear to lead to consistently better performance than the random letters, one is left wondering if perhaps suppressive interactions are once again affecting the results. The pseudo-letters were constructed by maintaining the same line segments, while interchanging their relations to one another. Several naive subjects were also consulted as to whether the pseudo-letters looked like any of the letters of the alphabet, or familiar shapes. When the answer was affirmative, then the pseudo-letters were further modified, until the final set (listed in Figure 12) was

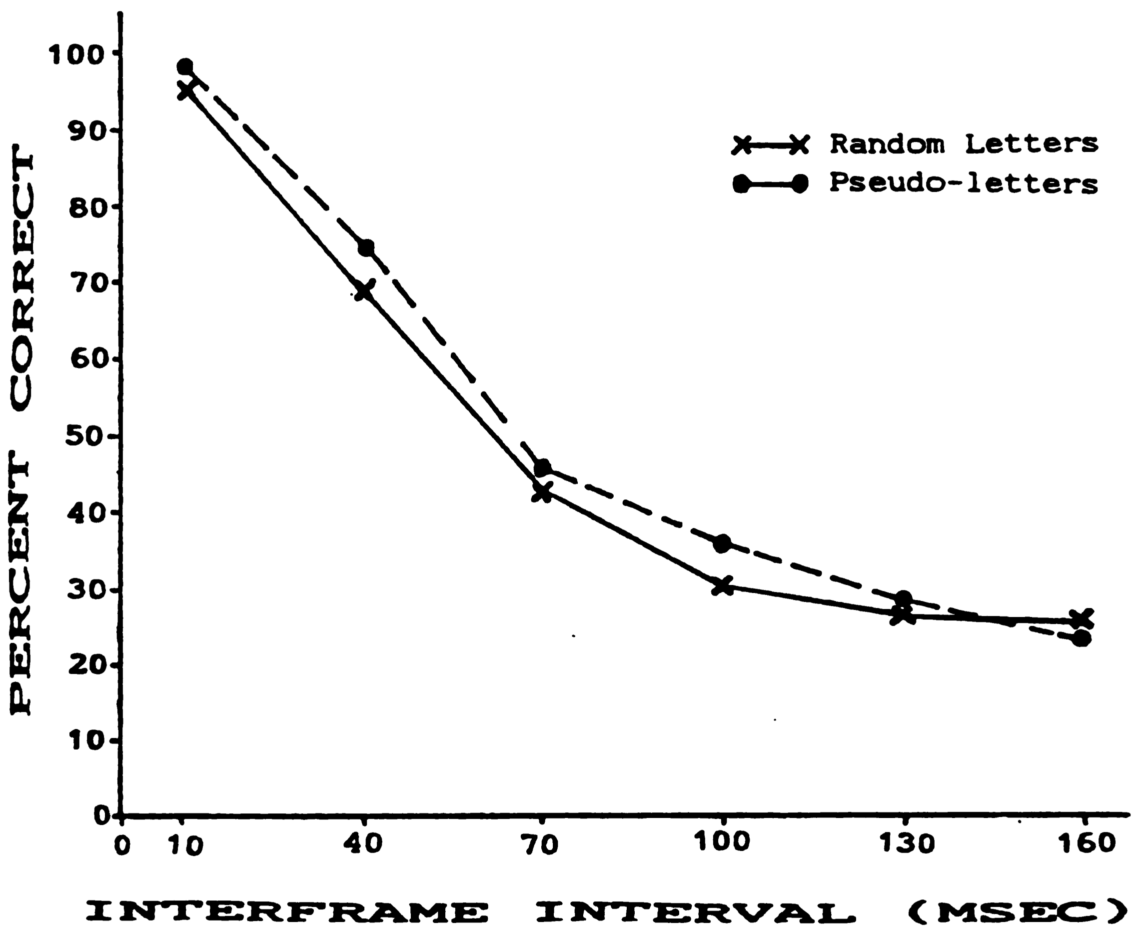


Figure 16. Percent correct for random letters and pseudo-letters as a function of interstimulus interval for the pooled data of experiments 9 and 10.

Table 14. Individual and mean results (% accuracy) from the pooled data of experiments 9 and 10, as a function of interframe interval

Stimuli: Random Letters						
	Interframe Interval					
Subject #	10	40	70	100	130	160
1	100	97	83	58	46	45
2	95	53	19	15	15	20
3	94	54	25	20	18	15
4	91	49	20	18	20	21
5	93	73	48	31	35	24
6	98	94	64	47	39	38
MEAN	95.17	70.00	43.17	31.50	28.83	27.17
Stimuli: Pseudo-Letters						
1	100	99	84	65	48	47
2	99	64	18	22	14	17
3	94	59	27	18	17	10
4	92	49	21	28	19	19
5	100	76	46	39	42	32
6	99	97	73	45	37	20
MEAN	97.33	74.00	44.83	36.17	29.50	24.17

arrived at. This construction method certainly did not rule out the possibility of differential suppression effects, however the main point to be made is that there was little support for a complexity effect as the two types of stimuli did not persist differentially (i.e., one type did not asymptote later than the other), even if accuracy was slightly higher for pseudo-letters.

