Notes and Comment

Perception of lowercase letters in peripheral vision: A discrimination matrix based on saccade latencies

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The main method used to study the role of features for letter recognition is that of generating letter confusion matrices (Bouma, 1971; Geyer & DeWald, 1973; Gilmore, Hersh, Caramazza, & Griffin, 1979; Roethlein, 1912; Sanford, 1888; Townsend, 1971; van der Heijden, Malhas, & van den Roovart, 1984). The data of a confusion matrix are an indirect but useful measure of inter-letter similarity. Yet, the confusion matrix method has various problems. First, the identification task may evoke response bias phenomena due to different guessing strategies (Bouma, 1971; Sanford, 1888). Second, the data matrix is often incomplete: Some letters are not confounded at all, and the empty cells in the matrix weaken its utility. Third, it is also known that different methods used to degrade viewing conditions and to produce a sufficiently high number of confusion errors lead to different patterns of confusions (Bouma, 1971; Garner & Haun, 1978; Geyer, 1977). For researchers interested in the dynamics of letter perception, a final inconvenience is, of course, that the data of a confusion matrix tell us nothing about the timecourse of feature extraction during letter and word recognition.

In the present paper, we introduce a simple and economic method that allows estimates of the time required for observers to discriminate two lowercase letters presented in peripheral vision. The method leads to a discrimination matrix that is based on saccade latencies and that provides information about each of the 26×26 letter pairs of the alphabet. The matrix can be used as a baseline for a variety of studies interested in temporal characteristics of letter recognition in peripheral vision. In addition, the error rates allow the experimenter to establish a sort of letter confusion matrix that supplements the information given by the temporal matrix. The use of a

lowercase alphabet seems ecologically valid with regard to reading and, above all, allows analysis of the role of global features (e.g., size or height-to-width quotient) for letter perception, as demonstrated by Korte's (1923) classical study.

METHOD

Stimuli, Apparatus, and Experimental Conditions

The font used in this experiment corresponded to the standard font established by the French Center for Studies in Telecommunications and Television. The lowercase alphabet we used is presented in Figure 1. The character matrices had 9×10 pixels; on average, their height and width subtended $.5^\circ$ of visual angle at a viewing distance of 60 cm. Stimuli appeared on a VELEC VS display terminal using a fast P4 phosphor. Lighting conditions were photopic and were kept identical across subjects, as were screen brightness and contrast. The display background luminance was about 0.7 cd/m^2 , and the stimulus luminance was about 70 cd/m^2 . Stimulus presentation and data collection were controlled by an Acorn-BBC microcomputer. The subject's eye movements were recorded using a photoelectrical scleral reflection technique and analyzed in real time by the computer, which sampled eye position at a 100-Hz rate (O'Regan, Levy-Schoen, & Jacobs, 1983). This allowed the computer to test whether the subject fixated the central mark dur-

Figure 1. Lowercase alphabet used in the present study. The characters correspond to the standard font established by the French Centre Commun d'Etudes en Television et Telecommunication for use with monitors.

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ing a trial. Automatic identification of saccades and fixations was done in accordance with the following principle: A saccade was defined as a change in eye position of more than one character space, taking less than 50 msec and giving rise to a fixation lasting at least 50 msec. Saccade latency was defined as the time elapsing between stimulus onset and saccade onset.

Procedure

The subject was seated comfortably in an adjustable chair at a 60-cm viewing distance from the screen, with his/her head stabilized by a chin/forehead rest. After an initial calibration phase of the eye-movement recording device, the subject triggered the first trial by pressing the space bar of the computer keyboard. Each trial consisted of the presentation of a randomly chosen uppercase letter at the center of the screen, representing the target to look for. The subject fixated this uppercase letter. When the computer detected correct fixation, the central uppercase letter was removed from the screen, and two isolated lowercase letters appeared simultaneously, one to the left and one to the right of the center. One of the lowercase letters (the target) corresponded to the central upper-

case letter. The subject's task was to make a saccade toward this lowercase letter. Figure 2 gives a schematic representation of the procedure. Presentation eccentricity was nine letter positions from the center (4.5°) and was kept constant across trials. Pilot studies had shown that in these conditions a performance level of 100% could be attained. Presentation side of the lowercase letters was permuted across trials and subjects. The lowercase letters were displayed until the subject's gaze had moved to either direction (see Figure 2), at which time, the next central uppercase letter appeared and remained onscreen to be fixated by the subject. Thus, subjects could control the rate at which stimuli appeared. This individually controlled presentation rate was necessary to ensure that the subjects achieved the response accuracy criterion that was fixed to 90% (± 5) correct responses (i.e., saccades in the direction of the target letter).

