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Identification of scanned and static tactile patterns

JAMES C. CRAIG
Indiana University, Bloomington, Indiana

Most of the studies in which the interactions between target and nontarget spatial patterns have been examined have tested patterns that are generated statically. Static patterns are those in which all the elements of the pattern are presented at the same time and at a fixed location on the skin; however, most tactile information comes to the skin by means of patterns' being scanned across the surface of the skin. In the present study, the interactions between target and nontarget patterns were measured for patterns generated in both the static and the scanned modes. Nontarget patterns often interfere with the perception of target patterns. Using patterns generated in the static mode, previous studies have identified two factors that produce interference in pattern identification: response competition and masking. Masking, in turn, appears to be the result of temporal integration of the target and nontarget patterns, as well as the displacement of target features. In the present study, these factors were examined for patterns generated in both static and scanned modes. Regardless of the mode in which the patterns were generated, similar functions were obtained relating identification performance to the temporal separation between the target and the nontarget patterns. Although statically generated patterns are more easily identified than scanned patterns, particularly at brief durations, mechanisms such as response competition, temporal integration, and the displacement of target features appear to be factors that affect scanned patterns to nearly the same degree as static patterns.

Most of the information that we acquire by touch comes to us by means of spatial/temporal patterns arriving successively at the fingertips. During haptic exploration, individual patterns move across the fingerpads in what is referred to as a *scanned mode.* This is the mode of pattern generation in reading braille or identifying the surface features of an object. With the development of arrays of tactors that can be used to present spatial/temporal patterns, it has been possible to generate patterns in a number of different modes, including a static mode (Bach-y-Rita, 1972; Bliss, 1974; Bliss, Crane, Link, & Townsend, 1966; Geldard, 1966; Gottheil, Cholewiak, & Sherrick, 1978; Scadden, 1973). In most of these studies, as in the present study, patterns were generated by tactors vibrating against the skin. With these displays, the mode of pattern generation is considered *static* in the sense that the elements making up the patterns—line segments and curves—remain in the same location on the skin. In several studies, different modes of generating spatial patterns have been examined and it has been shown that identification performance is affected by the mode of presentation. Loomis and Lederman (1986) provide a summary of these results. The relative superiority of particular modes of generating spatial patterns depends on a number of factors, including the site of stimulation, the size of the pattern, and the duration of presentation (Loomis & Lederman, 1986).

Because the fingerpad is one of the most sensitive areas of the body and also the area most often used in haptic exploration, several studies have used it as the site of stimulation in examining various modes of pattern generation (Craig, 1980, 1981). In these studies, the display from the Optacon, a reading aid for the blind, was the device used to generate the patterns. In one study, five different modes of pattern generation were examined. At brief display times, the mode of pattern generation had a large effect on identification performance. For example, at a pattern duration of 26 msec, correct identification of the 26 letters of the alphabet ranged from just over 20% (scanned mode) to over 70% (static mode; Craig, 1981). These two modes of generation were examined in the present study. In the static mode, the entire pattern is presented to the fingerpad at the same time. In the scanned mode, the pattern moves across the display from one side to the other. Figure 1 illustrates how the patterns are generated.

For relatively small patterns presented to the fingerpad, the scanned mode produces higher levels of performance than does the static mode (Loomis, 1980), whereas with larger patterns (Loomis, 1980) and brief display times, the static mode produces better identification performance than does the scanned mode (Craig, 1980, 1981). Loomis hypothesizes that when the size of the spatial

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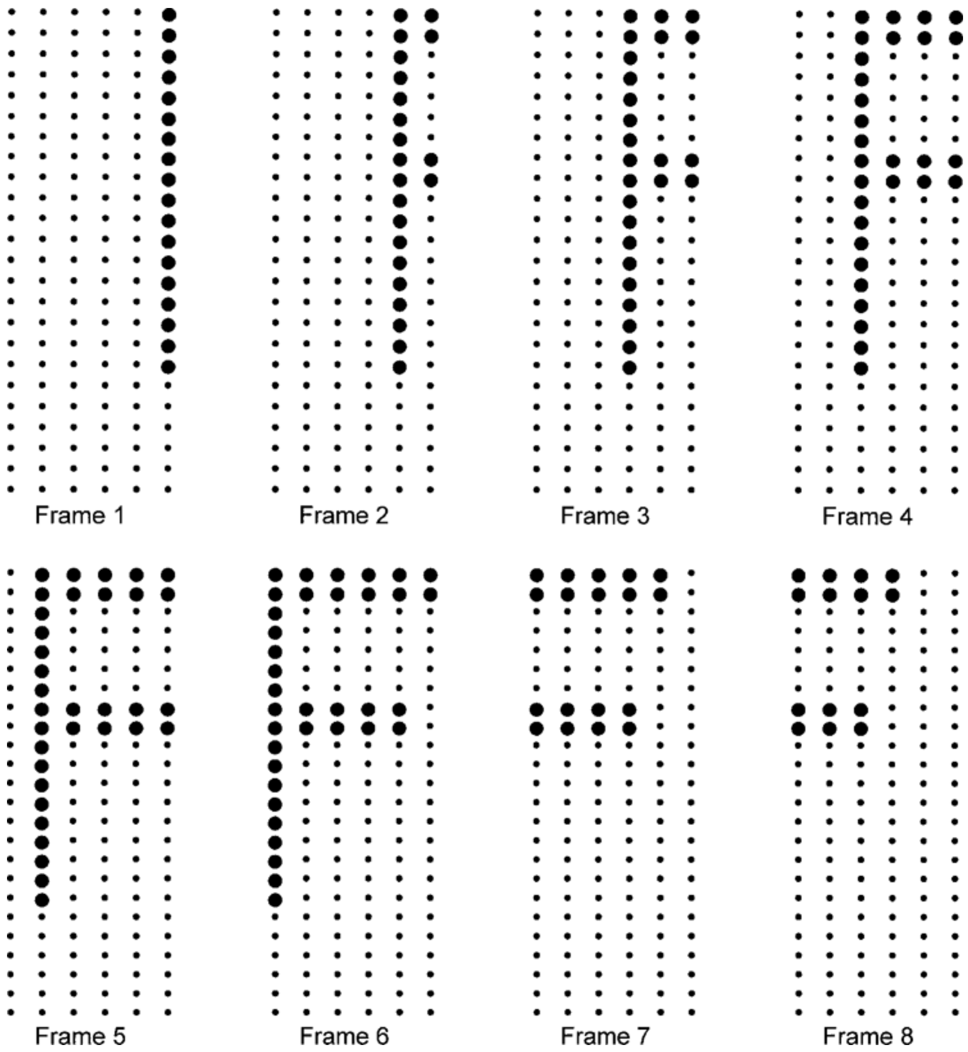

Figure 1. A representation of the letter "F" as it appears in the first eight frames of the scanned mode.

pattern is small relative to the spatial sensitivity of the area of skin being stimulated, scanning patterns across the skin will lead to better performance because phase information is provided. With larger patterns, there is no advantage to scanning the pattern (Loomis & Lederman, 1986). In a number of subsequent studies, the static mode has been used, in part because it produced superior performance with the brief pattern durations that were being tested and in part because it permitted more precise specification of the onset and offset of patterns.