It seems likely that subjects did better in experiment 10 because they had become familiar with the task and stimuli during experiment 9. This is especially evidenced by the fact that the experiment x typestim x delay interaction did not approach significance. Thus, experiment 10 appears to exhibit more of a practice effect, than support for the "process" hypothesis.

Post-hoc analyses were also performed on two other interactions, since they showed marginal significance. Analysis of the experiment x delay interaction (Scheffe halfwidth = 8.19) showed no differences to be significant. In general, experiment 10 resulted in higher accuracy than experiment 9, particularly at the longer delays, but these differences were small and nonsignificant at each delay.

Finally, a post-hoc analysis of the experiment x block x typestim x delay interaction (Scheffe halfwidth = 14.80) showed no comprehensible pattern of results. In fact, when comparisons were restricted to each of the particular delays, only one difference was significant, and it is reasonable to assume that this comparison was the result of a Type I error. Several comparisons across delays were significant, however, it has been well established that delay (i.e., interframe interval) is a very powerful determinant of performance in these experiments.

To summarize the results of experiment 10: (1) performance was found to deteriorate as the interframe interval increased; (2) there was some suggestion that pseudo-letters resulted in better performance than random letters when a report was required, however this was shown to be more likely to represent a practice effect, since subjects always took part in experiment 10 after experiment 9; (3) there was little evidence of a complexity effect, since the two types of stimuli did not appear to asymptote differentially; and (4) there was some suggestion that the random letters and pseudo-letters may have shown differential suppression effects.

GENERAL DISCUSSION

The preceding experiments were designed to investigate some ways in which human perception operates upon an environment filled with many diverse objects. Some aspects of the environment are simple, while others are complex (e.g., predictable groupings of objects versus random arrays). Does this make any difference to the visual system? There are two possible answers to this question: yes and no. If the complexity of the perceived stimulus affects the duration of visual processing, then this can be described as support for the "process" hypothesis, whereas the failure of complexity to affect the duration of visual processing can be described as support for the "neural" hypothesis (i.e., a standard neural sequence of events occurs regardless of what is viewed).

In order to address this question, there are two important aspects of the procedure to be considered: (1) the stage of visual perception at which to look for a complexity effect; and (2) complexity itself. It is obvious that complexity becomes important at higher levels of cognition (e.g., differences in reading speed for text inverted in various ways--Kolers, 1975), but it is interesting to determine if complexity differences might exist from the earliest stage of visual processing. Thus, the goal of this project was to look for a complexity effect at the level of visible persistence, which can probably be equated with neural persistence (see Coltheart, 1980). Coltheart's definition therefore implies that this stage is neural, and hence unlikely to be affected by complexity manipulations. DiLollo seems to take a similar stance. This "neural" hypothesis is not universally accepted, however, since other researchers purporting to study the same stage have demonstrated positive complexity effects (e.g., Erwin, 1976; Avant & Lyman, 1975). Since these researchers believe that the duration of visible persistence is directly related to the amount of information to be coded, their view (i.e., the "process" hypothesis) suggests that complexity can affect visible persistence duration.

The way in which to define complexity is a much more difficult aspect of the research plan, since there are so many possible manipulations. A quick scan of the literature shows many ways of defining this variable. For example, orders of approximation to English (Erwin & Hershenson, 1974; Erwin, 1976); number of interior angles of a line drawing (Attneave, 1957); the ratio of the squared perimeter to the area of a figure (Stenson, 1966), as well as several other operational definitions have been proposed. Initially we decided to use a global measure (i.e., rectangles versus letters) since these stimuli varied both cognitively and featurally, with the stipulation that more fine-grained complexity manipulations were planned if a true complexity effect was found. The rectangles and random letters were equated for the number of dots comprising them (as were the stimuli in later experiments), and this served to remove a potential confound of differential retinal excitement.

It was critical to the success of this project that we demonstrate the viability of our complexity manipulations. Thus, various complexity checks were instituted throughout the design stage of these experiments. These aspects can probably best be characterized as a set of rules or criteria. Each of the experiments employed at least one of these criteria, although these complexity principles were generally not mutually exclusive from one another. The major Complexity Criteria considered in this research project were the following.