The subjects were instructed to move their gaze as quickly as possible to the target letter without making more than 10% errors. Feedback about error/performance level was given after each sub-block of 100 trials. There were 26×26 possible letter pairs, that is, a total of 676 trials per experimental block. Each block was

Figure 2. Schematic representation of the experimental task. The procedure for each trial was as follows: First, a central uppercase letter, chosen randomly from the alphabet, appeared at the center of the screen and indicated the target to look for. The subject had to fixate this uppercase letter, which was controlled by the computer via an eye-movement monitoring device. After correct fixation of this letter, it was removed from the screen, and two isolated lowercase letters appeared simultaneously in peripheral vision. One of these letters (the target) corresponded to the central uppercase letter; the other (the distractor) was chosen randomly from the alphabet. The subject, who could not anticipate on which side the target would appear, had to make a saccade toward the target. Further explanations are provided in the text.

Table 1
Discrimination-time Matrix Giving Mean Latencies of Saccades (in msec) Directed Toward the Target Letter as a Function of the Distractor Letter,
for Each Letter Pair of the Alphabet

DISTRACTOR																											
	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	M
a	0	333	316	295	348	306	295	295	290	282	294	297	306	304	324	312	329	291	330	287	288	303	281	294	317	318	306
b	306	0	305	344	328	306	354	315	268	284	325	307	306	292	318	313	326	273	312	308	302	304	310	281	326	310	308
c	339	321	0	314	337	286	308	333	308	293	301	307	314	300	319	312	318	301	330	309	315	303	302	304	288	312	312
d	301	333	329	0	321	308	329	315	306	276	311	295	303	316	308	339	340	322	288	292	310	301	300	290	295	315	312
e	324	329	344	285	0	296	310	307	305	305	304	289	294	300	292	330	317	319	315	315	318	318	298	285	315	318	309
f	299	327	318	319	315	0	310	329	316	325	332	312	285	300	275	325	329	367	306	307	314	295	317	334	288	330	316
g	319	314	321	326	319	321	0	303	302	280	320	280	269	290	304	299	341	297	308	295	313	302	280	281	292	324	305
h	302	300	323	297	286	331	321	0	306	311	305	293	290	332	309	311	299	316	297	315	328	297	318	303	315	310	309
i	283	277	276	284	283	306	294	304	0	333	307	317	279	273	303	294	281	312	312	311	301	293	289	291	303	292	297
j	299	313	280	302	296	301	287	299	354	0	309	334	282	287	282	292	306	332	320	298	286	300	281	293	315	293	302
k	285	297	308	300	296	303	297	304	292	332	0	314	347	307	303	300	290	365	316	344	305	311	314	338	321	293	311
l	301	300	302	327	304	312	299	310	369	337	287	0	294	318	290	274	318	327	296	293	282	288	278	302	315	302	306
m	295	279	288	299	307	298	292	303	303	276	311	295	0	306	287	272	288	286	274	275	321	298	305	287	288	299	296
n	305	310	301	322	310	340	308	342	305	284	317	279	340	0	291	315	307	324	320	317	347	304	328	323	306	310	314
o	320	324	295	333	297	293	300	283	293	290	300	297	306	299	0	282	296	269	311	289	312	291	299	313	304	285	300
p	312	330	311	298	304	309	317	297	287	307	316	298	297	285	314	0	335	308	315	308	311	309	291	311	310	328	304
q	314	332	274	332	337	306	332	297	282	298	319	306	292	303	312	323	0	290	314	295	294	308	301	285	301	292	305
r	300	306	337	315	313	362	317	316	329	301	327	310	311	314	296	332	328	0	346	320	299	338	320	325	305	329	321
s	312	307	313	312	358	328	315	296	294	287	297	305	315	327	335	299	323	313	0	320	313	316	319	313	316	298	314
t	283	320	325	347	323	341	298	309	350	325	362	346	283	302	310	321	295	330	318	0	309	317	298	301	303	297	318
u	313	295	323	294	307	315	300	296	309	302	311	290	308	338	289	313	291	294	290	306	0	293	298	298	334	315	305
v	303	320	308	305	295	321	297	301	290	272	324	310	312	283	285	286	315	297	339	306	356	0	319	298	324	295	308
w	299	292	305	285	299	314	279	304	273	287	292	280	337	300	277	285	277	290	282	298	289	293	0	320	311	301	295
x	300	294	313	309	315	287	278	322	295	286	328	291	340	301	297	308	275	294	294	307	318	307	292	0	313	312	301
y	305	303	306	309	310	309	275	321	296	333	300	312	288	294	292	294	290	304	298	317	304	256	314	303	0	304	301
z	318	303	303	294	330	304	324	313	292	342	333	300	298	305	299	297	295	327	357	314	319	333	314	357	349	0	315
M	306	309	310	312	313	313	306	309	305	303	313	303	306	303	301	301	308	311	312	308	310	304	303	303	310	306	

