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Perceptual adjustments on representations of familiar patterns: Change over time and relational features

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Subjects classified individual stimuli as exact copies or as distortions of previously viewed prototype letters. Perceptual adjustments were induced by the presence of difficult (subtle) distortions within the stimulus set. In Experiment 1, subjects initially made feature-based adjustments, and, with experience, adjustments became identity-based. Decisional adjustments also occurred. A similar change over time was obtained in Experiment 2; in addition, the feature-based adjustments could not be explained by overall similarity between letters. Experiment 3 indicated that feature-based adjustments can be long lasting under appropriate circumstances. Experiment 4 indicated that the relevant features are not functionally independent parts of letters, but rather relations between neighboring parts. The results are consistent with the idea that adjustments can change between levels over time, and that the adjusted features are relational in nature.

We performed the present experiments in order to study how perceptual representations of familiar patterns can be adjusted as a result of experience within a given task environment. Our experimental strategy was to induce subjects to make situation-specific adjustments on their perceptual representations. Situation-specific adjustments are consistent with the general idea of perceptual set (see, e.g., Haber, 1966, Pachella, 1975). In the present experiments, adjustments were induced by the insertion of difficult discriminations into the stimulus set, an approach that has been used previously (e.g., by Crist, 1981, and Miller & Bauer, 1981). We systematically examined several possible types of adjustments, as well as changes in adjustments as a function of experience and task characteristics. In addition, we examined adjustments based on features in some detail, in order to investigate some issues concerning the nature of perceptual features.

In the experiments, subjects began sets of blocks by viewing a small set of prototype letters. Then the prototypes were removed, and on each trial, a single item was presented. The item was either a prototype or a distortion of one of the prototypes, and the subject was to quickly and accurately classify it as a prototype or a distortion. Most distortions were obvious violations of a prototype's structure. However, in some conditions, the distortions of one *manipulated* prototype involved only a subtle change in the size of one *critical part* of the prototype. Initially, these difficult distortions were often wrongly classified as a prototype by subjects, and error feedback was provided (including relevant stimuli). As a result, subjects adjusted their processing system, as indicated by increases in accuracy with the difficult items and increases in reaction time (RT) for certain items. In general, such adjustments can be assumed to reflect increases in subjects' criteria for accepting certain types of evidence (see, e.g., Miller & Bauer, 1981).

A basic empirical question concerns the level of representation at which adjustments are based. This should be indicated by the pattern of RTs for "yes" (prototype) responses, and there are at least three possible classes of adjustments that can be expected.[1] First, in a task with two responses, adjustments might be at the level of *decisions*. Such adjustments would mean that more evidence would have to be gathered before a decision was made, with the result that RTs for all prototypes would be increased. A second class of adjustments will be termed *identity* adjustments; these involve either the abstract identities of the manipulated prototype, or the exact form of the prototype. In either case, such adjustments result in increased RTs for the manipulated prototype, but not for other prototypes. Of particular interest, however, was the last class of adjustments, that involving perceptual features.

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In addition to affecting the manipulated prototype, such *feature-based* adjustments would increase RTs for prototypes that shared the difficult, critical part (or, more precisely, for prototypes that shared the features associated with that part).

Note that adjustments in terms of perceptual features may be implemented at the level of features, or at another level. For example, feature-based adjustments could be implemented at the letter level for all letter units possessing the critical feature(s). In the present experiments, we were concerned primarily with the bases on which adjustments were made (e.g., features or identities), not with the actual locus of such adjustments in the processing system. Two issues relating to the bases of adjustments were of particular interest.

Nature of Features

The first issue concerns the nature of the features underlying feature-based adjustments. The construct of features has been central to perceptual models for decades, and it is clear that the construct is useful. For example, items that share more parts or properties are more likely to be confused (see, e.g., Keren & Baggen, 1981). (For reviews, see Massaro & Schmuller, 1975, and Treisman, 1986.) However, there is not much direct evidence on the nature of features, and alternative definitions of features persist. Also, certain basic assumptions about features have not been tested rigorously.