Symmetry

In general, symmetry can be associated with complexity (i.e., the less symmetrical a stimulus is, the more complex it is). Symmetry can be measured by how much stimulus halves would overlap, if they were folded on an imaginary midline. Some evidence for this can be seen by the fact that the subjects in the Ichikawa (1985) experiment rated symmetrical dot patterns to be more simple. Symmetry can also be at least partially equated with the Gestalt term "goodness."

Subject Ratings

As suggested previously, subject ratings are another potential complexity criterion. This is different from the other types of complexity, and in fact is probably heavily dependent on some introspective awareness of these other aspects (e.g., symmetry). An example of this complexity manipulation can be found in the experiments of Ichikawa (1985). The simplest rated dot patterns are those that appear to conform to many of the Gestalt grouping principles. In general, the simple patterns might be refered to as "good" Gestalts. The differences between these two types of patterns can be seen by referring to Appendix A.

Groupability

As suggested in the subject ratings section, subjects often appear to base their complexity judgments on how "good" the arrangement of elements seem to be. For example, Figure 6 has more of a sense of randomness to it than Figure 5, and thus is rated by subjects as being more complex. If one were to attempt to verbally describe Figure 6, this description would be more complex than that of Figure 5 as well, thus suggesting that how elements group may well play a role in the ease or difficulty of their coding.

Nameability

It seems plausible that an object which has a name may be more easily coded than a similar object with no name. For example, reports of pseudo-letters in experiment 10 were found to be much more difficult than the reports of random letters, since the attached name codes (i.e., A, B, C, etc.) can more easily be placed in durable memory storage.

Distinctiveness

Another complexity manipulation that was employed in the present series of experiments was the distinctiveness of array elements from one another. This section shall argue that if an array is composed of identical elements (e.g., dots, rectangles, X's, etc.), it will have a lower complexity value than an array composed of a random collection of letters or pseudo-letters (i.e., each element in these arrays will differ from its neighbors). With identical elements throughout the array, subjects would only have to process the arrangement, as opposed to the variable element arrays in which subjects would have to remember identities as well as the spatial arrangements. In other words, each of the elements in the identical array (e.g., X's) could serve as some sort of placeholder for the spatial arrangement when a report is required, whereas this would not be the case for an array of random figures (e.g., letters).

Predictability

The above criterion also seems to tie in with the predictability of an array, as do some of the other criteria (e.g., groupability and symmetry). In fact, it seems likely that predictability plays a big role in subject's ratings of complexity. With symmetrical objects (or arrangements), one only has to know (or see) part of the object (or arrangement) to become aware of what the whole object (or arrangement) looked like. Similarly, groupability allows a subject to more easily form a pattern during the first half of a matrix, so that the second half of the array will be more predictable. Erwin (1976; and Erwin & Hershenson, 1974) has manipulated complexity in a similar fashion with his orders of approximation to English. Thus, a random string of consonants is much less predictable than a string of letters that bears more similarity to the rules of English word formation.

The first three experiments varied several parameters and found little evidence for a complexity effect. There was a finding that suppression (similar to metacontrast masking) operated between stimuli neighboring each other in space and/or time. Suppression was found to increase as intercontour distance between array elements was decreased, with rectangles having the smallest amount of intercontour separation, and X's having the largest. Actually, dot arrays have even greater separations and pilot data have shown them to persist even longer than random letters and X's. Thus, the first three experiments must be viewed as demonstrating the role that suppression plays in temporal integration experiments.

Experiments 4 and 5 used stimuli that had independently been rated for complexity (see Ichikawa, 1985), and found no complexity effect when using the temporal integration paradigm. This can be taken as fairly strong evidence against the "process" hypothesis of visible persistence. This claim would be made even more convincing however, if a complexity effect could be demonstrated with these same stimuli and a more subjective technique. The task we chose to use was the Erwin onset-offset technique, since it is free from many of the problems found with other techniques (e.g., there is a memory component involved when performing the task used by Avant and Lyman, 1975), although even this technique relies on judgments that are not visible to the experimenter. Thus, most of our efforts were directed at showing that the complexity effects obtained with subjective techniques do not stand up when the same stimuli (and complexity manipulations) are used in our more objective temporal integration paradigm.

The above rationale was used for experiments 6-10. In experiment 6, we attempted to find a complexity effect using the Erwin onset-offset technique and stimuli that showed no such effect with the temporal integration paradigm (i.e., the Ichikawa (1985) rated complexity patterns). Likewise, experiment 7 attempted to find a complexity effect with the Erwin method, and random letters versus X's. Remember that experiment 3 found no complexity effect with these stimuli and the temporal integration technique. Finally, we also used random letters and pseudo-letters in the Erwin technique to try to demonstrate a complexity effect (experiment 8). None of these attempted replications of Erwin were successful however, so it could be argued that we did not manipulate complexity effectively. It is unclear whether this is true or not, since some subjects did show an effect of complexity, however this could have occurred simply due to chance. This leads us to believe that Erwin's task is unreliable, and that his results may have been due to any number of reasons (e.g., particularly motivating instructions, predictability of the onset of stimuli, etc.).