Note—Rows indicate targets; columns indicate distractors.

Table 2
Discrimination-time Matrix Resulting from Averaging Row and Column Latencies of Table 1

	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	0	319	327	298	336	302	307	298	286	290	289	299	300	304	322	312	321	295	321	285	300	303	290	297	311	318
b		0	313	338	328	316	334	307	272	298	311	303	292	301	321	321	329	289	309	314	298	312	301	287	314	306
c			0	321	340	302	314	328	292	286	304	304	301	300	307	311	296	319	321	317	319	305	303	308	297	307
d				0	303	313	327	306	295	289	305	311	301	319	320	318	336	318	300	319	302	303	292	299	302	304
e					0	305	314	296	294	300	300	296	300	305	294	317	327	316	336	319	312	306	298	300	312	324
f						0	315	330	311	313	317	312	291	320	284	317	317	364	317	324	314	308	315	310	298	317
g							0	312	298	283	308	289	280	299	302	308	336	307	311	296	306	299	279	279	283	324
h								0	305	305	304	301	296	337	296	304	298	316	296	312	312	299	311	312	318	311
i									0	343	299	343	291	289	298	290	281	320	303	330	305	291	281	293	299	292
j										0	320	335	279	285	286	299	302	316	303	311	294	286	284	289	324	317
k											0	300	329	312	301	308	304	346	306	353	308	317	303	333	310	313
l												0	294	298	293	286	312	318	300	319	286	299	279	296	313	301
m													0	323	296	284	290	298	294	276	314	305	321	313	288	298
n														0	295	300	305	319	323	309	342	293	314	312	300	307
o															0	298	304	282	323	299	300	288	288	305	293	292
p																0	329	320	302	314	312	297	288	309	302	312
q																	0	309	318	295	292	311	289	280	295	293
r																		0	329	325	296	317	305	309	304	328
s																			0	319	301	327	300	303	307	327
t																				0	307	311	298	304	310	305
u																					0	324	293	308	319	317
v																						0	306	302	290	314
w																							0	306	312	307
x																								0	308	334
y																									0	326
z																										0

Note—These data can be used as an estimation of interletter discriminability or similarity, independently of which letter of a pair served as the target.

preceded by 100 warm-up trials. Each subject carried out five blocks on different days, giving a total of 3,380 observations (10 observations per letter pair) for each subject. When a subject did not obtain at least 85% correct responses after half the trials of an experimental block, the session was stopped and started again on another day. During the main study, in about 90% of the cases, the prescribed performance level was attained directly. In about 10% of the cases, experimental blocks were repeated on a different day.

Observers

Six subjects (4 female, 2 male) participated as volunteers in this study. Four of the subjects were students of experimental psychology at the University René Descartes in Paris. Two were members of our research team. All had normal acuity. The average age was 25.

