Perception & Psychophysics
1982, 31 (6), 523-529

Vibrotactile masking: A comparison of energy and pattern maskers

JAMES C. CRAIG
Indiana University, Bloomington, Indiana

Subjects were required to identify vibrotactile patterns presented to their fingertips. The patterns, letters of the alphabet, were presented singly or in the presence of other vibrotactile masking stimuli. Two types of masking stimuli were used: an energy masker and a pattern masker. The effectiveness of these two types of maskers in interfering with letter recognition was tested, using them as forward and as backward maskers and presenting them at several different levels of intensity. The results showed more masking by the pattern masker, more backward than forward masking, and more masking as intensity increased. In addition, compared with the energy masker, the pattern masker showed both a greater difference between forward and backward masking and a greater increase in masking as masker intensity increased. The results are discussed in terms of a two-factor model of vibrotactile masking.

Both as a tool to investigate the processing of vibrotactile stimuli and as a phenomenon of importance in its own right, masking has received considerable experimental attention. Early investigations with tactile stimuli concentrated on the effect that a masking stimulus had on the detection of a target stimulus (Craig, 1978; Gescheider, Herman, & Phillips, 1970; Gilson, 1968, 1969; Sherrick, 1964; Snyder, 1977; Verrillo & Capraro, 1975). More recently, studies have also been concerned with examining how pattern identification is affected by masking stimuli (Craig, 1976, 1977, 1978, 1980; Kirman, 1973; Loomis & Apkarian-Stielau, 1976; Schindler & Knapp, 1976). In these latter studies, such variables as temporal and spatial separation between target and masker, individual differences among subjects, the mode of generating the target and masking stimuli, and the intensity of the masking stimulus have been examined.

Several parallels between vibrotactile recognition masking and visual masking have emerged from these studies. For example, consistent with studies of visual masking, there is considerably more backward than forward masking with vibrotactile stimuli (Craig, 1976), and the time course of forward and backward masking for the two modalities is similar (Craig, 1976, 1978, 1980; Spencer & Shuntich, 1970). Also, the tactile equivalent of a metacontrast paradigm produces results similar to those found in studies of visual metacontrast (Weisenberger & Craig, 1982).

In studies of visual pattern recognition, considerable importance has been attached to the kind of stimulus used as a masker. Results obtained when a visual target is masked by a random noise masker are different from those obtained when it is masked by a pattern masker (Breitmeyer & Ganz, 1976; Massaro, 1975; Turvey, 1973). The differences in masking functions obtained with different types of maskers have become important in theoretical accounts of pattern recognition. Many of these theoretical accounts hold that temporal masking functions result from two processes: integration and interruption. Integration is thought to depend more upon the energy relations between the target and mask, whereas interruption depends more upon the features held in common between the target and mask (Breitmeyer & Ganz, 1976; Massaro, 1975). If integration were primarily responsible for a masking function, the function should be symmetrical; that is, there should be equal amounts of forward and backward masking. Interruption increases the amount of backward masking resulting in U-shaped masking functions (Massaro, 1975).

Many of the theoretical accounts of the visual results do not necessarily have to be limited to the visual modality. It may be useful to see to what extent the theories of visual processing can be generalized to another modality, such as the skin, that is also capable of processing spatially extended stimuli. Even if it is argued that the dissimilarities between the two modalities are such that one should not expect visual theories to account for tactile results, it is still important to examine types of vibrotactile maskers. The same motivation that led to undertaking the visual studies would lead to undertaking similar studies with tactile stimuli, viz., to help formulate an adequate theory of cutaneous pattern per-

This research was supported by Grant NS-09783 from the National Institutes of Health. The author wishes to thank Roger Rhodes for his assistance in conducting these experiments. The author's address is: Department of Psychology, Indiana University, Bloomington, Indiana 47401.

  0031-5117/82/060523-07$00.95/0

ception and to see to what extent recognition masking depends more upon feature similarity between target and mask rather than the signal-to-noise ratio.