Owing to the fact that most of the information coming to the skin comes by means of patterns arriving successively, investigators have been concerned with the way in which the perception of target patterns is affected by nontarget patterns presented in close temporal proximity to the target patterns. With scanned patterns, the leading edge of the pattern contacts the skin before the rest of the pattern, and specifying the exact temporal relationship between elements in the target pattern and elements in the nontarget pattern is difficult. Precise specification of temporal intervals is particularly important when significant changes in performance are seen with small changes in the temporal separation between the target and the nontarget (Craig, 1996). As has been noted, there are results that show that, for patterns presented by themselves (i.e., in the absence of other patterns), identification performance is strongly affected by the mode of pattern generation. In addition, there are a number of studies, using statically generated patterns, in which the effects of nontarget patterns on pattern identification have been examined (e.g., Cholewiak & Craig, 1984; Craig & Qian, 1997); yet, in haptic exploration, the most common way in which spatial patterns are generated tactually is via the scanned mode. One earlier study did generate temporal masking functions for both static and scanned patterns (Craig, 1980). The temporal functions were similar to one another, but the overall levels of performance were different, making direct comparisons problematical.

The major aim of the present study was to compare static and scanned modes of pattern generation: Are spatial patterns presented to the fingerpad processed differently as a function of the mode of generation? In particular, we wanted to examine some of the factors that have been found to affect temporal interactions between successively presented patterns when the patterns are presented in a static mode, as compared with a scanned mode. Clearly, the generalizability of previous studies would be markedly reduced if the mechanisms shown to interfere with the perception of static patterns did not interfere in the same way with scanned patterns. What are these mechanisms? Broadly speaking, two mechanisms have been identified by which a nontarget pattern can interfere with the perception of a target pattern (Craig, 2000). One mechanism is by altering the representation of the target pattern. This change in the representation is generally assumed to take place at an early stage of processing and is often referred to as *masking*. Two of the ways in which masking may alter the representation are by displacing the apparent location of features of the target (Craig, 1989) and through temporal integration of the target and the nontarget (Craig, 1996; Evans & Craig, 1986). A second mechanism is response competition. In this case, interference is the result of the subject's mistakenly responding with the nontarget rather than with the target. The nontarget is assumed to be processed to the point of evoking a response, and the subject errs by selecting it, rather than the target response (Craig, 1996; Evans & Craig, 1992).

The fact that subjects often respond with the nontarget does not eliminate the possibility that the features of the target and the nontarget are being integrated with one another. There could still be considerable interference with the representations of the target and nontarget patterns at an early stage of processing—that is, masking. However, subjects may respond with the nontarget because its features are more clearly perceived than those of the target. This result would be consistent with response competition. In the present study, two types of nontarget patterns were used: nontarget patterns drawn from the set of target patterns (letters) and neutral patterns (nonletters) that were not part of the set of target patterns. Both letters and neutral patterns should produce similar amounts of masking, but performance may decline with the letter nontargets, because subjects may mistakenly respond with them. It is in this sense that response competition has been shown to affect pattern identification performance with static patterns.

There is an additional factor that might cause subjects to respond with the nontarget: replacement. If the nontarget eliminates the representation of the target and replaces it, subjects might respond with the only remaining pattern—that is, the nontarget. Previous studies suggest that this is unlikely with static patterns (Craig, 1995). The possibility that replacement is a factor with scanned patterns is examined in the present study.

One might expect scanned and static patterns to be processed differently for several reasons. First, there is the obvious difference in the perception of movement. Scanned patterns, even at high rates of presentation, give a strong sense of movement across the surface of the skin. Second, the features of spatial patterns are generated in the two modes in different ways. For example, there is a marked difference in the way in which, relative to the display, horizontal lines and vertical lines (Figure 1) are generated on the fingerpad in the two modes. In the static mode, horizontal and vertical lines stimulate the same locations for a period of time and then are turned off. In the scanned mode, a vertical line sweeps across the entire array, activating all of the tactors and presumably stimulating a large number of the peripheral afferents. By contrast, a horizontal line stimulates a restricted area of the fingerpad. Third, and related to this latter point, space is represented differently in the two modes. For static patterns, spatial extent is represented directly. For scanned patterns, vertical extent is also represented directly; line segments move as a unit across the skin. With horizontal extent, the line segment appears at the right side of the array, increases in extent as it moves on to the array, and then decreases in extent as it moves off the left side of the array. Because of the relatively brief time that a horizontal line segment is centered on the array, the most salient cue for distinguishing a short from a long line segment may be the amount of time that the segment occupies the array.

As has been noted, in contrast to masking, response competition is thought to occur at a relatively late stage of processing (Craig, 2000). As such, response competition itself might be relatively unaffected by the mode in which the patterns are generated. If response competition results from subjects' choosing between two responses, the mode of generation of a pattern may be of little consequence, as long as it evokes an appropriate response. In short, one might expect that the static and the scanned modes would differ in terms of masking, but not response competition.

The present study consisted of four experiments. In Experiments 1 and 2, pattern identification was measured in the presence and in the absence of nontarget patterns. Static patterns were used in Experiment 1, and scanned patterns were used in Experiment 2. In Experiment 3, we examined the possibility that the increase in responding with the nontarget observed in Experiments 1 and 2 was the result of the nontarget's replacing the target, rather than response competition per se. In Experiment 4, two possible mechanisms by which a nontarget affects the representation of the target—temporal integration and feature displacement—were examined with both scanned and static patterns.

EXPERIMENT 1

Most of the previous studies of response competition used a categorization task in which subjects made the same response to several patterns. It has been shown, however, that this task may overestimate the amount of interference from response competition and underestimate the contribution of masking. It has been suggested that better estimates of the relative contributions of masking and response competition are obtained from an identification task in which a neutral pattern is used as a nontarget (Craig, 2000). Identification performance is measured under two conditions: one in which the nontarget is selected from the set of possible target patterns, and the second in which the nontarget is a neutral pattern—that is, it is not a possible target. As has been noted, if response competition is a factor, then on those trials in which the nontarget is selected from the target set, subjects should err by responding with it. Overall performance should be lower in this condition than when the nontarget is a neutral pattern, a pattern that subjects cannot respond with.

A number of the previous studies with static patterns used letters as target patterns. Letters are convenient to use because there is an available response set and because the device used in the present study, the Optacon, is a reading aid for the blind that presents letters to the skin. Users can read at rates of 30–60 words per minute (Goldish & Taylor, 1974), demonstrating that they are able to process letters at rates of 5–6 letters per second. On the basis of these rates, subjects are able to process letters presented for durations of about 100 msec, with 50 msec between the offset of one letter and the onset of the next letter. When reading with the Optacon, the patterns are scanned across the fingerpad. Reading rates have not been measured with statically presented letters.

In earlier studies of temporal masking, subjects were tested in an identification task, and in some instances, the 26 letters of the alphabet were used; however, in these earlier studies, the kinds of errors that subjects made were not analyzed (Craig, 1980). Thus, it is not known whether subjects responded with the nontarget and whether response competition is a significant factor when the number of possible responses is large. Experiment 1 differed from previous masking studies in that we examined the errors that subjects made in a letter identification task and determined the probability of responding with a nontarget. Identification performance was also measured when a neutral pattern was used as the nontarget.

Method

Subjects. The subjects in all the experiments were trained in tactile pattern identification prior to data collection. The subjects were undergraduate and graduate students at Indiana University and received an hourly rate for their participation. The subjects were selected from a group of subjects in the laboratory on the basis of their schedules and availability. Seven subjects, 5 women and 2 men, were tested in Experiment 1.