RESULTS AND DISCUSSION

First, for each subject, we computed saccade latency matrices separately for correct and incorrect responses by averaging the data across the five experimental blocks. We computed the final letter-discrimination matrix for correct responses (see Table 1) by taking the average across subjects. Table 2 summarizes the data of Table 1 by averaging row and column latencies (targets and distractors). This allows an estimation of interletter similarity, independently of which letter of a pair served as the target. We also took the average across subjects to compute the confusion matrix (see Tables 3 and 4), which

presents the absolute number of cases in which a saccade was made in the wrong direction (i.e., toward the distractor letter).

The data of Tables 1 and 2 show that saccade latency is a useful measure of letter discriminability since it differs sensitively as a function of the graphic similarity between targets and distractors. The row means of Table 1 also reveal that there was little variability in the overall discriminability of the letters: The average overall discrimination time across the 26 row means was 307 msec, with a standard deviation of 6.7 msec. Discrimination times of some letters lie outside this 300.3–313.7-msec region: On the low side were *i*, *m*, and *w*, with mean discrimination times of about 295 msec; on the high side were *r* and *t*, with mean discrimination times of about 320 msec. The low variability found in row means and individual letter comparisons (e.g., *o*, *s*, *p*, and *z* vs. *a*, *g*, *q*, and *m*) indicates that the form of the uppercase target letter had no influence on the observed discrimination times. The column means (*M*) given in the bottom row of Table 1 can be interpreted as showing that the overall *distraction value*—that is, the extent to which a given letter can slow down correct discrimination of any other letter of the alphabet—was almost constant across the 26 letters, although the letters may have differed in their familiarity/frequency value and luminance/dot density (see Note 1).

As supplementary information to Tables 1 and 2, we also computed an error or confusion matrix representing

Table 3
Error or Confusion Matrix Giving Absolute Number of Saccades Directed Toward the Distractor for Each Letter Pair of the Alphabet

	DISTRACTOR																									
	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	0	3	6	1	5	5	6	5	1	1	1	0	1	4	11	5	8	2	5	3	3	3	2	1	1	3
b	3	0	3	10	2	1	1	3	2	2	1	0	1	1	1	4	7	2	4	4	2	3	1	1	2	1
c	4	2	0	2	6	0	0	4	1	0	1	0	0	1	5	2	2	3	5	0	1	2	0	0	1	1
d	8	16	6	0	5	1	11	0	0	1	2	3	5	1	2	9	1	1	2	0	2	1	2	0	3	1
e	5	3	6	2	0	0	10	0	0	1	2	0	4	1	4	4	3	0	6	4	1	3	2	4	1	2
f	1	3	1	0	3	0	2	3	1	4	8	1	1	0	0	2	2	5	3	3	0	1	2	1	2	3
g	7	8	4	9	6	3	0	2	0	0	1	0	3	1	2	2	6	1	3	1	1	4	3	1	4	2
h	0	3	1	4	1	1	3	0	0	2	9	1	4	4	0	2	2	2	0	2	3	2	5	3	1	6
i	1	1	1	1	0	0	0	1	0	8	2	19	0	1	1	0	0	1	0	3	1	0	0	1	3	0
j	0	1	1	3	0	4	0	1	4	0	2	2	0	2	0	1	0	6	1	4	0	2	0	0	1	5
k	1	1	1	0	3	2	3	3	0	1	0	0	3	1	2	4	2	2	3	4	1	4	5	2	4	5
l	1	2	0	2	2	5	1	7	9	10	2	0	1	1	0	1	1	4	2	2	3	3	2	1	2	0
m	2	1	0	0	1	0	3	3	0	0	2	1	0	1	2	0	1	0	1	1	0	0	7	3	3	1
n	2	2	0	0	2	2	0	9	1	1	4	2	10	0	1	0	2	0	3	2	5	2	4	2	2	1
o	12	2	0	1	4	0	2	1	1	0	0	1	1	0	0	5	4	0	2	3	2	0	2	0	0	1
p	3	6	0	6	2	3	6	3	0	1	0	2	2	0	4	0	6	3	1	1	0	0	0	3	1	3
q	3	3	0	11	4	0	15	2	0	1	1	2	4	4	8	10	0	1	2	2	2	2	1	2	1	3
r	4	6	1	4	5	4	3	5	1	3	1	0	3	0	0	7	6	0	6	6	2	2	4	2	2	11
s	3	2	5	2	9	0	6	3	1	0	1	0	3	3	2	3	4	2	0	4	3	4	3	1	2	1
t	2	2	5	4	0	6	1	5	9	13	6	7	1	0	0	1	4	4	1	0	1	1	2	2	1	5
u	4	4	1	1	3	3	5	7	2	0	2	0	4	7	0	0	1	1	0	0	0	4	5	1	5	1
v	1	3	2	3	2	0	4	5	0	0	1	0	2	4	2	3	2	2	1	3	7	0	1	2	7	2
w	2	1	0	1	0	1	0	4	1	1	1	0	9	1	0	2	2	2	3	1	9	3	0	2	4	0
x	2	2	0	2	2	1	1	1	1	1	4	0	3	2	0	1	0	2	4	1	2	4	9	0	4	2
y	2	4	3	4	1	9	1	6	3	3	6	3	3	4	0	0	2	2	2	4	4	11	3	5	0	6
z	3	1	3	3	0	2	2	3	0	3	1	0	2	3	0	1	1	5	2	2	2	6	2	3	7	0