Several previous studies have produced results relevant to the question of the nature of the tactile masking stimulus. These studies generated vibrotactile patterns using the tactile array of the Optacon, a reading aid for the blind. This array consists of 144 pins arranged in a 6 column × 24 row matrix that fits against the user's index fingertip. In one study, the masking stimulus was generated by passing the camera of the Optacon, which registers and transmits optical images, over a black rectangle to create a pattern of vibration that moved across the top 18 rows of the tactile display. A stimulus of this type, which consists of turning on all the pins in the area of the array on which the target is presented, can be referred to as an "energy" masker. One masker was presented just before a target letter, serving as a forward masker, and one was presented just after the target, serving as a backward masker. The effectiveness of this pair of maskers in interfering with the recognition of the target was compared with the effectiveness of a pair of letters used as forward and backward maskers. Although considerable interference was produced, the results showed no difference in the amount of masking produced by the two types of maskers (Craig, 1976).

A second study compared the effectiveness of a letter and a filled rectangle when each was used as a backward masker alone. Again, similar amounts of masking were produced by the two types of maskers. In this same study, it was also demonstrated that as the intensity of a masker was increased, the amount of masking increased as well (Craig, 1978). In both studies that compared directly a rectangular with a letter masker, the masker produced by the rectangle was composed of 108 pins (the top 18 rows and all 6 columns of the array), whereas the letters serving as maskers were composed of an average of 41 pins. It is likely that if the number of pins in the rectangle masker were reduced, the amount of masking would also be reduced. Thus, one conclusion from these measurements is that there might be some masking effect produced by the organization of the masker itself; that is, with number of pins equated, a pattern masker might produce greater interference in letter recognition than an energy masker.

In these studies, the maskers and targets were generated in what is termed the "scan" mode; that is, the pattern enters on the right side of the array, moves across the array, and exits on the left side. This mode produces relatively poor letter recognition unless patterns are displayed for long periods of time. The total time for displaying letters in the previous studies ranged from 150 to 300 msec. A static mode of presenting letters, in which all elements of the letter are turned on simultaneously, has been shown to produce much better letter recognition at brief durations (Craig, 1980, 1981). For this reason, and because it permits a more precise definition and control of stimulus onset and offset, the static mode was chosen for the present experiment.

The experiment compared the relative effectiveness of pattern masks and energy masks in interfering with letter recognition. Both types of maskers were used as forward and backward maskers and presented at several levels of intensity. Predictions based on results from both visual and vibrotactile studies are that (1) the pattern masker should produce more masking than the energy masker; (2) the difference between the two types of maskers should be greater when both are used as backward maskers than when both are used as forward maskers; and (3) as stimulus intensity is increased, both the difference between forward and backward maskers and the difference between pattern and energy maskers should decrease.

METHOD

Subjects

The subjects, three women and one man, were hourly employees of the laboratory. All subjects passed a screening test (Craig, 1980) and received several weeks of training in identifying tactile patterns before formal data collection began.

Apparatus

The apparatus consisted of a PDP-11/34 computer interfaced with the tactile display of the Optacon. The tactile display is 1.1 cm wide × 2.7 cm high and is composed of 144 pins arranged in a 6 column × 24 row array. Each pin in the 6 × 24 array is addressed individually and vibrates at 230 Hz. Further details of the apparatus can be found in Craig (1980).

Procedure

The procedure was similar to one used previously by Craig (1980). Subjects were presented sans-serif uppercase letters of the alphabet on the Optacon display. The letters were presented on the top 18 rows of the display and, with the exception of I and J, occupied all six columns, an area of 1.1 × 2.0 cm. The subjects placed their left index fingertips on the tactile array. A trial was initiated by the subject's pressing a key to receive a cue stimulus (the letter I presented for 26 msec). One second later, the subject received a randomly selected letter of the alphabet (also presented for 26 msec). Responses were made by pressing one of the keys on the keyboard and were followed by immediate visual feedback on a CRT display.

