Vibratory temporal integration as a function of pattern discriminability

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In a recent study, we measured temporal integration for vibrotactile spatial patterns presented to the fingertips. The patterns were generated on the tactile array of the Optacon, a reading aid for the blind (Bliss, Katcher, Rogers, & Shepard, 1970; Craig, 1980). Several different tasks involving letter recognition were used in the study. In one task, letters were divided in half and the time between the presentation of the first and second half was varied, with the result that recognition performance declined as the time between the onset of letter halves increased. In a second task, the time between the onset of a letter and the onset of its complement, that portion of the tactile array not occupied by the letter, was varied. Letter recognition improved as the letter emerged from its complement (Craig, 1982). The results were similar to previous measures involving detection of vibratory stimuli in that the major portion of the integration took place within 50 to 100 msec of the onset of the first pattern (Gescheider, 1976; Green, 1976; Verrillo, 1965).

The measurements with patterned stimuli and the temporal integration functions thus generated were similar to one another in that the skin showed complete temporal integration only over time periods of 10 msec and performance reached asymptotic levels as the time between stimuli approached 100 msec. There were, however, some differences in the functions produced by the several tasks, and it is the differences between functions that are the focus of this note.

The task involving a letter and its complement produced sharper temporal integration functions, that is, performance reached asymptotic levels at briefer temporal separations than in the task in which letters were divided in half. The letter-complement task also turned out to be an easier task, in that levels of performance were higher than in the divided-letter task. The results suggested either that differences in the nature of the two tasks (such as ceiling effects) may have resulted in differences in the temporal integration functions or that the ease of discriminability of spatial patterns might produce differences in the functions, that is, patterns that

are easier to discriminate have sharper temporal integration functions.

Because complex spatial patterns such as letters are composed of a number of features that are likely to differ in their discriminability, a finding that there existed a family of temporal integration functions might suggest that the temporal integration function measured with letters is the summed result of a number of different functions. In other words, what may be reflected in the data with letters is not a unitary process but the result of "subfunctions" from features varying in their discriminability.

Using a gap-detection task, the present study determined temporal integration functions with stimuli that are relatively easy and ones that are relatively difficult to discriminate. This task was selected for several reasons. First, detecting a gap in a pattern of stimulation is necessary in discriminating between vibrotactile patterns such as letters, for example, O from C. Second, it is a relatively simple matter to vary the difficulty in a gap-detection task by varying the size of the gap. Third, there already exist data on the discrimination of gaps with statically presented (nonvibratory) stimuli (Johnson & Phillips, 1981).

The gap was created by presenting pairs of horizontal bars on the tactile array, each pair consisting of two rows of stimulators turned on for 26 msec. Two rows, rather than a single row, were selected to define each boundary of the gap in order to provide a more intense stimulus and to simulate the conditions encountered when the Optacon is used as a reading aid. When reading with the Optacon, each horizontal stroke is generally represented by two rows of stimulators. A duration of 26 msec was used to provide a brief, yet clearly perceptible, signal.

On those trials when a gap was present, the pairs of horizontal bars were separated by 1, 2, 3, or 4 rows of inactive stimulators. "No-gap" trials were defined as those on which no row of stimulators intervened between the pair of horizontal bars. Half of the trials were gap trials and half were no-gap trials, with the subjects pushing one of two buttons to indicate which. Trial-by-trial feedback was provided. Because the center-to-center spacing of the pins in the vertical direction of the array was 1.1 mm, subjects presented with a one-row gap were discriminating between separations of 2.2 and 1.1 mm, the smallest separation possible on a no-gap trial. Thus, we took 1.1 mm as the separation in the two-row condition, and so forth.

On each trial, the subject received a pair of bars that could occur anywhere within a 15-mm vertical distance on the fingerpad, with a gap between the two bars of up to four rows (4.4 mm; Figure 1). In addition, the bar that was presented second occurred either distal or proximal to the first bar. These trial-by-trial changes in the

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location of the bars were thought necessary to prevent the subjects from simply using the absolute location of one of the pair of bars as the basis for their decision. Finally, the time between the onsets of the horizontal bars, the stimulus onset asynchrony (SOA), was varied from 0 msec (the onsets of the bars coincidental in time) out to 204 msec (the onset of the second bar trailing the first by 204 msec). This mix of stimulus conditions, that is, size and location of gap and SOA, was meant to simulate the sort of complexity a subject faces when trying to recognize spatial patterns moving across the fingerpad. In such circumstances, the subject typically does not have precise information in advance on the location or size of gaps or on the time between onsets of the elements producing the gaps.¹

Correct responses on gap trials were considered hits, whereas incorrect responses on a no-gap trial (responding "gap") were considered false alarms. From the hit and false-alarm rates thus generated, a d' was calculated for each SOA (Swets, 1964), and from d' , $P(C)_{\max}$ was calculated (Craig, 1983; McFadden, 1970). The percent correct, $P(C)_{\max}$, plotted as a function of SOA is shown in Figure 2. Each point represents the results from four subjects and approximately 800 trials, 400 gap and 400 no-gap.