Note—Rows indicate targets; columns indicate distractors. Despite the fixed error rate and the resulting limited number of observations, the data in the confusion matrix agree, in principle, with those in the discrimination-time matrix in that they show relatively high confusions between letters from a same-feature group (e.g., *i*, *j*, *l*; or *b*, *d*, *g*, *p*, *q*; see Table 5).

Table 4
Confusion Matrix Resulting From Averaging Row and Column Data of Table 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
a	0	3	5	4.5	5	3	6.5	2.5	1	0.5	1	0.5	1.5	3	12	4	5.5	3	4	2.5	3.5	2	2	1.5	1.5	3
b		0	2.5	13	2.5	2	4.5	3	1.5	1.5	1	1	1	1.5	1.5	5	5	4	3	3	3	3	1	1.5	3	1
c			0	4	6	0.5	2	2.5	1	0.5	1	0	0	0.5	2.5	1	1	2	5	2.5	1	2	0	0	2	2
d				0	3.5	0.5	10	2	0.5	2	1	2.5	2.5	0.5	1.5	7.5	6	2.5	2	2	1.5	2	1.5	1	3.5	2
e					0	1.5	8	0.5	0	0.5	2.5	1	2.5	1.5	4	3	3.5	2.5	7.5	2	2	2.5	1	3	1	1
f						0	2.5	2	0.5	4	5	3	0.5	1	0	2.5	1	4.5	1.5	4.5	1.5	0.5	1.5	1.5	5.5	2.5
g							0	2.5	0	0	2	0.5	3	0.5	2	4	11	2	4.5	1	3	4	1.5	1	2.5	2
h								0	0.5	1.5	6	4	3.5	6.5	0.5	2.5	2	3.5	1.5	3.5	5	3.5	4.5	2	3.5	4.5
i									0	6	1	14	0	1	1	0	0	1	0.5	6	1.5	0	0.5	1	3	0
j										0	1.5	6	0	1.5	0	1	0.5	4.5	0.5	8.5	0	1	0.5	0.5	2	4
k											0	1	2.5	2.5	1	2	1.5	1.5	2	5	1.5	2.5	3	3	5	3
l												0	1	1.5	0.5	1.5	1.5	2	1	4.5	1.5	1.5	1	0.5	2.5	0
m													0	5.5	1.5	1	2.5	1.5	2	1	2	1	8	3	3	1.5
n														0	0.5	0	3	0	3	1	6	3	2.5	2	3	2
o															0	4.5	6	0	2	1.5	1	1	1	0	0	0.5
p																0	8	5	2	1	0	1.5	1	2	0.5	2
q																	0	3.5	3	3	1.5	2	1.5	1	1.5	2
r																		0	4	5	1.5	2	3	2	2	8
s																			0	2.5	1.5	2.5	3	2.5	2	1.5
t																				0	0.5	2	1.5	1.5	2.5	3.5
u																					0	5.5	7	1.5	4.5	1.5
v																						0	2	3	9	4
w																							0	5.5	3.5	5.5
x																								0	4.5	2.5
y																									0	6.5
z																										0

the number of saccades directed to the distractor (see Tables 3 and 4). However, these data can be considered only as having a limited value because of the fixed error rate and the resulting limited number of observations in each cell of the matrix.