When a masking stimulus was presented, it either preceded or followed the target letters by an interval (ISI) of 4 msec. The masking stimulus was either an energy masker that was generated by turning on all pins in the top 18 rows of the display or a pattern masker. The pattern masker was created by dividing the top 18 rows of the display into six equal-sized segments, 6 rows high and 3 columns wide, and by randomly assigning to each segment a part of a letter, such as a vertical line, horizontal line, curved line, and so forth. There were 26 different pattern maskers, with the number of pins making up each masker ranging from 34 to 49. However, the average number of pins in the pattern maskers and the target letters was the same (41). It was also observed that varying the number of pins activated on the tactile display produced no perceptible change in the intensity of a single pin in the display. On each trial involving a pattern masker, one of the 26 maskers was randomly selected to be paired with a target letter.

The apparatus did not permit independent control of the intensity of vibration by changing the amplitude of vibration. To vary the effective intensity of vibration, we took advantage of the fact that the skin integrates energy over brief temporal intervals. Increasing the duration of vibrotactile signals both lowers the absolute threshold (Gescheider, 1976; Green, 1976; Verrillo, 1965) and increases the perceived magnitude of the stimulus (Berglund, Berglund, & Ekman, 1967). To vary the effective intensity of the masker, masking stimuli were presented for three different durations, 13, 22, and 52 msec. A matching procedure showed that increasing masker duration from 13 to 52 msec resulted in an approximate 12-dB increase in the setting of a matching vibrator. A magnitude-estimation task produced just over a threefold increase in magnitude estimations for the same increase in masker duration. These two different ways of estimating the increases in perceived intensity of the masker as duration was increased apparently produce similar results by the following logic: If the slope of the function relating amplitude (the first measure used) to magnitude estimations were 1, then a 12-dB increase would be expected to produce a fourfold increase in magnitude estimations (the second measure used). Since it is generally agreed that the slope is less than one (Stevens, 1968; Verrillo, 1972), finding a threefold increase is consistent with a 12-dB change in amplitude.

Trials were grouped in 30-trial blocks, with each block testing either single-letter recognition (no masking stimulus) or one of the 12 masking conditions (a pattern or energy masker at an ISI of either +4 msec or −4 msec, at one of three masker durations). During an experimental session, the subject was tested first with one of the two types of maskers at all three durations, at both ISIs, and in the no-masker condition, and then with the other type of masker. The order of the conditions was reversed for the next session. Within each condition, the order of presentation of masker durations and ISIs was determined randomly.

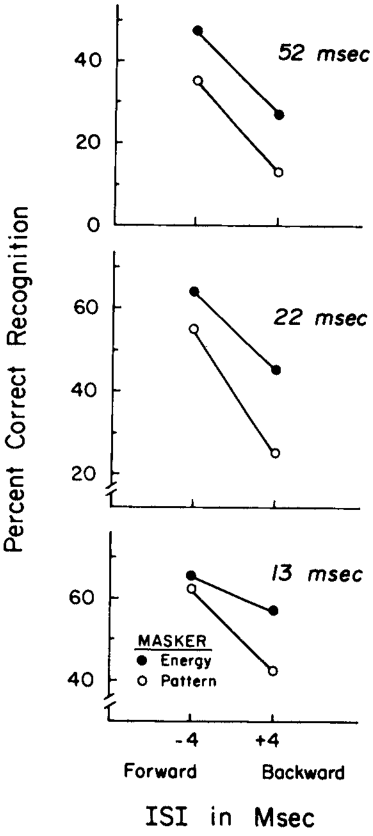

Figure 1. Percent correct letter recognition as a function of the ISI between target and masker. Each panel represents a different duration of masker.