Why did Erwin (1976) get a complexity effect with the onset-offset technique while we could not? This issue is worthy of further consideration. There were a number of differences between the two experiments. First of all, Erwin used 50 ms exposures, whereas our exposure durations were 10 ms (experiment 6) or 20 ms (experiments 7 and 8). It may be that our exposures were too brief to allow a cognitive complexity effect (i.e., the complexity difference was not perceived).

Another difference between the two procedures was the size and shape of the arrays (i.e., Erwin used a row of 7 letters, while we used 8 elements arranged randomly in a 4 x 4 array). Erwin's arrays subtended 2.3 degrees horizontally and .5 degrees vertically, while our arrays were 3.1 degrees horizontally and 3.6 degrees vertically. Combined with our short presentation times, it is possible that our complexity manipulations were ineffective because of the difficulty subjects may have had perceiving the whole array (especially in experiment 6, where the entire pattern of dots determined how complex that particular stimulus was). Since subjects had difficulty reporting more than a few items from the array, this view is at least tenable, although output interference is at least as good an explanation for this result.

A third and probably most important difference between our results and Erwin (1976) were the subjective aspects of the two experiments. For example, some of our subjects showed a complexity effect while others showed either no complexity effect or some strange reporting phenomena (e.g., shorter persistence durations when a report was required). It may be that Erwin's subjects were provided with more highly motivating instructions than our subjects, and thus adopted a strategy that best corresponded to the demand characteristics of his experiment. Our subjects were provided with relatively neutral instructions, informing them whether to respond to the "onset" of the stimulus, or when the stimulus appeared to disappear off the screen (offset). Our subjects were also instructed to report correctly as many of the elements as possible in their correct locations, including educated guesses. Erwin (1976) instructed subjects not to guess, so this may have also had an effect on performance of the task, although it is not clear what effect this would have.

A final difference between our experiment and that of Erwin was the complexity manipulations that we used. A possible complexity manipulation that could have been studied was the effect of using orders of approximation to English in the same two tasks (in fact, Erwin used this manipulation for his study). This would be an exceedingly difficult manipulation for the temporal integration task, although perhaps an effect would emerge with these stimuli. This would suggest that the way in which complexity is manipulated has a direct bearing on whether a complexity effect is found.

The last point to be considered is the implications that the findings of this research program will have. Additionally, how can these findings be incorporated into current models of perception? As mentioned earlier, some researchers have claimed all along that visible persistence is neural in nature (e.g., Coltheart, 1980; DiLollo, 1980). These researchers have proposed models that assume an early neural stage which is unaffected by such cognitive aspects as complexity. Thus, it is quite likely that many models of perception will not have to be altered, or at the most, only slightly altered to accommodate the results if the "neural" hypothesis proves true. The big surprise would have occurred if strong evidence for the "process" hypothesis had been found, however, this seems highly unlikely, since very little evidence was found supporting this view. Experiment 10, however, showed a trace of a report effect, so perhaps complexity does have some effect that we have not manipulated effectively enough. A complexity finding would result in a major upheaval of several current visual perception issues, particularly the level at which cognitive complexity can have effects (i.e., this point would be pushed back to the earliest stage of visual processing). This would have implications for the interaction of top-down and bottom-up processing, and would almost assuredly tie in with the skills of reading. In fact, some research had already been performed which suggests that the duration of visible persistence affects the quality of reading, and may be a determinant of certain types of dyslexia (e.g., DiLollo, Hanson, & McIntyre, 1983).

It might be illustrative to place visible persistence within a current model of visual processing. Irwin and Yeomans (1984, 1986) have proposed a model of the early stages of visual perception. This model has explicated in considerable detail the processes that occur during informational persistence (or knowledge about the visual properties of the stimulus), and is diagrammed in Figure 17.

