Notes and Comment

A confusion matrix for tactually presented letters

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A recent study by Gilmore, Hersh, Caramazza, and Griffin (1979) collected recognition data for visually presented letters and constructed a confusion matrix from these data. The data, based on a large number of trials, were collected to provide a reliable measure of similarity among letters and to see the extent to which certain models might fit the data.

I have recently completed a study of vibrotactile pattern recognition in which the ability of subjects to recognize letters of the alphabet presented to their fingertips was measured (Craig, in press). In the course of training the subjects and conducting the experiments, which were concerned primarily with comparing several modes of generating vibrotactile patterns, considerable data on letter recognition were collected. In light of the Gilmore et al. study, the tactile data presented in the form of a confusion matrix might serve a function parallel to that of the visual data by providing a reliable measure of similarity among tactually presented letters and might serve also as a basis of comparison for letter recognition for the visual and cutaneous modalities.

A subset of the total data collected in the tactile experiments is shown in Table 1. This subset was selected because the procedures used to generate it were similar to the procedures followed in the Gilmore et al. study. The letters in both studies were uppercase letters of the alphabet generated on dot matrices. In the Gilmore et al. study, the letters were generated within a 5 by 7 matrix on a CRT display. In my study, the letters were generated on a 6 by 18 matrix that is part of the tactile display of the Optacon, a reading aid for the blind (Bliss, 1978; Craig, 1976). The letters were generated in both cases by simultaneously turning on all the elements making up the letter, leaving the letter on for a fixed period of time, and then simultaneously turning off all the elements. The tactile letters were presented for durations ranging from 4 to 100 msec, whereas, in the Gilmore et al. study, the durations ranged from 10 to 70 msec. The stimulus durations in the Gilmore et al. study were adjusted to produce a proportion correct of .51. The stimulus durations

of the tactually presented letters were preselected with another purpose in mind, but happened to result in a proportion correct of .52. The Gilmore et al. study presented each letter 1,200 times. For the data shown in Table 1, the numbers of presentations for each letter ranged from 1,169 to 1,314 with a mean of 1,217 presentations.

In the tactile study, the average letter occupied a space of 1.1×2.0 cm on the tactile array that was in contact with the subject's fingertip. For most of the trials, the letters were presented to the subject's left index fingertip, although, for several blocks of trials, letters were presented to the left middle fingertip or to the right index fingertip. On each trial, the subject received one of the 26 letters, attempted to identify the letter, and received feedback. Based on a total of 31,645 trials collected from 12 subjects, the tactile confusion matrix shows the proportion of responses in each cell.

It may be instructive to compare the tactile and visual confusion matrices. The product-moment correlation was computed on the proportions of correct responses in the two matrices. The rather strong, positive correlation obtained, .88, suggests that similar processes are involved in identifying letters presented via the two modalities. Correlations between visual and tactile letter recognition were also reported by Apkarian-Stielau and Loomis (1975) and by Loomis and Apkarian-Stielau (1976). In these studies, subjects attempted to identify blurred visual letters and letters presented tactually by means of an array of vibrators placed against the subjects' backs. The correlations, based on from 40 to 80 presentations of each letter, ranged from a low of +.49 to a high of +.81. Although the correlations computed from their results are somewhat lower than that computed in the present study, the data indicate a similarity in processing between the two modalities.

Investigators may also be interested in applying the models developed for visual letter recognition to the data shown in Table 1. If the visual models succeed in fitting the tactile data, and the above correlations suggest that the fit could be very good, then it would indicate that visual models ought not to rely too heavily on mechanisms assumed to be unique to the visual system. If the visual models fit the tactile data, one could assume that mechanisms similar to the visual mechanisms must be part of the cutaneous system and/or that the models might do well to emphasize the similarities among the letters and among the modes of pattern generation (Craig, in press).