RESULTS AND DISCUSSION

The data shown in Figure 1 represent the results from 840 trials, 210 trials from each of the four subjects. The single-letter condition, no masker, is based on 1,680 trials, and produced 74% correct responses. Each panel represents a different duration of masker. The standard error of the mean was computed for each point by averaging across 30-trial blocks. The standard errors ranged from 1.5% to 3% and did not vary significantly as a function of masker duration or masker type. An analysis of variance showed significant main effects for the type of masker, for ISI (forward vs. backward masking), and for the duration of the masker [$F(1,3) = 11.32$, $p < .05$; $F(1,3) = 20.42$, $p < .05$; $F(2,6) = 94.92$, $p < .01$, respectively]. Significant interactions were found for masker type × ISI and ISI × duration of masker [$F(1,3) = 33.50$, $p < .05$; $F(2,6) = 5.83$, $p < .05$, respectively].

A pattern mask interferes more effectively with letter recognition than does an energy mask at every masker duration tested, and in both forward and backward masking conditions. The average difference in percent correct for the two types of maskers was 12%. The relative effectiveness of the pattern masker may be even greater than is immediately apparent. The energy masker comprises 108 pins, whereas the average pattern masker comprises 41 pins. Thus, it is to be expected that, at equal durations, the energy masker would feel more intense than the pattern masker (Cholewiak, 1979; Green, Note 1). Such was the case. Subjects felt that an energy masker presented for 13 msec was approximately equal to a pattern masker presented for 22 msec. When the amount of masking is compared across these two masker durations, the pattern masker (at 22 msec) produces an average of 21% more masking than the energy masker (at 13 msec).

The question that might be asked is: Was the greater masking produced by the pattern maskers less a result of features held in common than of the fact that there were a number of different pattern maskers (26) but only a single energy masker? There are two possible responses to this question: First, it might be expected that as subjects had more and more exposure to the pattern maskers, the maskers would begin to produce less masking and the difference between energy and pattern maskers might decline over trials. It did not. There was neither a significant main effect of trial repetitions nor a significant interaction between trial repetitions and kind of masker. There was some indication of the reverse trend, that is, a tendency toward less interference by the energy masker on the final blocks of trials as compared with the initial blocks of trials. Second, some additional measurements were made with a single pattern mask to study its effectiveness with repeated use. The results from these measurements are shown in Table 1. Each entry represents the results from 2,160 trials, 540 from each of four subjects. The measurements were made with a 26-msec target and mask. The average difference in performance between a forward energy mask and a forward pattern mask is 5%; the difference for backward maskers is 13%. These values should be compared with the average difference of 8% and 16% for forward and backward maskers, respectively, when 26 different pattern maskers were used. There may be a slight increase in the amount of masking attributable to the use of 26 patterns as opposed to a single pattern, but a clear difference remains between pattern and energy masks. Again, this difference would presumably be even greater if the intensity of the two types of maskers had been equated.

The data in Table 1 were analyzed for changes in performance over trials. Because there was only a single pattern mask, subjects might learn to separate the features in the masker from those in the target. Even though each subject received over 1,000 trials with the same pattern mask, there was virtually no change in performance between the first half and the last half of the trials.

Finding more masking produced by a pattern masker than an energy masker and more backward than forward masking is consistent with previous visual and vibrotactile results. Also, consistent with results of visual studies is the finding that the difference in effectiveness between a pattern and energy masker is more apparent with backward than with forward maskers. As noted above, there is a significant interaction between the type of masker and ISI. The results suggest that energy masks produce more symmetrical masking functions, whereas pattern masks produce more U-shaped functions, that is, a greater difference between backward and forward masking.

The results also show that increasing pattern duration, and thus intensity, produces a significant increase in the amount of masking for both pattern and energy maskers. In order to see this effect more clearly, the data presented in Figure 1 were replotted in Figure 2.