Our initial conjecture was that easier tasks might produce sharper temporal integration functions; however, the results do not show any clear effect of task difficulty on integration times. If any trend is evident, it is that temporal integration seems to extend over time periods that are longer for the two easier discriminations (larger gaps) than for the more difficult discriminations. However, performance levels are so high with the easier discriminations, particularly at the briefer SOAs (97% to 98% correct), that there is the distinct possibility that a ceiling effect may obscure the shape of these temporal integration functions. A clearer test of the effect of discriminability is seen in the comparison of the data from the 1.1- and 2.2-mm gap conditions. Here, there is a marked difference in the level of

Figure 1. Representations of the patterns. Panel A shows a no-gap pattern, Panel B a 1.1-mm gap, and Panel C a 3.3-mm gap.

Figure 2. Percent correct detection of gaps, $P(C)_{\max}$, as a function of stimulus onset asynchrony. The parameter is the size of the gap.

performance due to the size of the gap, but almost no difference in the overall form of the two temporal integration functions. In short, these data provide little evidence that ease of discriminability produces differences in the shape of temporal integration functions.

The temporal integration functions shown in Figure 2 are very similar to those seen in the letter-recognition task referred to before—complete temporal integration over the first 15 to 20 msec with performance declining to asymptotic levels by 100 msec. These results are consistent with a model of tactile pattern processing in which the first pattern presented is stored briefly and is available to be integrated with succeeding patterns if the time interval is relatively brief. One might speculate that beyond 100 msec subjects may shift to a different strategy, such as verbal encoding of location, to decide on the presence or absence of a gap. Clearly, performance is well above chance even at the longest SOAs.

To the extent that these measurements reflect the kinds of discriminations required in the processing of spatial patterns, the conclusions are straightforward: Manipulating the difficulty of pattern recognition by varying spatial parameters, such as the size of the pattern, should not affect temporal integration. Furthermore, to the extent that there appears to be no relationship between ease of discriminability and temporal integration functions, the present results offer no support for the conjecture that temporal integration measured with letters is the summed result of a number of sub-functions.

Although these measurements were designed primarily to answer questions about temporal integration, the fact that the task involves gap detection permits the results to be compared with the results obtained by Johnson and Phillips (1981) in a related task, but one not concerned with temporal integration.

Johnson and Phillips (1981) measured the ability of subjects to discriminate the presence of gaps in an otherwise smooth surface when stimuli were pressed (not

vibrated) against the fingerpad. The results of their measurements along with the data from Figure 2, replotted to show how performance changes as a function of distance, are presented in Figure 3. In the Johnson and Phillips study, the two edges defining the gap contacted the skin at approximately the same time, and thus their data should be compared with the results from the briefer SOAs. Even restricting the comparison to the briefer SOAs, the static stimuli produce higher performance levels. This difference in performance may be due to differences in the type of neural mechanisms that encode the spatial patterns generated by the Optacon display, a vibratory stimulus, and the neural mechanisms that encode patterns generated by indentation of the skin. Johnson (1983) has presented evidence indicating that the spatial patterns presented via the Optacon display are encoded by rapidly adapting fibers, whereas statically presented patterns are encoded by slowly adapting fibers, and, furthermore, that the spatial acuity of fibers of the rapidly adapting type is less than that of the slowly adapting type (Johnson & Lamb, 1981; Phillips & Johnson, 1981). Although the role that other fiber types play in transducing spatial patterns presented via the Optacon has not been established, a difference in fiber type for static and vibratory patterns might help to account for the poorer performance seen with vibratory gap detection.² Consistent with the present findings, Loomis and Lederman (in press) have compared the results of several studies that used embossed letters contacted by an essentially stationary finger with results from studies in which letters were presented via the Optacon display. They found that better performance could be obtained with smaller embossed letters than with Optacon letters. Loomis and Lederman also suggested the possibility that this difference might be the result of different types of nerve fibers' being activated.

If neural mechanisms that can be activated when gaps are generated on the skin with a vibratory array

are different from those activated by static indentations of the skin, then it may be worthwhile to examine temporal integration with nonvibratory, spatial patterns. Such measurements would tell us whether temporal integration functions are similar for vibratory and nonvibratory patterns and whether, as appears to be the case for vibratory patterns, level of discriminability does not affect the shape of the temporal integration function.

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NOTES

1. Whether reducing the number of variables that can change on a trial-by-trial basis improves discrimination performance or not seems to depend upon the nature of the reduction. Testing the same SOA within a block of trials did not lead to performance superior to that achieved when trial-by-trial variations in SOA were allowed. However, when SOA was held constant at 0 msec and when the location of the gap on the fingerpad remained centered on the fingerpad from trial to trial, higher levels of performance were achieved. Discrimination performance under these conditions was slightly better than that shown in Figure 3 for the Johnson and Phillips (1981) results.

2. In designing this task, it was decided to keep the number of active stimulators constant as the size of the gap was varied. This kept changes in perceived intensity due to changes in the

Figure 3. The data from Figure 2 replotted as a function of gap size. Also shown are data from a study by Johnson and Phillips (1981).

number of stimulators from acting as a cue for gap detection; however, it also meant that the overall length of the pair of stimuli was correlated with gap size. The distance between the outer edges of the pair of stimuli with no gap was 3.3 mm, whereas the distance for the pair with a 1.1-mm gap was 4.4 mm. Thus, in showing that subjects can reliably detect the presence of a one-row gap, the results do not eliminate the possibility that subjects were using overall length as a cue. However, whether

subjects were using overall length or size of gap, they were able to discriminate a 1.1-mm change in distance. Overall length was not a cue in the Johnson and Phillips (1981) study, a fact that should be kept in mind when comparing the present results to their results.

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