Apparatus. The apparatus consisted of a tactile display that fit against the subject’s fingerpad. The display was part of the Optacon, a reading aid for the blind. The display measured 1.3 × 2.7 cm and consisted of 144 tactors arranged in a 6 column × 24 row array. The tactors were driven at 230 pps. A computer controlled both the tactile display and a visual monitor that was used to present instructions and feedback to the subjects. The subjects responded by means of a keyboard.

Stimuli. Both the target and the nontarget patterns were presented for 26 msec. The target patterns were the uppercase letters of the alphabet. The letters occupied the top 18 rows of the display and all six columns, with the exceptions of “I” (one column) and “J” (five columns). Two types of nontargets were used: letters of the alphabet and a neutral pattern. The neutral pattern was a diagonal bar that extended from the upper left to the lower right of the display and was generated by turning on 41 tactors. Representations of some of the patterns are shown in Figure 2.

Procedure. The same general procedure was followed in all four experiments. The subjects were trained to identify the target patterns. After reaching relatively stable levels of performance, data collection was begun. The target pattern was presented along with a nontarget pattern, either a letter or the neutral pattern. Depending on the block of trials, the nontarget either preceded or followed the target. The subject attempted to identify the target, responded by

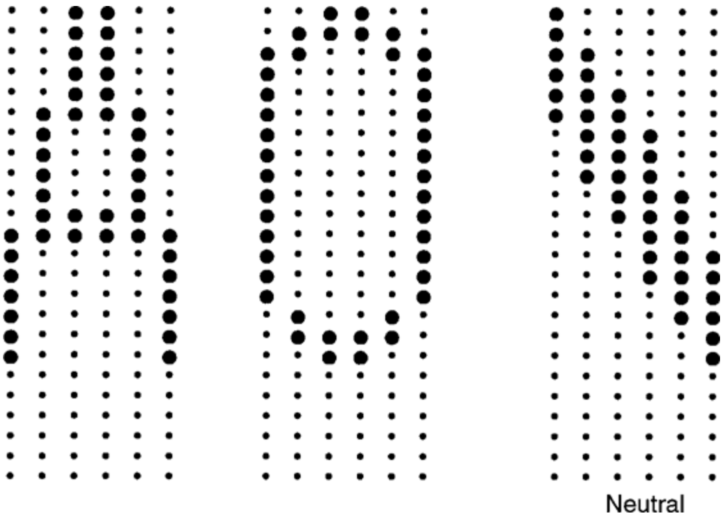

Figure 2. Representations of the letters and the neutral pattern.

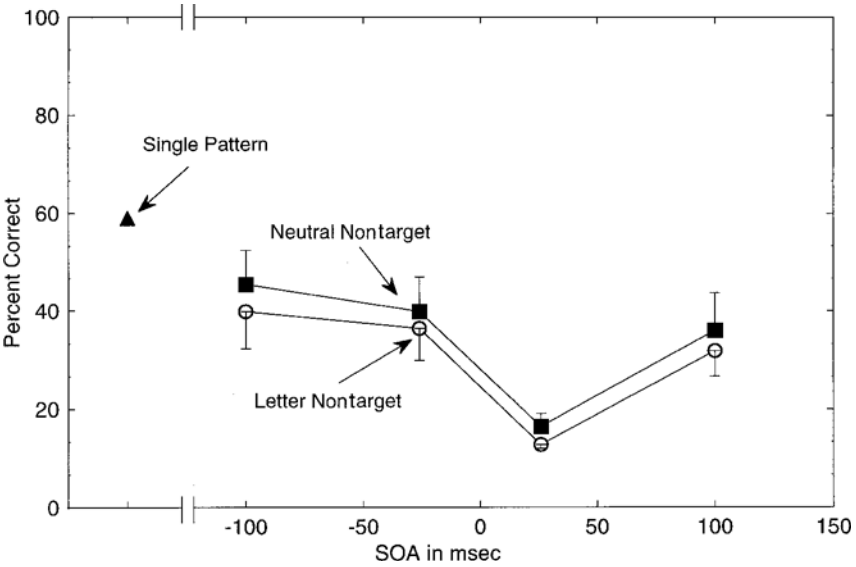

Figure 3. Percentages of correct letter identifications for static patterns as a function of stimulus onset asynchrony (SOA). The results from two types of nontargets—neutral pattern and letters—are presented, as well as single-pattern performance. Error bars represent one standard error of the mean.

means of the keyboard, and received trial-by-trial feedback. The subjects were seated with their left hands extended and their left index fingers resting on the array. They wore earphones through which white noise was presented, to prevent them from using auditory cues produced by the array.

In Experiment 1, trials were grouped into 50-trial blocks. A session consisted of five blocks of trials and began with a block testing single-pattern identification—that is, with the target presented by itself. Following this block of trials, each subsequent block tested a different temporal interval (stimulus onset asynchrony [SOA]) between the target and the nontarget. The four SOAs were −100, −26, +26, and +100 msec. Negative SOAs refer to conditions in which the nontarget led the target, and positive SOAs refer to the conditions in which the nontarget trailed the target. Prior to each block of trials involving nontargets, a message appeared on the CRT telling the subject that the target pattern would be either the first or the second pattern presented. Relatively brief SOAs were used because we were interested in producing substantial amounts of interference. Greater amounts of interference permit a more detailed analysis of the types of errors that subjects make. The four blocks with nontargets were presented in random order. On approximately half of the trials, the nontarget was 1 of the 26 letters of the alphabet, selected at random. On the remaining trials the neutral pattern was the nontarget. Six of the subjects were tested for eight sessions. One subject was tested for five sessions.

Results and Discussion

The results presented in Figure 3 show the percentage of correct letter identification as a function of the time between the target and the nontarget. Evidence for response competition can be found both in the overall levels of performance and in an analysis of the particular responses to nontarget letters. If response competition is affecting performance, nontarget letters should lower performance more than neutral nontargets, and subjects should respond more frequently than chance with nontargets. The two functions in Figure 3 show the results with a neutral nontarget and a letter nontarget, with the latter resulting in slightly lower performance than the former. Although the overall difference between the two conditions is small, a two-way analysis of variance showed a main effect of type of nontarget [$F(1,6) = 7.77$, $p < .05$] and SOA [$F(3,18) = 13.93$, $p < .0001$], but no significant interaction [$F(3,18) = 0.20$, $p = .90$].

To see the overall effects of response competition more clearly, those trials on which the nontarget was a letter were analyzed to see what letters the subjects responded with when incorrect and to see if these responses corresponded to the nontarget pattern that was presented. Table 1 presents the results for those trials on which the nontarget pattern was a letter and shows the percentage of those trials on which the target letter was selected (percentage correct) and the percentage of trials on which the incorrect response was the nontarget letter (evidence of response competition). By chance, this probability would be 1 in 25, or 4%. The fact that the rate of responding with nontargets was two to six times

Table 1
Static Mode: Percentage of Responses That Were Target Responses Versus Nontarget Responses

SOA (msec)	Target	Nontarget
−100	39.9	4.0
−26	36.4	10.9
+26	12.7	23.7
+100	31.9	18.2

higher than that shows that response competition is evident in an identification task and with a large number of available responses. In fact, at +26 msec, subjects are more likely to respond with the nontarget than they are with the target.