Although the effect of intensity is in general agreement with visual results, the specific effects are in disagreement. For example, results from visual masking studies have shown that increasing the intensity

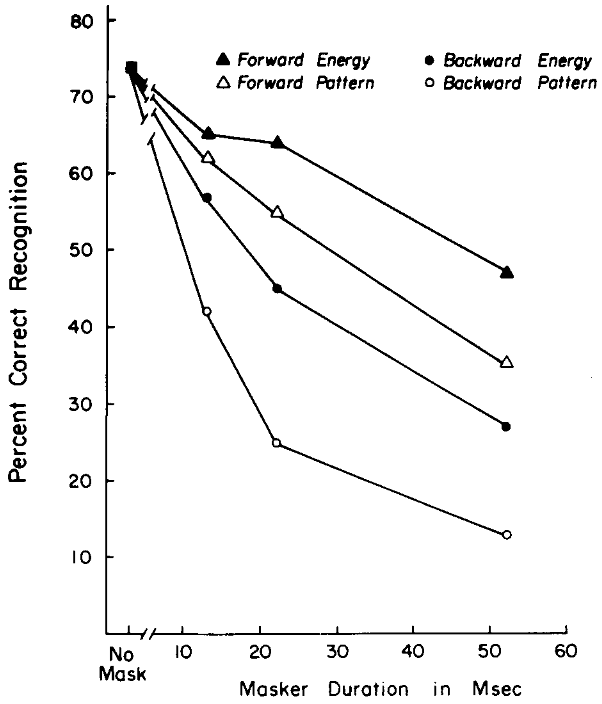

Figure 2. Data from Figure 1 replotted to show percent correct letter recognition as a function of the duration of the masker. The parameters are the ISI (forward vs. backward) and the type of masker (energy vs. pattern).

of the masking stimulus has a greater effect on forward maskers than on backward maskers (Breitmeyer & Ganz, 1976; Spencer & Shuntich, 1970). In the present study, the average decrease in percent correct as masker duration increased from 13 to 52 msec for forward maskers was 22.5%; the comparable decrease for backward maskers was greater, 29.5%. There was a significant interaction between masker duration and ISI. Also, in accordance with visual results (Breitmeyer & Ganz, 1976), increasing the intensity of the masker would be expected to produce a relatively greater effect on the energy mask. Again, the results are in the opposite direction. As masker duration increased from 13 to 52 msec, the average decrease in percent correct for the energy maskers was 24%; the comparable decrease for the pattern maskers was 28%. However, there is no significant interaction between masker duration and masker type.

Setting aside the visual results for a moment, some previous measures of detection masking using vibrotactile stimuli have shown more forward than backward masking (Craig, 1978; Sherrick, 1964). Presumably, in the detection of simple sinusoids, the relative energies in the test and masking stimuli (the signal-to-noise ratio) are the most important variables. If an energy masker is reducing the signal-to-noise ratio in the present experiment in much the same way that

Table 1
Percent Correct Letter Recognition

No Mask	Type of Masker	ISI Forward	ISI Backward
78.3%	Energy	57.2%	41.5%
	Pattern	51.9%	28.7%

a masking stimulus affects performance in a detection masking paradigm, then one might expect that an energy mask would produce more forward than backward recognition masking, a result not obtained in any previous measures (Craig, 1976, 1978, 1980) or in the present study.

To consider some of the results that were not predicted by earlier studies, it is necessary to be explicit about the effect that masking stimuli may have on pattern recognition. First, maskers probably reduce the signal-to-noise ratio of the target, a reduction that might decrease the perceived intensity of the pattern. The effect of reducing the signal-to-noise ratio of a pattern should be relatively independent of the structure of the masking stimulus, yet it should nevertheless reduce the recognizability of the pattern. Previous work with pattern identification showed that reducing the intensity of static patterns did indeed reduce their recognizability (Craig, 1980).