One of the most basic assumptions frequently made about features is that they correspond to separate, functionally independent parts of the stimulus (see, e.g., Townsend & Ashby, 1982; Tversky, 1977). This quality is similar to the idea of "separable" dimensions (Garner, 1974), which can be attended to independently of other dimensions, and whose processing is not facilitated by redundant information on other dimensions. Separable dimensions can be contrasted with other types of dimensions, such as "integral" ones, which cannot be selectively attended to and whose processing is facilitated by redundant information on other dimensions (Garner, 1978). However, there have been few rigorous tests of the separability of parts of letters or other familiar patterns. In one relevant identification study, Townsend and Ashby (1982) found that, contrary to the idea of independence, the probabilities of identifying different parts of letters were correlated (cf. Townsend, Hu, & Evans, 1984). Also, there is a growing literature on the importance of emergent features created by relations between component lines or curves, which can cause nonindependent processing of those components (Pomerantz & Pristach, 1989; Pomerantz, Sager, & Stoever, 1977; Treisman & Paterson, 1984).

An alternative assumption about features is that they exist in relational networks (see, e.g., Oden, 1979; Palmer, 1975). Such networks specify both the parts of a stimulus and their relations to other parts. In such a model, stimulus information may be sampled by independent detectors (e.g., Oden, 1979, 1984), but the information may pertain to relations between parts (e.g., Oden, 1979; Sanocki, in press-a). Therefore, parts of a stimulus may not be processed in a functionally independent manner.

In the present experiments, the initial assumption was that features correspond to separate, independent parts of letters. This assumption was used in the first several experiments with mixed success. The alternative assumption, that parts of letters are not processed independently, was tested directly in Experiment 4.

Change over Time

There is a growing literature on how perceptual processes adjust in response to properties of the task environment. For example, stimulus probability can affect several loci (see, e.g., Dykes & Pascal, 1981, Miller, 1979), and search strategies vary with the identity of the distractors (see, e.g., Gleitman & Jonides, 1978; Hock, Rosenthal, & Stenquist, 1985). Furthermore, recent evidence indicates that the degree of separability (vs. integrality) can change as a function of task set (Smith & Kemler-Nelson, 1984; Ward, 1983). Of interest here were changes over time (over blocks of trials) in the type of adjustment: changes from adjustments based on similarities (i.e., shared features) to adjustments based on identity. Although there is evidence of adjustments based on similarity (Crist, 1981) or identity (Miller & Bauer, 1981), changes from one type of adjustment to another have not (to our knowledge) been examined previously.

EXPERIMENT 1

Our purpose in Experiment 1 was to look for adjustments like those mentioned above as subjects gained experience with a set of stimuli. In the experiment, subjects classified prototypes and distortions in each of two types of *environments*. The environments were either *easy*, which meant that all distortions were obvious violations of the prototype's structure, or *difficult*. Difficult environments were the same as the easy environments, except that, for one manipulated letter, the obvious distortions were replaced with difficult distortions. The difficult distortions involved subtle changes in the size of one critical, local part of the manipulated letter. This manipulation follows from the idea that features correspond to independent parts of letters. We expected that adjustments would occur in the difficult environment. Indeed, each of the three hypothesized adjustments (decisional, identity-based, and feature-based) occurred in the experiment.

Method

Design and Stimuli. There were four sets of prototype letters. The sets are summarized in Table 1, and one complete set is shown in Figure 1. The prototypes were lowercase, sans serif block letters. Each set comprised one manipulated prototype and three nonmanipulated prototypes. For each set of prototypes, two sets of distortions were created, one easy and one difficult. In the easy sets, each prototype had two distortions that involved obvious changes in the prototype's structure (see Figure 1). The difficult sets were

Table 1
Four Letter Sets and Critical Parts in Experiment 1

Letter Set	M	SF	PSF	C	Critical Part
"d"	d	b	p	u	height of ascender
"f"	f	t	r	o	width of crossbar
"e"	e	c	a	n	size of opening/ extent of bottom terminator
"h"	h	l	i	m	height of ascender

Note—Each set included a manipulated letter (M), a shared-feature letter (SF), a partial shared-feature letter (PSF), and a control letter (C).

the same as the corresponding easy sets, except that the easy distortions of the manipulated letter were replaced with two difficult distortions (Figure 1). The difficult distortions were minor changes in the size of one critical part of the letter. In one distortion, the part was extended, whereas in the other it was constricted. The critical part for each letter set is listed in Table 1.