Although response competition clearly affected performance, as is evidenced by the fact that letter nontargets produced significantly more interference than did a neutral pattern (diagonal bar), the neutral pattern also reduced performance considerably. Not all of this reduction in performance should be attributed to masking. An analysis of the responses that were made in the presence of the neutral nontarget shows that the subjects respond with the letter "N" an unusual percentage of the time. At an SOA of +26 msec, 16% of all the letter responses in the presence of the neutral nontarget were the letter "N." The average percentage of "N" responses obtained in the single-pattern condition and on those trials in which a letter was used as the nontarget was 2%. Thus, the neutral pattern, a diagonal bar, resulted in an eightfold increase in the percentage of "N" responses. The representation of the neutral pattern in Figure 2 suggests some reasons for the large number of "N" responses. One is that the diagonal is a prominent feature of the letter "N." At close SOAs, subjects may be processing both the target letter and the neutral pattern but misperceiving the neutral pattern, a diagonal, as the letter "N." Such an error could be classified as response competition.

The main conclusions from Experiment 1 are that response competition is a factor (1) that interferes with performance not only in categorization tasks, but also in identification tasks, and (2) that is evident even with a large number of patterns.

EXPERIMENT 2

In Experiment 2, we extended the measurements to include scanned patterns. To achieve high levels of performance with the scanned patterns, we used longer pattern durations than were used with the static patterns. At brief pattern durations, static patterns produce much higher levels of identification performance than do scanned patterns (Craig, 1980, 1981). Increasing pattern duration improves performance for scanned letters. In the present experiment, it was necessary to have relatively good levels of letter identification performance with scanned patterns for several reasons. First, if performance is very poor, it will be difficult to see any decline from the presence of a nontarget. Second, response competition requires that both the target and the nontarget are processed to the point of evoking a response. Obviously, poor performance means that the target is not evoking a correct response, and thus it is also very unlikely that the nontarget would evoke a response. Third, one of the aims of the present study was to compare confusion matrices with letter patterns generated in static and in scanned modes. Reasonable levels of performance are necessary to make such comparisons meaningful.

Method

Subjects. Eight subjects were tested, 5 women and 3 men.

Stimuli. The stimuli were similar to those used in Experiment 1. The major difference was that the patterns were presented in what is termed a *scanned* mode. With this mode of presentation, the patterns appear to move from the right side of the array across the fingerpad and to exit on the left side of the array (Figure 1). Pattern duration is measured by the total time that it takes a vertical segment of a letter to cross the array. For example, with the letter "I" and a pattern duration of 156 msec, the letter was presented on each of the six columns of the array for 26 msec. With an average letter, such as "L," the vertical segment would also occupy the array for 156 msec, but the total duration of exposure for the letter, as measured from the onset of the vertical edge on the right side of the array to offset of the horizontal edge on the left side of the array, is 286 msec. This definition of pattern duration, the amount of time required for a particular point on a letter to traverse the array, reflects how soon a second pattern could be generated on the array. With the scanned mode, unlike the static mode, elements of both the target and the nontarget can stimulate the finger simultaneously, although they never overlap spatially.

Procedure. The procedure was similar to that used in Experiment 1. The subjects were trained to identify letters of the alphabet presented either singly or in the presence of nontarget patterns. The major difference in procedure was that the patterns were scanned across the array. Several sets of preliminary measurements were made, using a pattern duration of 52 msec. Identification performance was considerably poorer than that obtained with static patterns, and a longer pattern duration (156 msec) was tested. This duration was selected for two reasons. First, previous studies showed a substantial improvement in letter identification when the pattern duration was increased from 52 to 156 msec (Craig, 1980, 1981). Second, 156 msec corresponds to a reading rate of approximately 50 words per minute. This rate is one that Optacon readers have achieved (Goldish & Taylor, 1974), demonstrating that scanned letters can be perceived at such pattern durations. Because of the greater pattern duration, the briefest SOA that could be tested was 156 msec. Four SOAs were tested: −500, −156, +156, and +500 msec.

Results and Discussion

The results are shown in Figure 4. The form of the functions relating performance to SOA is similar to ones that have been obtained with static patterns. As with the static patterns, overall performance was slightly lower when the nontarget was a letter than when the nontarget was a neutral pattern. Also similar to the results of Experiment 1, there was a significant effect of type of nontarget [$F(1,7) = 9.80$, $p < .05$], a significant effect of

Table 2
Scan Mode: Percentage of Responses That Were Target Responses Versus Nontarget Responses

SOA (msec)	Target	Nontarget
−500	55.8	4.3
−156	37.4	10.0
+156	34.1	11.3
+500	58.3	3.6

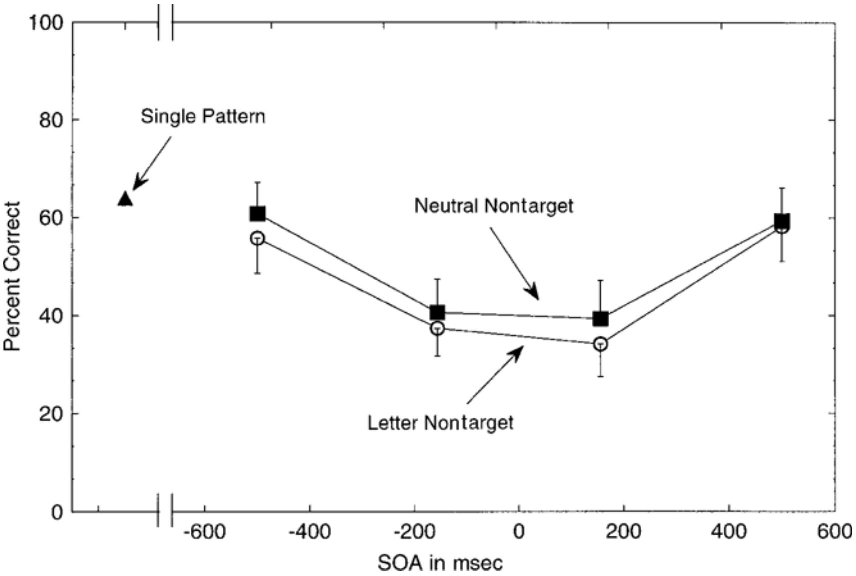

Figure 4. Percentages of correct letter identifications for scanned patterns as a function of stimulus onset asynchrony (SOA). The results from two types of nontargets—a neutral pattern and letters—are presented, as well as single-pattern performance. Error bars represent one standard error of the mean.

SOA [$F(3,21) = 43.75$, $p < .0001$], but no significant interaction [$F(3,21) = 0.84$, $p = .49$]. The results were also analyzed, as they were with the static patterns, to see the extent to which the subjects responded with nontargets. The results of this analysis, similar to Table 1, are shown in Table 2. As with static patterns, at the briefer SOAs, the subjects were several times more likely than chance to respond with the nontarget. These results indicate that, as with static patterns, the subjects are processing the nontarget and responding with it. To compare static and scanned modes, we looked at performance at the briefest SOAs in the scanned condition, +156 or −156 msec. The average percentage of nontarget letter responses at these SOAs was 10.6%. This value compares with the average percentage of nontarget letter responses for static patterns (Experiment 1) of 11.1% at SOAs of +100 and −100 msec.

In the absence of nontarget patterns, the overall percentage of correct responses was 63.3%, similar to that obtained with the static patterns in Experiment 1 (59.5%). These comparable performance levels in the absence of nontarget stimuli allow us to ask whether comparable levels of interference are seen with the two modes. The closest SOAs possible for comparison are +100 or −100 msec for static patterns and +156 or −156 msec for the scanned patterns. The results of this comparison are shown in Table 3. As is evident from Figures 3 and 4, both modes show substantial interference; however, the scanned mode shows somewhat greater interference, even when measured at longer SOAs than the static mode.