Second, the features of a masker probably interfere with the perception of features in a target. Given that subjects attempt to identify the patterns by analyzing the features of the letters, a masker may reduce letter recognition because its features distort or are confused with features in the target. It would therefore be expected that a pattern masker would produce greater masking than an energy masker. It might also be expected that increasing the intensity of a pattern masker would not produce much of an increase in masking, certainly a smaller increase than would be expected from an energy masker. A consideration of the following result might help explain why, in the present case, the reverse was true. Previous measurements have shown that pattern recognition is a direct function of pattern duration. For patterns presented in the static mode, as were those in the present study, increasing the duration from 4 to 52 msec produced a change from 40% to over 70% correct letter recognition (out of 26 letters) (Craig, 1980). If it is assumed that vibrotactile patterns are recognized by analyzing the features of the patterns, then the improvement in letter recognition with increasing duration is apt to be the result of features of these letters being perceived more clearly. In the present study, as duration increases, the features in the pattern maskers are presumably also being perceived more clearly and thus interfere more with the features of the target letters.

Accordingly, a masker may interfere in pattern recognition because of either or both of these factors, reducing the signal-to-noise ratio or altering or distorting the perception of its features. This two-factor theory of masking implies that increasing the intensity of both types of maskers used in the present study causes increased interference in pattern recognition because of changes in both the perceived intensity of the target and in the perceived clarity of the features of the maskers. The relative change in the two factors is likely to depend upon the nature of the maskers, that is, number of features, number of pins, duration, etc.

A two-factor theory may help explain why the energy masker produces more backward than forward masking: It acts, not only to decrease the signal-to-noise ratio of the target, but also to produce masking, because it, like the pattern mask, shares features with the target letter. The energy mask, being a filled rectangle, has edges and angles that might interfere with the extraction of similar features in the target. Considered in this way, the energy masker is not qualitatively different from the pattern masker but simply has fewer features to interfere with the target. The energy masker in the present study would be viewed as occupying some position between a pure pattern masker and a pure energy masker.

Even though the two types of maskers may not differ qualitatively, they do differ quantitatively. It might be expected that the two types of maskers would affect the individual target letters differentially. Stimulus-response confusion matrices were constructed for the single-letter (no-mask) condition, the pattern mask condition, and the energy mask condition. Product-moment correlations were computed on the percentage of correct responses, following an arc-sine transform, between the single-letter and pattern mask condition (+.92) and the single-letter and energy mask condition (+.93). The type of masker seems to make only a slight difference in the correlation. The size of the effect may not be too surprising when one considers that 26 different pattern maskers were used. Averaging across the 26 maskers might obscure the effect that particular pattern maskers have on particular target letters. Calculating product moment correlations on the data in Table 1, in which only one pattern mask was used, might reveal a greater differential effect of the type of masker. The product-moment correlation between the single-letter and energy mask condition was +.93 and between the single-letter and the pattern mask condition, +.69. A test of the significance of the difference between dependent correlation coefficients (Cohen & Cohen, 1975) showed a significant decrease in the size of the correlation ($p < .01$). This decrease in correlation indicates that a pattern mask may interfere with the perception of certain target letters to a greater degree than the energy mask, which tends to reduce performance on all target letters more uniformly.

The major change in the rank orderings between the single-letter and pattern mask conditions was in three letters, C, E, and K. All three of the letters showed a large improvement in their rankings in the presence of the single pattern masker. The improvement was not the result of an improvement in absolute level of performance; rather, the three letters showed relatively less masking than the other letters.

Some recent work in our laboratory showed that two patterns serving as maskers have differential effects on targets, depending upon the judged similarity of the particular masker to the target. Maskers judged to be similar to the target produced less interference than those judged to be dissimilar (Weisenberger, 1981). Thus, we might expect the particular pattern mask we used to be judged to be similar to the letters C, E, and K.