Feature Analysis

The following analysis was aimed at determining whether certain global and/or local features were effective for discriminating two lowercase letters in peripheral vision. In particular, we wanted to test, using a different font and paradigm, whether or not we could replicate Bouma's (1971) finding that the most important cue determining the discriminability of two letters is the dissimilarity in their envelopes, including such global features as the height-to-width quotient. To determine the functional importance of certain features under consideration, we proceeded similarly to the way Bouma (1971) did in his post hoc analysis of cue values, using his list of features that were supposed to be effective for the perception of lowercase letters. Given Bouma's definition of the letter envelope (see below) and the differences between our special type font and the one used by Bouma (IBM Courier), some modifications in the original list had to be made. The modified list, given in Table 5, contained 15 functional features, some of which were more global (e.g., slenderness, circular envelope) and others were more local (presence of inner parts, right gap; cf. Bouma, 1971, Table 1, p. 466). Use of the relative terms *more global* and *more local* indicates that we consider the feature dimension to be continuous rather than binary. Thus,

the two categories, *global* and *local*, represent extremes on a continuous scale (Appelman & Mayzner, 1982).

Following Bouma, the letters sharing a given feature were grouped. To determine the role that a given feature played in letter recognition in peripheral vision, we computed the average within-group discrimination time (the average time required for discriminating each letter of a given group from each other letter of the group). This within-group discrimination time then was compared with the average discrimination time that resulted from comparison of each of the letters of the group with all other letters outside the group. A significantly higher within-group discrimination time would indicate that the feature constituting the group was effective in peripheral vision. Table 5 summarizes the results of this analysis. The functional value of each of the 15 features under consideration is represented by the amount of difference (D) between the mean within-group (M_w) and the mean outside-group discrimination times (M_o).

In sum, among the 15 lowercase letter features considered in the list of Table 5, 3 appeared to be very effective for recognition of our lowercase alphabet in peripheral vision: "belly plus bar," "very slender," and "slender, right-handed." These three features are descriptions of what Bouma called the *letter envelope*, defined as the smallest polygon around a letter without indentations. Each yielded a difference value higher than 20 msec and, according to Bouma, was on the global end of a hypothetical, continuous dimension with the extremes global and local. Six features appeared to be moderately effective in peripheral vision, yielding difference values between

Table 5
Estimates of the Functional Importance of Certain Lowercase Letter Features

Feature	Letters		M_w	M_o	D	$t(s)$	p
	Within-Group	Outside-Group					
Short ($H/W \leq 1.0$)	a, c, e, m, n, o, s, u, v, w, x, z	all others	309	303	6	2.7	< .025
Belly + Bar	b, d, g, p, q	all others	330	303	27	4.0	< .01
Circular Envelope	a, c, e, o	all others	319	304	15	3.3	< .025
Left Part Circular Envelope	a, c, e, o, g, d, q	all others	316	303	13	4.6	< .005
Very Slender ($H/W = 7$)	i, j, l	all others	348	298	50	4.9	< .005
Slender, Right-Handed ($H/W = 1.7$)	f, k, r, t	all others	338	312	26	6.4	< .001
Ascenders	b, d, f, h, i, k, l	all others	313	306	7	4.7	< .005
Descenders	g, j, p, q, y	all others	305	304	1	0.4	n.s.
Two Parallel Vertical Lines	h, m, n, u	all others	320	303	17	2.3	< .05
Two Parallel Horizontal Lines + Inner Parts	e, g, s, z	all others	324	309	15	3.4	< .01
Right Gap	c, e, f, r, s, t, x, z	all others	319	311	8	4.2	< .005
Lower Gap	h, m, n	all others	317	304	13	2.1	< .05
Upper Gap	u, v, w, y	all others	310	301	9	1.9	n.s.
Left Upper Extension	b, h, k	all others	307	310	-3	0.6	n.s.
Oblique Parts	k, v, w, x, z	all others	314	304	10	3.8	< .01