Confusion matrices were generated for patterns presented in the static mode (Experiment 1) and in the scanned mode. These are shown in Figures 5 and 6. For the single-pattern conditions, the static and the scanned matrices were similar. The overall correlation between correct responses in static and scanned modes (negative diagonal in the confusion matrices) was .89. Confusion matrices were also generated for the various nontarget conditions. The correlations between static and scanned modes were lower than those in the single-pattern condition. To see the overall effect of nontargets, two confusion matrices were generated, one for the scanned patterns at SOAs of +156 and −156 msec for both neutral and letter nontargets and one for static patterns at SOAs of +100 and −100 msec for both neutral and letter nontargets. The correlation between these two matrices was .74, somewhat lower than that for the single-pattern conditions. Part of the reason for this lower correlation is the nature of the spatial patterns, letters, and the mode of pattern generation. In an earlier study (Craig, 1980), it

Table 3
Decline in Percentage Correct

SOA (msec)	Letter Nontarget	Neutral
	Static	
−100	19.1	13.6
+100	27.1	23.0
	Scan	
−156	26.5	23.3
+156	29.8	24.5

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	*num*
A	73	•	•	•	•	•	2	1	•	2	2	•	•	2	•	•	•	1	1	•	•	1	•	13	•	2	92
B	•	33	9	3	18	•	3	2	•	•	1	3	1	•	3	4	1	13	2	•	1	•	•	1	1	1	103
C	•	•	68	15	•	2	2	•	•	•	•	1	•	•	9	1	1	1	1	•	1	•	•	•	•	•	128
D	•	•	11	50	•	•	3	•	•	2	•	•	•	•	22	1	5	•	•	•	5	•	1	•	•	•	101
E	•	3	•	3	81	7	•	•	•	•	•	2	•	•	•	1	•	1	•	•	•	•	1	•	•	•	79
F	•	•	•	•	•	91	•	•	•	•	1	•	1	•	•	6	•	•	•	•	•	•	•	•	•	1	106
G	•	6	9	17	7	3	27	1	1	1	•	•	•	1	9	2	4	6	•	•	2	1	2	2	•	•	98
H	1	2	•	2	•	2	•	57	•	2	2	•	2	8	•	•	•	•	3	•	7	3	6	2	•	2	91
I	•	•	•	•	•	•	•	•	96	1	•	•	•	•	•	•	•	•	•	2	1	•	•	•	•	•	113
J	•	•	•	•	•	•	•	1	•	94	•	•	•	•	•	•	•	•	•	•	•	1	•	•	1	3	96
K	1	•	1	•	•	•	1	1	•	•	56	2	•	2	•	•	•	1	•	•	•	•	2	27	•	6	100
L	•	•	•	•	•	•	•	•	•	•	1	99	•	•	•	•	•	•	•	•	•	•	•	•	•	•	111
M	5	3	1	1	•	2	•	12	•	1	3	•	16	8	•	•	•	3	2	•	2	7	25	1	3	4	85
N	•	•	•	•	•	2	•	19	•	•	6	1	10	31	•	•	•	2	1	1	5	8	11	1	3	1	96
O	•	•	7	43	•	•	1	•	•	•	•	•	•	•	28	2	9	•	1	•	8	•	•	•	•	1	101
P	•	1	•	1	•	19	•	•	•	•	1	•	1	•	•	65	•	10	•	1	1	•	•	•	1	1	116
Q	•	1	4	22	•	•	4	•	•	2	•	•	•	•	19	2	30	3	1	•	8	1	2	•	•	•	106
R	2	11	1	2	2	4	5	2	•	•	1	•	1	2	1	17	•	38	3	•	1	•	1	4	2	2	102
S	•	8	10	4	12	8	7	•	•	•	1	•	•	•	•	2	•	3	43	•	•	•	•	•	•	2	91
T	•	•	•	•	•	•	•	•	13	1	•	•	•	•	•	•	•	•	•	82	•	•	•	•	4	•	105
U	•	•	7	•	•	•	•	5	•	3	•	1	2	•	1	•	•	•	•	•	71	2	8	•	•	•	95
V	•	1	•	•	•	•	•	•	•	•	•	•	•	2	•	•	•	•	•	•	•	83	1	1	13	•	103
W	2	1	•	1	•	1	•	5	•	•	•	•	13	4	•	•	1	2	2	1	15	10	37	1	2	•	94
X	3	•	1	•	•	•	•	•	•	•	16	1	•	2	•	•	•	•	•	•	•	•	•	61	2	14	108
Y	•	•	•	•	•	•	•	•	•	•	1	•	•	1	•	•	•	•	•	6	•	6	1	1	85	•	120
Z	3	•	2	•	•	1	•	1	•	1	8	•	•	•	•	•	•	1	2	1	•	•	•	7	2	71	109
	3	3	6	4	4	6	2	4	5	4	4	5	2	2	4	4	2	3	2	4	5	5	3	5	5	5	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	

Figure 5. Pooled confusion matrix from 7 subjects, a total of 2,649 trials. The results are from Experiment 1, with static patterns presented singly. The negative diagonal represents correct responses. The frequency of presentation of the letters is shown on the rightmost column. The bottom row shows the overall percentage of responses for each letter.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	*num*
A	56	2	•	1	•	1	2	4	•	2	6	1	•	6	•	1	1	1	1	•	1	5	2	5	1	1	184
B	•	52	1	7	1	1	3	10	•	•	1	•	•	3	1	1	1	9	6	1	2	•	1	•	•	1	173
C	•	•	90	1	•	•	•	•	•	•	•	•	•	•	2	•	•	•	•	•	•	•	•	•	•	2	206
D	1	1	6	54	•	•	1	1	•	•	•	•	•	1	26	•	5	1	1	•	2	•	•	•	1	•	164
E	•	4	2	•	89	2	•	1	•	•	•	•	•	1	•	•	•	•	2	•	•	•	•	•	•	•	188
F	•	•	•	•	1	95	•	•	•	•	•	•	•	•	•	2	•	•	1	•	•	•	•	•	1	•	189
G	2	21	6	8	3	1	27	2	•	•	2	•	1	•	5	1	4	6	10	•	•	•	1	•	1	•	157
H	•	2	•	1	1	•	•	80	•	•	•	•	•	3	2	•	•	•	•	•	9	2	2	•	1	•	169
I	•	•	•	•	•	•	•	•	97	1	•	•	•	•	2	•	•	•	•	•	1	•	•	•	•	•	171
J	•	•	1	•	•	•	•	•	2	87	1	4	•	•	•	•	•	•	•	•	5	•	•	•	•	•	195
K	•	•	3	•	1	1	•	1	•	•	77	1	•	1	•	•	•	•	1	•	•	1	•	7	2	4	189
L	•	•	2	•	•	•	•	•	•	•	•	94	•	•	•	•	•	•	•	•	2	•	•	•	•	•	181
M	3	2	•	1	•	•	•	17	1	1	2	•	18	19	•	•	•	2	•	•	8	5	20	2	•	•	177
N	•	2	•	•	•	•	•	23	•	1	•	•	7	35	•	•	•	1	1	1	9	4	10	5	1	•	170
O	•	1	9	41	•	•	1	1	•	•	•	•	•	•	34	•	5	•	•	•	6	•	•	•	•	•	198
P	•	•	•	1	•	5	•	2	•	•	•	•	•	•	•	88	•	2	2	•	•	•	•	•	•	•	194
Q	1	2	7	15	•	•	1	3	•	•	•	•	•	•	20	2	32	2	2	1	8	•	•	1	1	•	223
R	2	23	•	7	1	•	2	4	•	•	1	•	•	3	•	9	•	39	7	•	•	•	•	1	1	•	218
S	•	12	2	•	17	8	1	•	•	•	2	•	•	•	1	3	•	1	52	•	•	•	•	1	•	•	174
T	•	•	•	•	•	•	•	•	2	2	•	•	•	•	1	•	•	•	•	87	1	•	•	•	4	•	204
U	•	•	1	1	•	•	•	2	4	4	2	•	•	2	•	•	•	•	•	•	83	•	1	•	•	•	179
V	•	•	•	•	•	•	•	1	•	•	3	•	•	1	•	1	•	2	•	1	1	64	1	2	23	•	197
W	1	5	•	1	•	•	1	16	•	•	1	•	12	12	1	2	•	•	1	•	7	6	35	1	•	•	163
X	2	1	•	•	•	•	•	2	•	•	22	•	•	•	1	•	•	•	1	•	•	•	•	51	4	14	194
Y	•	•	•	•	•	2	•	1	•	•	2	•	1	1	•	•	•	1	•	4	•	2	•	1	85	•	174
Z	1	•	3	•	•	1	•	2	1	1	16	•	1	•	•	1	•	2	1	•	•	•	•	16	•	56	168
	3	5	6	5	5	5	2	6	4	4	6	4	1	3	4	5	3	3	3	4	6	4	3	4	5	3	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	