This two-factor theory of masking, and the distinction between performance limitations resulting from reduced signal-to-noise ratios and limitations resulting from interactions between features in the target and features in the masking stimulus suggest the distinction made by Garner (1974) between process and state limitations. As an example of a state limitation, Garner discusses the failure of subjects to identify clearly written letters because the contrast is poor or the duration of presentation is brief. As an example of process limitations, Garner points to the inability of subjects to identify which of two letters has been presented when the letters were carelessly written. Paralleling Garner's distinctions are those made by Norman and Bobrow (1975), who refer to signal data-limited processes and memory data-limited processes. In a signal data-limited process (similar to Garner's state limitation), the level of performance is determined primarily by the signal-to-noise ratio. In a memory data-limited process, similar to Garner's process limitation, the signal is clearly suprathreshold and perceptible; performance is limited because the representation of the stimulus in memory is imperfect. The first factor proposed to account for the present results, the reduction in signal-to-noise ratio by a vibrotactile masker, is clearly an example of a state limitation (or a signal data-limited process). The second factor, the distortion of features, may be considered an example of a process limitation (or memory data-limited process). Such a distinction implies that certain manipulations will be more effective if one or the other limitation is operative. For example, reducing the number of targets, which effectively reduces the memory load, should produce greater improvements with a pattern masker than with an energy masker. Additional experiments might reduce the number of both the targets and maskers to see if subjects could learn the altered features produced by the several combinations of targets and pattern maskers. However, one indication that Garner's state-process distinction may not be applicable to the present results is the finding that, as noted before, considerable training with a single pattern masker did not produce substantial improvement in performance. However, the large number of targets used in the present study, 26, may have provided too formidable a task to be a fair test of the distinction.

Although a two-factor theory of masking appears to be useful in forming a coherent view of masking and pattern recognition, it is troublesome that different types of maskers depend differentially on the two factors, and that the two factors respond similarly, although not identically, to intensity changes. Some previous results might help separate the two factors. Craig (1980, 1981) found that, when pattern duration for static patterns was increased beyond about 50 msec, there was no longer an increase in pattern recognition, even though perceived intensity continued to increase. Assuming that this failure to find increases in pattern recognition indicates that, beyond a certain point, increasing intensity no longer improves feature perception, the effectiveness of pattern maskers of longer durations than those used in the present study could be compared to that of energy maskers. Increasing pattern masker duration at longer durations should increase masking solely because of increases in the energy component of the masker. In other words, the change in masking with increasing duration for a pattern masker should be greater than that for an energy masker at briefer durations, but the same at longer durations.

Increasing the duration of vibrotactile maskers may, however, not be the best way to increase the intensity of the masker, particularly at longer durations. Beyond about 50 msec, the rate of increase in perceived intensity with greater durations lessens, making it more difficult to see the effects of intensity. Also, increasing the duration of the masker not only changes intensity, but also changes the temporal relationship between the target and masker, particularly the time between the onset of the masker and target (Craig, Note 2). The further study of intensity and type of masker is currently awaiting the development in our laboratory of a tactile display that permits the control of intensity by changing the amplitude rather than the duration of vibration.

REFERENCE NOTES

1. Green, B. G. *Perceived magnitude as a function of duration and size for stimuli presented on the Optacon.* Manuscript in preparation, 1981.
2. Craig, J. C. *Temporal integration of vibrotactile patterns.* Paper presented to the Psychonomic Society, Philadelphia, November 1981.

REFERENCES

Berglund, B., Berglund, U., & Ekman, G. Temporal integration of vibrotactile stimulation. *Perceptual and Motor Skills*, 1967, **25**, 549-560.

Breitmeyer, B. G., & Ganz, L. Implications of sustained and transient channels for theories of visual pattern masking, saccadic suppression, and information processing. *Psychological Review*, 1976, **83**, 1-36.

Cholewiak, R. W. Spatial factors in the perceived intensity of vibrotactile patterns. *Sensory Processes*, 1979, **3**, 141-156.

Cohen, J., & Cohen, P. *Applied multiple regression/correlation analysis for the behavioral sciences.* Hillsdale, N.J: Erlbaum, 1975.

Craig, J. C. Vibrotactile letter recognition: The effects of a masking stimulus. *Perception & Psychophysics*, 1976, **20**, 317-326.

Craig, J. C. Vibrotactile pattern perception: Extraordinary observers. *Science*, 1977, **196**, 450-452.