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Table 1
Confusion Matrix

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
A .553	.027	.001	.002	.006	.013	.026	.024	.000	.002	.057	.000	.043	.025	.004	.008	.003	.041	.031	.002	.001	.007	.005	.086	.009	.022
B .015	.350	.007	.014	.117	.018	.106	.044	.000	.007	.007	.002	.027	.011	.023	.044	.021	.102	.046	.000	.008	.000	.015	.010	.002	.003
C .006	.018	.407	.111	.015	.006	.033	.010	.001	.008	.006	.018	.005	.003	.222	.014	.044	.011	.009	.004	.039	.000	.002	.000	.000	.007
D .011	.029	.095	.270	.001	.005	.027	.014	.001	.023	.002	.004	.010	.006	.357	.016	.060	.007	.013	.000	.043	.001	.002	.000	.000	.004
E .010	.108	.004	.005	.538	.095	.036	.032	.000	.001	.012	.012	.005	.006	.003	.037	.007	.033	.024	.001	.002	.000	.006	.007	.000	.019
F .004	.008	.000	.003	.030	.740	.004	.020	.001	.001	.009	.004	.002	.006	.002	.123	.002	.003	.004	.011	.001	.001	.001	.008	.005	.009
G .016	.116	.032	.039	.042	.022	.281	.029	.000	.006	.015	.004	.036	.013	.060	.044	.066	.087	.042	.002	.016	.002	.019	.006	.002	.003
H .020	.042	.002	.006	.052	.026	.035	.398	.000	.023	.047	.004	.061	.070	.006	.016	.007	.022	.021	.000	.031	.010	.055	.021	.003	.022
I .000	.000	.000	.000	.000	.001	.000	.000	.971	.005	.000	.001	.000	.000	.000	.000	.000	.000	.000	.016	.000	.001	.000	.000	.003	.002
J .001	.000	.000	.002	.001	.000	.001	.006	.036	.887	.004	.012	.001	.002	.006	.000	.000	.002	.001	.002	.016	.002	.012	.001	.002	.005
K .033	.006	.002	.001	.011	.024	.011	.042	.003	.003	.417	.003	.022	.039	.001	.012	.000	.022	.012	.002	.000	.015	.008	.226	.033	.054
L .000	.000	.004	.000	.001	.000	.001	.000	.001	.008	.003	.003	.003	.000	.000	.000	.000	.001	.000	.000	.007	.000	.000	.000	.000	.001
M .022	.040	.003	.004	.010	.015	.024	.105	.000	.017	.046	.005	.245	.116	.005	.007	.007	.021	.009	.000	.033	.047	.163	.041	.008	.007
N .038	.034	.001	.002	.014	.008	.019	.096	.000	.006	.063	.002	.128	.276	.006	.011	.002	.022	.022	.002	.026	.049	.108	.046	.012	.005
O .007	.007	.098	.150	.001	.003	.017	.009	.002	.017	.004	.003	.013	.004	.468	.023	.073	.008	.005	.002	.074	.005	.003	.002	.001	.003
P .015	.034	.006	.004	.033	.216	.006	.025	.001	.000	.012	.002	.002	.005	.005	.007	.542	.005	.036	.014	.002	.086	.009	.012	.002	.006
Q .006	.016	.055	.102	.002	.002	.022	.018	.001	.024	.003	.002	.008	.010	.345	.026	.210	.020	.012	.000	.086	.009	.012	.002	.006	.002
R .041	.134	.010	.032	.049	.026	.091	.033	.000	.003	.029	.005	.053	.009	.017	.070	.037	.260	.042	.000	.004	.002	.012	.024	.002	.014
S .038	.093	.002	.007	.054	.049	.068	.031	.001	.008	.035	.000	.021	.020	.019	.074	.018	.085	.312	.002	.004	.007	.003	.019	.013	.016
T .001	.000	.001	.002	.000	.002	.000	.002	.099	.010	.000	.000	.000	.001	.001	.002	.000	.001	.001	.827	.000	.002	.001	.000	.035	.014
U .001	.002	.013	.013	.001	.002	.003	.041	.002	.089	.002	.032	.008	.009	.038	.000	.005	.003	.002	.000	.693	.016	.024	.002	.000	.001
V .007	.004	.004	.002	.001	.001	.002	.011	.005	.026	.009	.005	.007	.018	.002	.002	.001	.002	.001	.002	.025	.704	.024	.025	.105	.005
W .018	.037	.004	.009	.004	.008	.030	.071	.003	.021	.017	.003	.121	.071	.023	.008	.014	.025	.011	.003	.084	.041	.346	.009	.010	.009
X .041	.006	.000	.002	.002	.011	.004	.042	.004	.003	.157	.000	.012	.022	.000	.002	.001	.002	.004	.002	.002	.038	.010	.507	.065	.052
Y .003	.000	.000	.000	.000	.004	.002	.011	.023	.012	.020	.000	.006	.005	.001	.006	.001	.002	.001	.043	.002	.082	.000	.016	.758	.002
Z .014	.014	.008	.005	.013	.012	.016	.013	.005	.010	.063	.010	.004	.007	.002	.009	.008	.025	.018	.032	.002	.004	.008	.046	.010	.643

Note—Letters labeling rows are stimuli; letters labeling columns are responses.

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