Figure 6. Pooled confusion matrix from 8 subjects, a total of 4,799 trials. The results are from Experiment 2, with scanned patterns presented singly. The negative diagonal represents correct responses. The frequency of presentation of the letters is shown on the rightmost column. The bottom row shows the overall percentage of responses for each letter.

Table 4
Static Mode: Percentages of Responses in the Two-Response Paradigm, 26-msec SOA, With Chance Levels of Performance

	First Response		Second Response					
			Target		Nontarget		Other	
	Result	Chance	Result	Chance	Result	Chance	Result	Chance
Target	13.4	3.8	–	–	12.8	4.0	87.2	96.0
Nontarget	24.5	3.8	8.6	4.0	–	–	91.4	96.0
Other	62.1	92.3	8.9	4.0	15.5	4.0	75.6	92.0

was noted that the scanned mode resulted in certain letters being more affected by a trailing nontarget than were other letters. Specifically, right-hand (R) letters are affected more than symmetrical letters (S). The right-hand letters are B, C, D, E, F, G, K, L, P, Q, and R. The remaining letters, with the exception of J, are symmetrical. The R-letters have information critical for their identification in the trailing edge, in close temporal proximity to the trailing nontarget. For scanned R-letters, there was an 8.6% drop in identification performance from an SOA of −156 msec to one of +156 msec. For scanned S-letters, performance actually improved by 3.8% between the two SOAs. For static letters there should be little or no difference between the effect of a leading versus a trailing nontarget on the two types of letters, and there was not. R-letters showed a 9.8% decline, and S-letters showed a 9.4% decline between the two SOAs.

EXPERIMENT 3

The results from Experiments 1 and 2 demonstrated that subjects respond with the nontarget pattern more often than chance, a result that is consistent with a response competition view of interference; however, the results are also consistent with an alternative view—namely, that the nontarget replaces the representation of the target. With the target eliminated, the subject responds with the only pattern available, the nontarget. In a previous study using static patterns, subjects were required to make two responses on each trial: The first response was the pattern that the subjects thought was most likely to have been the target, and the second response was the next most likely pattern to have been the target (Craig, 1995). It was expected that the first response would be either the target or the nontarget. If subjects had both the target and the nontarget available, and thus, there was evidence for response competition, the probability should be above chance that the second response was either the target or the nontarget pattern, and not simply a random response. If, however, the nontarget replaced the target, the second response would be randomly selected from among the available patterns. The previous results supported a response competition view in that the probability of targets and nontargets as either first or second responses was above chance (Craig, 1995). Experiment 3 used a similar paradigm, requiring subjects to respond twice on each trial, and tested both static and scanned patterns.

Method

Subjects. Seven subjects were tested, 5 women and 2 men, in the static presentation. Six of these subjects, 4 women and 2 men, were tested in the scanned presentation.

Procedure. The procedure was similar to that used in Experiments 1 and 2. On each trial, the subjects received both a target and a nontarget pattern. The two patterns were selected at random from the 26 letters of the alphabet, with the stipulation that the two patterns were not the same. The subjects were required to respond twice on each trial. Their first response represented their best guess as to the target, and their second response represented their second-best guess. The subjects were prevented from making the same response twice. Feedback was provided following the subjects' second response, informing them which target had been presented.

With the static patterns, two SOAs were tested, +26 and +156 msec. With the scanned patterns, a single SOA was tested, +156 msec. Trials were run in 50-trial blocks. Seven blocks were completed in each static session, six blocks in each scanned session. With the static patterns, the two SOAs were tested in alternate blocks. At the beginning of each session, a block of trials was run testing single-pattern performance. The subjects were tested for seven sessions with the static patterns and eight sessions with the scanned patterns.

Results and Discussion

The results are presented in Tables 4, 5, and 6. The first-response results are shown on the left side of each table, and the second-response results are shown on the right side of each table. Looking just at the first response

Table 5
Static Mode: Percentages of Responses in the Two-Response Paradigm, 156-msec SOA, With Chance Levels of Performance

	First Response		Second Response					
			Target		Nontarget		Other	
	Result	Chance	Result	Chance	Result	Chance	Result	Chance
Target	39.7	3.8	–	–	6.8	4.0	93.2	96.0
Nontarget	12.6	3.8	18.0	4.0	–	–	82.0	96.0
Other	47.8	92.3	24.4	4.0	10.0	4.0	65.6	92.0

Table 6
Scanned Mode: Percentages of Responses in the Two-Response Paradigm, 156-msec SOA, With Chance Levels of Performance

	First Response		Second Response					
			Target		Nontarget		Other	
	Result	Chance	Result	Chance	Result	Chance	Result	Chance
Target	32.9	3.8	–	–	5.7	4.0	94.3	96.0
Nontarget	9.1	3.8	21.7	4.0	–	–	78.3	96.0
Other	58.0	92.3	22.3	4.0	6.9	4.0	70.8	92.0

results, these were divided into three types: correct responses and two types of incorrect responses, the nontarget or one of the remaining 24 letters of the alphabet. Table 4 shows, for example, that for a static pattern presented with a nontarget at an SOA of +26 msec, the percentage correct (target responses) is 13.4%, with chance performance being 3.8%, 1 out of 26 letters. As was expected, nontarget responses as first responses are a substantial percentage of the total responses. Similar to the results in Experiment 1, in the static condition with a nontarget presented at an SOA of +26 msec, nontarget responses are even more frequent (24.5%) than target responses (13.4%). At +156 msec in the static mode, the nontarget response rate is more than three times the rate predicted by chance. At +156 msec in the scanned mode, the nontarget rate is more than twice that predicted by chance.

The right sides of each table, the second-response results, present the results that are relevant to the question of whether the nontarget replaces the target or whether the subjects had both the target and the nontarget responses available more often than chance. If the subject's first response was the target, how likely was he or she to respond with the nontarget on the second response? Similarly, if the first response was the nontarget, how likely was it that the second response was the target? The second-response trials were divided into three types, depending on the nature of the first response—specifically, on whether the first response was the target, the nontarget, or one of the other 24 letters of the alphabet. If for static letters at an SOA of +26 msec the first response is the target (a correct response), 12.8% of the second responses are nontarget responses. By chance, one would expect 4%. An examination of the second-response results in Tables 4, 5, and 6 shows that in all cases, for both static and scanned patterns, the subjects were above chance in selecting either the target or the nontarget in preference to one of the other responses. The largest effect in the scanned mode is seen when the subjects' first response was the nontarget. In that case, the target was selected as the second response at a rate of more than five times that predicted by chance. These results support the view that subjects do have available both the target and the nontarget. It appears that response competition is a factor in scanned as well as static patterns and with fairly extensive sets of patterns.