Craig, J. C. Vibrotactile pattern recognition and masking. In G. Gordon (Ed.), *Active touch—the mechanism of recognition of objects by manipulation: A multi-disciplinary approach*. Oxford: Pergamon Press, 1978.

Craig, J. C. Modes of vibrotactile pattern perception. *Journal of Experimental Psychology: Human Perception and Performance*, 1980, **6**, 151-166.

Craig, J. C. Tactile letter recognition: Pattern duration and modes of pattern generation. *Perception & Psychophysics*, 1981, **30**, 540-546.

Garner, W. R. *The processing of information and structure*. Potomac, Md: Erlbaum, 1974.

Gescheider, G. A. Evidence in support of the duplex theory of mechanoreception. *Sensory Processes*, 1976, **1**, 68-76.

Gescheider, G. A., Herman, D. D., & Phillips, J. N. Criterion shifts in the measurement of tactile masking. *Perception & Psychophysics*, 1970, **8**, 433.

Gilson, R. D. Vibrotactile masking: Some spatial and temporal aspects. *Perception & Psychophysics*, 1969, **5**, 176-180.

Gottheil, E. F., Cholewiak, R. W., & Sherrick, C. E. The discrimination of vibratory patterns on a tactile matrix. *Bulletin of the Psychonomic Society*, 1978, **11**, 21-24.

Green, B. G. Vibrotactile temporal summation: Effects of frequency. *Sensory Processes*, 1976, **1**, 138-149.

Kirman, J. H. Tactile communication of speech: A review and an analysis. *Psychological Bulletin*, 1973, **80**, 54-74.

Loomis, J. M., & Apkarian-Steilau, P. A lateral masking effect in tactile and blurred visual letter recognition. *Perception & Psychophysics*, 1976, **20**, 221-226.

Massaro, D. W. *Experimental psychology and information processing*. Chicago: Rand McNally, 1975.

Norman, D. A., & Bobrow, D. G. On data-limited and resource-limited processes. *Cognitive Psychology*, 1975, **7**, 44-64.

Schindler, U., & Knapp, A. Ursachen der gegenseitigen Verdickung von taktil dargebotenen. Buchstaben: Unterbrechung, Summation, oder Verzogerung? *Psychological Research*, 1976, **38**, 303.

Sherrick, C. E. Effects of double simultâneous stimulation of the skin. *American Journal of Psychology*, 1964, **77**, 42-53.

Snyder, R. E. Vibrotactile masking: A comparison of psychophysical procedures. *Perception & Psychophysics*, 1977, **72**, 471-475.

Spencer, T. J., & Shuntich, R. Evidence for an interruption theory of backward masking. *Journal of Experimental Psychology*, 1970, **85**, 198-203.

Stevens, S. S. Tactile vibration: Change of exponent with frequency. *Perception & Psychophysics*, 1968, **3**, 223-228.

Turvey, M. T. On peripheral and central processes in vision: Inferences from an information-processing analysis of masking with patterned stimuli. *Psychological Review*, 1973, **80**, 1-52.

Verrillo, R. T. Temporal summation in vibrotactile sensitivity. *Journal of the Acoustical Society of America*, 1965, **37**, 843-846.

Verrillo, R. T. The effect of neural density and contactor surround on vibrotactile sensation magnitude. *Perception & Psychophysics*, 1972, **11**, 117-120.

Verrillo, R. T., & Capraro, A. J. Effect of extrinsic noise on vibrotactile information processing channels. *Perception & Psychophysics*, 1975, **18**, 88-94.

Weisenberger, J. M. *Tactile pattern similarity*. Unpublished doctoral dissertation, Indiana University, 1981.

Weisenberger, J. M., & Craig, J. C. A tactile metacontrast effect. *Perception & Psychophysics*, 1982, 31, 530-536.

(Manuscript received November 30, 1981;
revision accepted for publication February 16, 1982.)