This model assumes that sensory information from a display (sensory representation) is ultimately translated into relatively durable nonvisual identity codes that have associated with them some abstract representation of spatial position (e.g., spatial coordinates). This information is then transferred to short-term memory. As

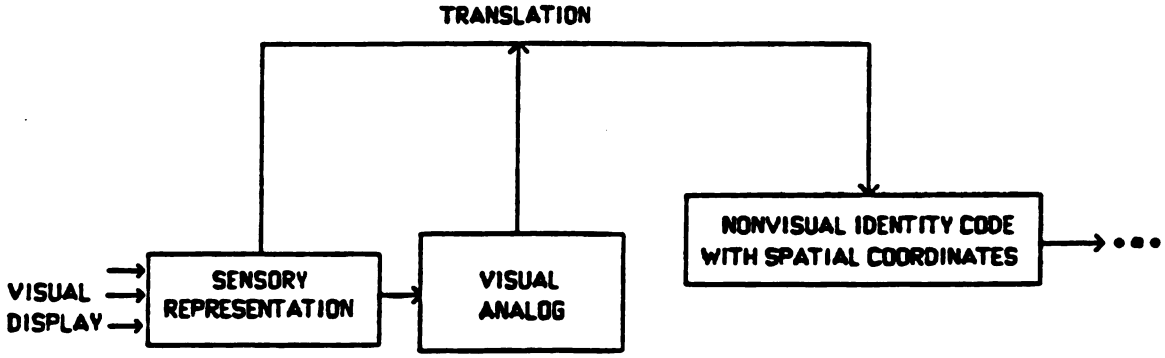


Figure 17. Irwin and Yeomans' (1986) model of the early stages of visual processing.

long as the display is present, translation can and will occur; however, when the display is terminated, the translation process must rely on stimulus persistence. The experiments performed by Irwin and Yeomans suggest that this stimulus persistence is best represented by a visual analog. The duration of the analog representation is sensitive to stimulus exposure conditions, such as the presence of masking stimuli, and it is assumed to decay with the passage of time. In other words, the visual analog maintains form and location information about the display for some period of time after stimulus offset in order to allow the translation process to extract further information about the presented items. In general, the analog lasts for 150-300 ms regardless of exposure duration. Translation is nonselective unless directed by a cue, such as used in a partial-report experiment.

It should be noticed that there is no mention of visible persistence in this model. This process has been dumped into the sensory representation box in the model, since not enough details were known about it. The findings from this research plan may ultimately give visible persistence a role in the model. The findings of this project best support the "neural" hypothesis, and this suggests that the role of visible persistence is that translation into identity codes occurs using information from the actual array or visible persistence, whichever of the two is longer. This makes sense since visible persistence has been described as the phenomenal impression that the stimulus is still visibly present (Coltheart, 1980). This mechanism guarantees the visual system a minimum of about 100 ms for using veridical information about the stimulus.

In conclusion, the question of how complexity affects visible persistence is an interesting and challenging one. It may not have been answered fully by this research plan, but certainly we took a step in the right direction. Perhaps the biggest contribution this research made was the introduction of an objective technique into a line of study that has traditionally been plagued by subjective methods. As so often happens to topics in psychology, complexity turns out to be more complex than meets the eye.