The percentage of trials on which both the target and the nontarget appeared to be available as responses is relatively small. This result is likely due to the low level of correct letter identification performance. If subjects fail to identify the spatial patterns, whether they are targets or nontargets, response competition will not be a factor. In an earlier study with fewer patterns and a higher rate of correct target identification, the percentage of trials on which both the target and the nontarget were given as responses was much higher (Craig, 1995).

EXPERIMENT 4

Experiments 2 and 3 indicate that both masking and response competition interfere with scanned pattern identification, and at levels comparable with that seen with static patterns. The fact that the mode of pattern generation appears to have little effect on response competition may not be surprising. For response competition, it may make little difference how a pattern is generated, as long as the pattern is processed to the point of evoking a response. Response competition is measured by the increase in interference produced by the letter nontarget, as compared with the neutral nontarget (Figures 3 and 4). The amount of response competition is relatively small and, given the overall reduction in performance produced by the nontarget (Figures 3 and 4), there are likely to be other factors contributing to the interference. Two such factors, typically considered under the rubric of masking, are temporal integration and feature displacement. These factors are thought to modify the representation of the target pattern at a fairly early stage of processing. It may be that the mode of pattern generation affects these processes.

Previous studies with static patterns had shown that temporal integration was a major factor in masking (Evans & Craig, 1986). To examine temporal integration, we modified and tested a set of patterns that had been used previously in a study with static patterns. The patterns are shown in Figure 7. A target and a nontarget were presented on each trial, and the subject's task was to identify the target and ignore the nontarget. With the static presentation in the earlier study, it was found that many of the errors indicated that the subjects were trying to respond with the composite of two of the simpler patterns. A composite response is an indication that the

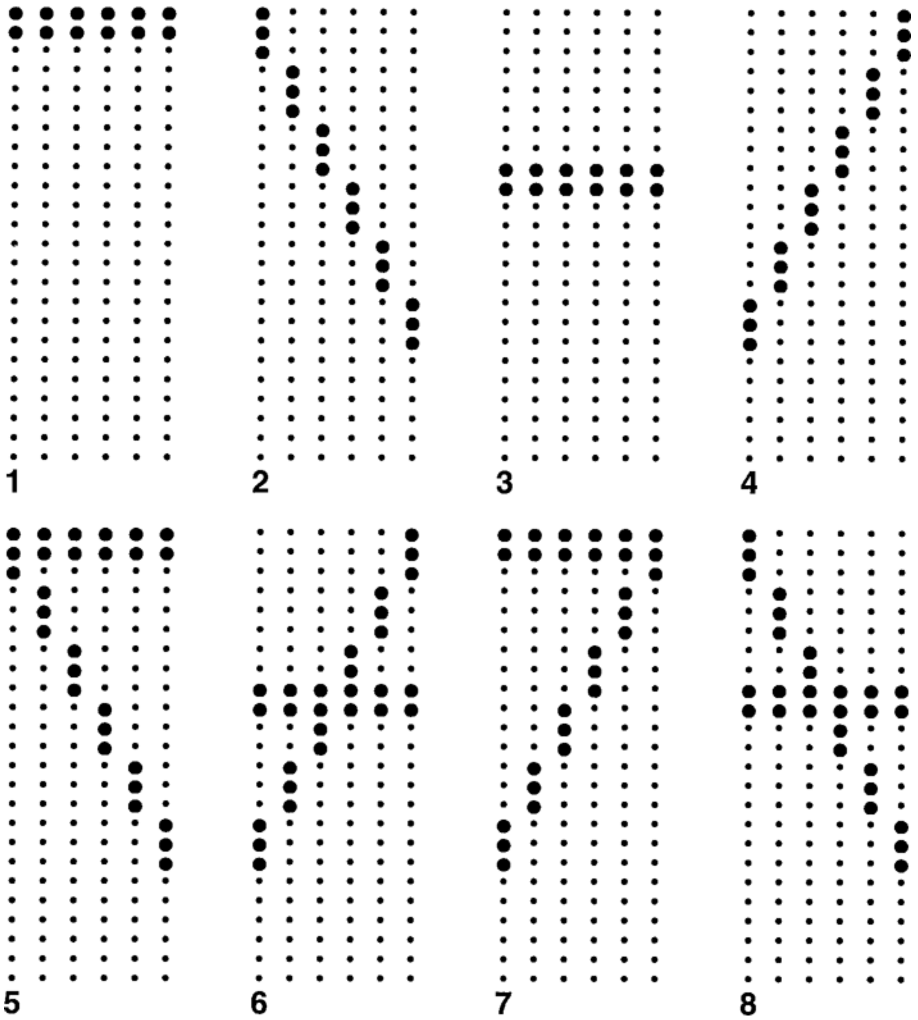

Figure 7. Representations of the patterns used in the integration task in Experiment 4.

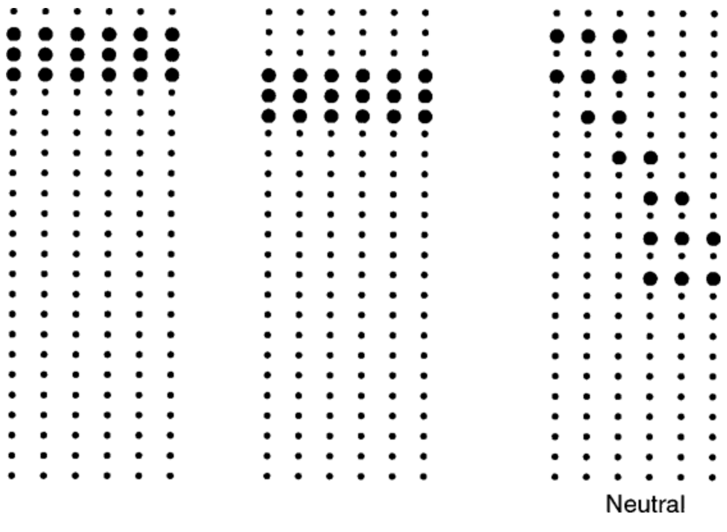

Figure 8. Representations of two of the patterns and the neutral pattern used in the feature displacement task in Experiment 4.

two patterns were being integrated into a single pattern. For example, if the target were Pattern 1 and the nontarget Pattern 2, subjects might respond with Pattern 5, a composite of the two patterns.

The second factor, displacement of features, was previously observed with a set of static patterns that had to be identified simply on the basis of their spatial location on the fingerpad. Nontarget stimuli presented in close temporal proximity to target patterns produced significant mislocalizations of the target patterns (Craig, 1989). A pattern set, similar to that tested primarily with static patterns, was used to measure the effect of a nontarget on mislocalization of scanned patterns.

Method

Subjects. In the integration task with static patterns, 7 subjects were tested, 5 women and 2 men. In the same task with scanned patterns, 6 subjects were tested, 4 women and 2 men. In the displacement task (scanned), 5 subjects, 3 women and 2 men, were tested.