Note—Feature groups refer to the type font presented in Figure 1. The 15 features are similar to those proposed by Bouma (1971) for a lowercase alphabet. M_w = mean within-group discrimination times; M_o = mean outside-group discrimination times; D = the difference between M_w and M_o . M_w , M_o , and D are expressed in milliseconds.

10 and 15 msec: “circular envelope,” “left part circular envelope,” “2 parallel vertical lines,” “2 parallel horizontal lines + inner parts,” “lower gap,” and “oblique parts.” They were between the two extremes, ranging from *more global* (e.g., “circular envelope”) to *more local* (e.g., “lower gap”). The remaining six features, “short,” “ascenders,” “descenders,” “right gap,” “upper gap,” and “left upper extension” had little or no effect upon discrimination times in peripheral vision. All of these features, with the exception of “short,” could be classified as being on the local end of the scale.

With these data, one can see that differences in the height-to-width quotient are most easily perceived in peripheral vision and most effectively used to discriminate between lowercase letters presented in an isolated way. In general, the present results (although they were obtained with a different type font and measured latency in a discrimination task rather than proportion correct in an identification task) strongly support Bouma's view that the letter envelope is an important feature, especially in peripheral vision. This is consistent with a *global-to-local* theory of visual information processing. The letters *b*, *d*, *g*, *p*, and *q* (see Table 5) are good examples. Their salient envelope—here called “belly + bar,” with no pretense that this is the best possible name—allows them to be easily discriminated from the rest of the alphabet, within about 303 msec (the dead time of the oculomotor system included). However, when the local feature “bar” has to be localized precisely with regard to the “belly” for within-group discrimination, it takes about 30 msec longer. This is additional evidence for the difficulty of peripheral vision to localize form elements.

In conclusion, the data of the main discrimination matrix (Table 2) based on saccade latencies provide estimates of the timing characteristics of letter recognition in peripheral vision that can be used in a variety of studies on letter recognition, visual search, or reading. Table 5 provides data about which properties are effective in peripheral vision by being more rapidly available to the low-acuity visual system than are others. The experimental paradigm introduced here appears to be simple and economic, using a dependent variable that reflects letter discriminability probably in a more direct and more sensitive way than do manual reaction times (Podgorny & Garner, 1979); the latter argument being testable in future experiments comparing both measures. The paradigm can be applied to theoretical questions about the similarity structure of a given type font, about the mechanisms underlying form perception, or about saccade control: In another recent study, it was used successfully to decompose saccade latency into central and peripheral processing times in a visual dual task (Jacobs & Levy-Schoen, 1988). It also can serve practical purposes, for instance, in studies on font or symbol design. The data of the main matrix contain a series of interesting questions, for example, concerning the obtained asymmetries (again, see Note 1) or the problem of the minimum time required to perceive a global feature, such as “slenderness,” as a function of stimulus eccentricity. In addition, it would be interesting to test if the present pattern of results changes with stimulus eccentricity, (e.g., whether more global features gradually lose their advantage over more local ones when stimuli are shifted toward the fixation point). A whole line of research is underway to answer these questions, given that the present literature on the mechanisms underlying

lowercase letter perception in peripheral vision still is very poor.

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NOTE

1. A remark concerning the apparent asymmetries in the matrix of Table 1 is in order. In light of recent theoretical developments concerning perceptual asymmetries (Garner & Haun, 1978; Krumhansl, 1982; Treisman & Gormican, 1988), the asymmetries seemed important enough to warrant follow-up experiments specifically concerned with the problem. The results of these experiments will be reported in a future paper. A preliminary result indicates that such simple factors as dot density (luminance), letter frequency/familiarity, or form-priming between the target indicator (uppercase letter) and the lowercase target cannot explain the asymmetries found in our matrix.

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