APPENDIX

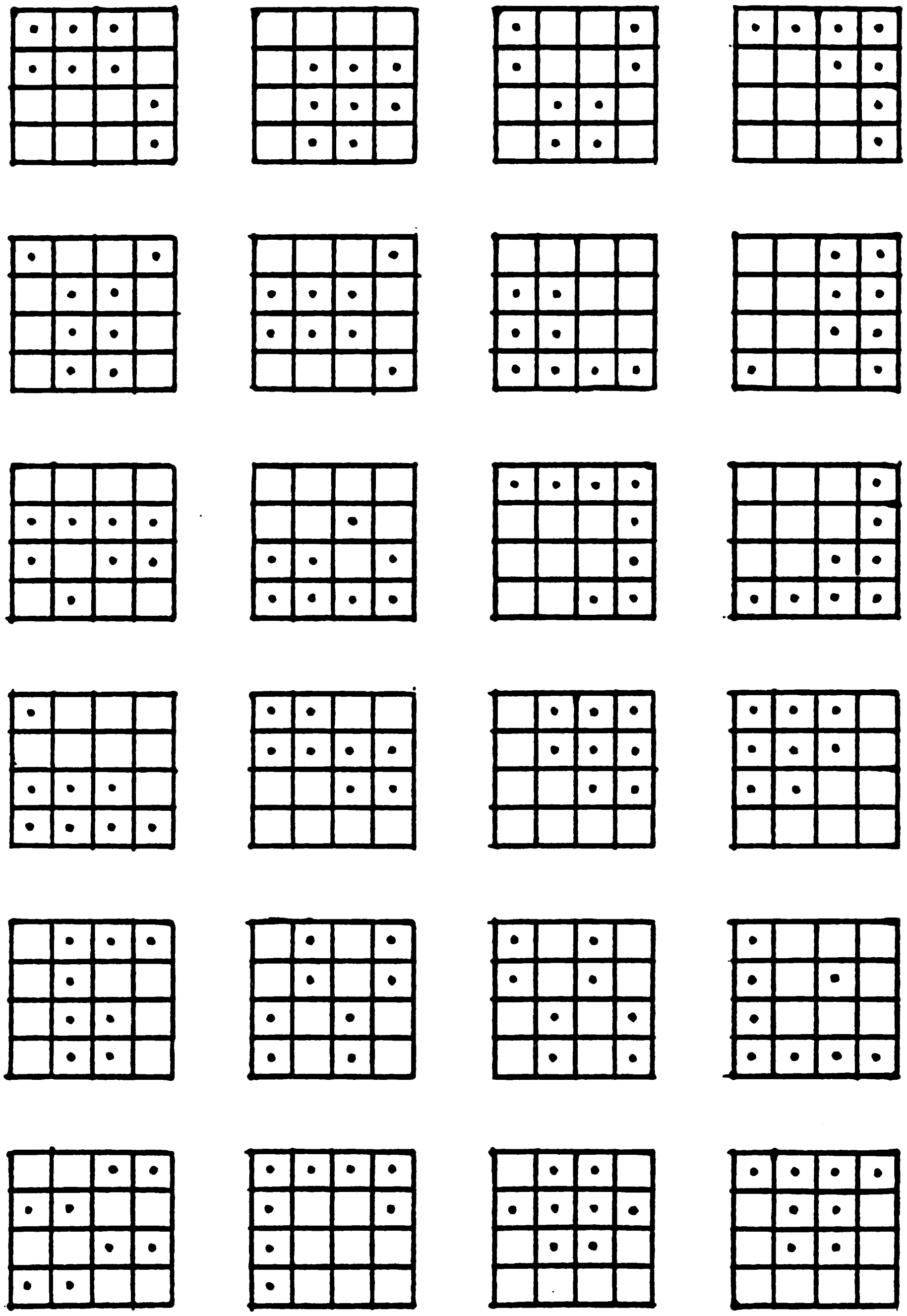


Figure A.1. Simple Ichikawa Stimuli: 26-49.