Stimuli. The patterns used in the integration task are shown in Figure 7. In the displacement task, there were six target patterns. The patterns differed from one another by their location along the proximal/distal axis of the finger. Samples of these patterns are shown in Figure 8. The patterns were presented between rows 2 and 14 on the display. The neutral nontarget pattern is also shown in Figure 8. Like the target patterns, it consisted of 18 tactors.

Procedure. In both the integration and the displacement tasks, the pattern duration was set at 52 msec. In the integration task, two SOAs were tested, +52 and −52 msec. For the displacement task, an SOA of +52 msec was tested. In both tasks, the subjects attempted to identify the target pattern and received trial-by-trial feedback. For the integration task, a testing session consisted of seven blocks of 50 trials each. One block of trials tested a single-pattern condition. In the remaining six blocks of trials, the nontarget was presented either at an SOA of +52 msec throughout the block of trials or at −52 msec. In the static mode, each subject was tested for 10 sessions. In the scanned mode, each subject was tested for 11 sessions.

For the displacement task, two types of nontargets were tested: a neutral pattern (Figure 8) and a pattern selected from the set of target patterns. The earlier study on displacement did not test the effect of a neutral pattern. In a block of trials, both types of nontargets were tested; one third of the trials tested the neutral nontarget, and two thirds tested the pattern nontarget. There were six blocks of 50 trials each per session, with the first block testing a single-pattern condition and the remaining blocks testing the effect of the nontarget. The subjects were tested for 10 sessions.

Table 7
Percentage of Responses to Pairs of Patterns That Form Composites

Pairs	Target	Nontarget	Composite	Other
		Static		
1–2	64.4	13.6	14.4	7.6
2–3	57.1	29.0	4.7	9.2
3–4	56.8	25.6	6.9	10.7
4–1	55.9	16.4	15.3	12.4
		Scanned		
1–2	53.6	19.9	13.6	12.8
2–3	42.8	29.3	5.3	22.6
3–4	44.7	29.5	15.4	10.4
4–1	45.2	15.5	10.5	28.8

Table 8
Percentages of Responses in Temporal Integration

	Static		Scanned	
Pairs	Composite	Other	Composite	Other
1–2	65.5	34.5	51.5	48.5
2–3	33.8	66.2	18.9	81.1
3–4	39.2	60.8	59.7	40.3
4–1	55.2	44.8	26.7	73.3
Mean	48.4	51.6	39.2	60.8

Results and Discussion

The integration data were similar at the two SOAs tested (+52 and −52 msec), and the data were combined. The results were analyzed to determine the number of composite responses that were made. There were four such pairs: Patterns 1 and 2 formed Composite Pattern 5, Patterns 1 and 4 formed Composite Pattern 7, Patterns 2 and 3 formed Composite Pattern 8, Patterns 3 and 4 formed Composite Pattern 6. Trials on which these pairs of patterns were presented were analyzed to determine the percentage of correct responses, nontarget responses, composite responses, and *other* responses. *Other* responses were neither correct nor a nontarget nor a composite response but corresponded to one of the six remaining patterns. Table 7 shows how subjects responded when presented with pairs of patterns that could form composites. Single-pattern performance for the static patterns was 87% and for the scanned patterns was 76%. As was expected, the subjects frequently responded with the nontarget, and in fact, under these conditions, nontarget responses were generally more frequent than composite responses.

To get a better estimate of the extent to which composite patterns are formed, we analyzed the data in the following way: On those trials in which the subjects did not respond with either the target or the nontarget, how likely were they to respond with a composite pattern, rather than with one of the remaining patterns? After removing the target and nontarget responses, the data were analyzed to determine what percentage of the remaining trials were composite responses versus *other* responses. After removing the target and nontarget responses, there were six possible responses. In other words, by chance the subjects should respond with a composite pattern on 17% of the trials. The percentages of trials on which subjects responded with a composite or with one of the other patterns are shown in Table 8. The overall percentage of composite responses for both scanned and static patterns is more than twice what would be expected by chance. Temporal integration appears to be a factor with both scanned and static modes of pattern generation.

The results from the displacement task showed that, as with static patterns, a scanned nontarget also interferes in localization. The overall percentage correct in the absence of a nontarget was 63.3%, in the presence of the neutral nontarget 50.7%, and in the presence of nontargets similar to the target 46.1%. Both the neutral nontarget and the nontargets that were similar to the target produced significant declines in performance (t test, $p < .05$ and $p < .01$, respectively). The evidence for displacement and the level of performance that results from the presentation of the nontarget and these scanned patterns is similar to results obtained earlier with static patterns (Craig, 1989).

The data were analyzed to see whether the distance between the target and the nontarget patterns affected the amount of interference. Specifically, the results when the target pattern was presented at the top of the array were analyzed to see whether the amount of interference changed depending on the location of the nontarget. The effects of nontargets located adjacent to the target site, in the middle of the array, or at the bottom of the array were examined. A similar analysis was carried out for the condition in which the target pattern was at the bottom of the array and the nontarget was either adjacent to the target, in the middle of the array, or at the top of the array. The results did not reveal any obvious effect of distance on the amount of interference.

GENERAL DISCUSSION

The results can be easily summarized: Nontarget patterns have similar effects on target identification whether the patterns are generated in a static or a scanned mode. The nature of the temporal interaction between target and nontarget patterns is not dependent on the mode of pattern generation. Thus, we can have two spatial patterns, one static, one scanned, which feel quite different from one another and, when presented at comparable brief durations, are quite different in identifiability; yet, when equated for identifiability, they interact with successively presented patterns in very similar ways. Within limits, the results from previous studies with static patterns may be generalized to scanned patterns.

The present results suggest how successive patterns are processed in an identification task. It may be that the skin treats each of the successively presented patterns as separate events, and it may make little difference how those events are generated. In the present study, the subjects received training in identifying target patterns. As the subjects learned the patterns, they developed an internal representation of each pattern. A correct identification required the subjects to match the incoming stimulus pattern with the stored representation. The stimulus pattern “A” accesses the representation for the letter “A” whatever the mode of generation. It was expected that in the temporal integration task (Experiment 4), the mode of pattern generation might produce a difference in the results. As with the letters, the subjects received training in identifying the patterns, learning to assign a number to a particular pattern. This training may result in subjects’ treating these simpler patterns in the same way as they do letters. If the elements making up a complex pattern are received within the temporal integration window of the skin, the elements may simply access the representation for that pattern. Only additional measurement could answer the question of whether generating one of the two simpler patterns in the scanned mode and one in the static mode would also produce temporal integration. According to this view, temporal interactions similar to those obtained in the present study should be obtained if the successive patterns are generated in two different modes.

Previous studies had shown that, at brief durations, the static mode produced better single-pattern identification performance than did the scanned mode (Craig, 1980, 1981). A similar result was found in the present study: The pilot work with scanned patterns at briefer durations (Experiment 2) produced identification performance considerably lower than that produced with static patterns. The present results also suggest that there is little or no advantage to using scanned patterns in tasks involving pattern identification in the presence of nontargets. Vega-Bermudez, Johnson, and Hsiao (1991) also found that allowing subjects to move their fingers across raised letters produced results similar to a static presentation of the letter. In the present study, the scanned mode did not lead to superior performance and, in the case of letter identification, required durations six times longer than the static patterns. On the other hand, in most tasks involving pattern identification, the target pattern is presented in the context of other, nontarget patterns. A static mode permits briefer patterns to be used, and thus, one could present more patterns in the same amount of time. The tradeoff is that as patterns are presented more closely together in time, there is more mutual interference. In such cases, the advantage for the static mode may be minimized.

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