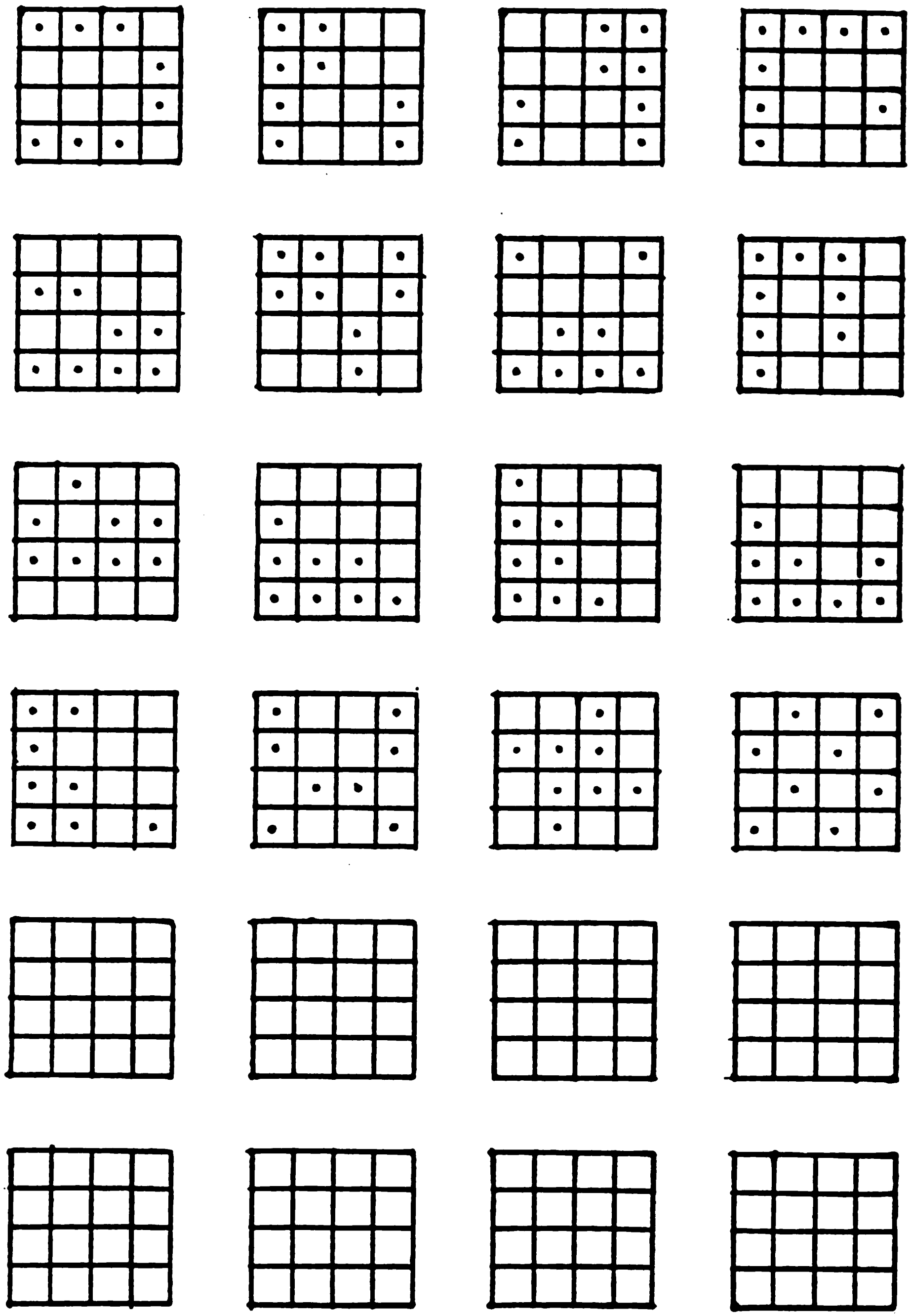


Figure A.2. Simple Ichikawa Stimuli: 50-65.

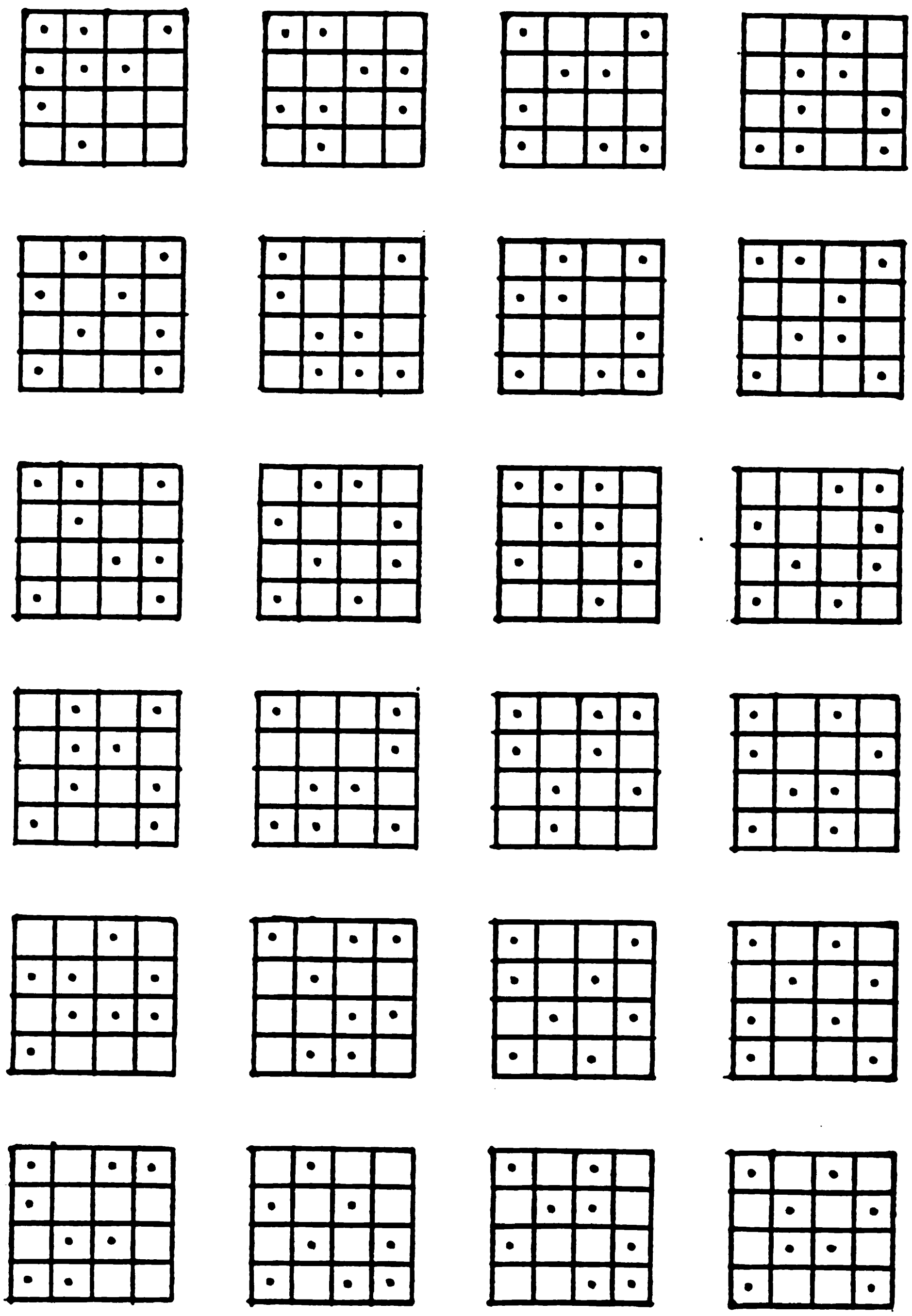


Figure A.3. Complex Ichikawa Stimuli: 101-124.

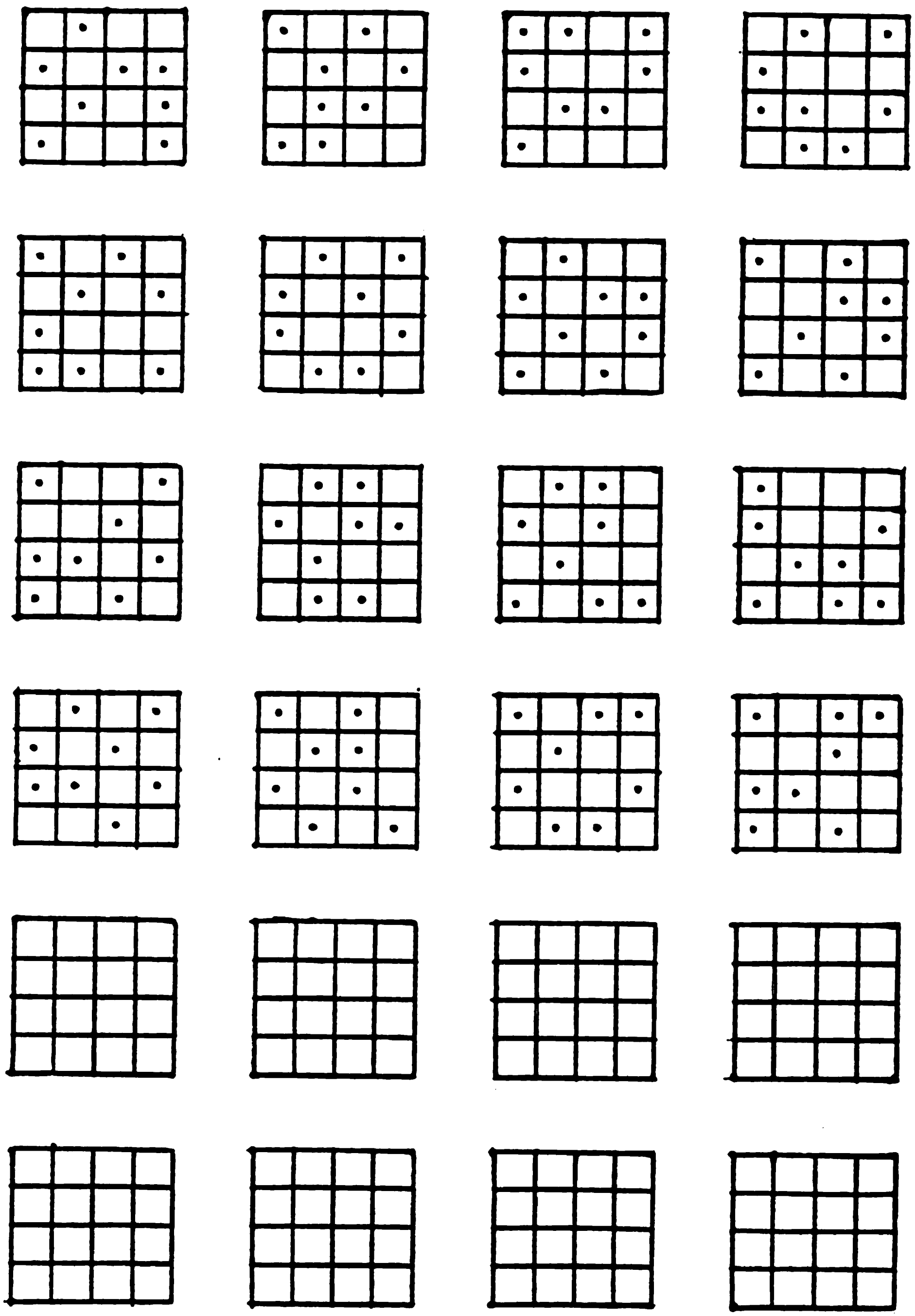


Figure A.4. Complex Ichikawa Stimuli: 125-140.

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