In creating the sets of prototypes, the nonmanipulated prototypes were chosen to vary in the degree to which they contained the critical part. The first nonmanipulated letter had the same part in approximately the same position as did the manipulated letter (shared-feature, or Type SF). For example, in Figure 1, the critical part is the height of the ascender of the letter "d," and the SF letter was "b," which has a similar ascender in the same vertical position. The second nonmanipulated letter had a further transformation of the part, which might or might not be in the same position (partial shared feature, or Type PSF). For example, the PSF letter in Figure 1 was "p," which had a descender of the same size and shape as did the ascender. The third nonmanipulated letter was a control (Type C), which did not contain the critical part (e.g., "u"). Judgments concerning features were made intuitively, and were intended to provide an ordinal classification of the degree to which the critical part was present.

A subject received one version of each stimulus set (easy or difficult) for 3 blocks of trials, making a total of 12 blocks (four letter sets) per subject. There were two stimulus lists, each assigned to half of the subjects. Alternative versions of each set of prototypes were assigned to each list, and each list had two easy and two difficult sets. Within a list, the order of environment types (easy or difficult) alternated. In addition, the order of sets within each list was counterbalanced across subjects. Because the conditions alternated, no subject saw the same or a similar critical part in two difficult environments.

Procedure and Apparatus. The subjects were run individually in sessions that lasted about 45 min. The stimuli were displayed white on black on a 9-in. CRT in a sound-attenuated booth, and

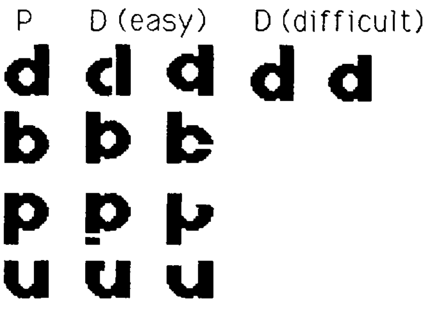

Figure 1. The prototypes (P) and distortions (D) in the "d" set of Experiment 1. The first column contains the four prototypes (P), the next two columns contain the easy distortions, and the last two (single-item) columns contain the difficult distortions.

responses were made with telegraph keys. The experiment was run by an Apple II+ microcomputer. Viewing distance was approximately 56 cm but was not strictly controlled. At this distance, the "d" was 1.4° in height.

At the start of the experiment, the four prototypes for the first stimulus set were displayed. The subjects were instructed that, when they were ready, the prototypes would be removed, and that one item at a time would appear on the screen. The subjects were instructed to respond to the item as quickly and accurately as possible by pressing the "yes" key if the item was the same as one of the prototypes, or the "no" key if it was a distortion of one of the prototypes. "Yes" and "no" responses were made with the dominant and nondominant hands, respectively. The subjects were told that they should look at the prototypes carefully, because "some of the parts might be difficult." They were also told that prototypes and distortions were equally likely to appear. Before each of the other three stimulus sets was used, the prototypes were displayed in the same way for the subjects to examine.

The sequence of trials within a block was structured to distribute trials with each of the manipulated distortions evenly throughout the beginning and middle of the blocks, and to provide buffer trials after those critical trials, in order to minimize temporary effects after errors. Blocks contained 24-26 trials, and the stimuli were selected randomly within the following constraints. A block began with 1-3 buffer trials involving any stimulus except for the distortions (easy or difficult) of the manipulated letter. In each block, there were 3 critical trials, each one followed by 2 more buffer trials. The critical trials involved the distortions of the manipulated letter. One critical trial occurred after the last buffer trial, 1 occurred during Trials 9-11, and 1 occurred during Trials 18-20. Each of the two versions of the manipulated distortion was presented on the 1st or 2nd critical trial; one of the two versions was also presented during the 3rd critical trial. The buffer trials that followed the critical trial involved one of the other prototypes and then one of the easy distortions. Data were recorded for the 3 critical trials and for the 14 remaining, nonbuffer trials. The 14 remaining trials included 2 trials with each of the four prototypes and 1 trial with each of the six nonmanipulated distortions. Each prototype appeared once in the first half of the remaining trials and once in the second half.

At the start of each trial, a small "x" appeared in the middle of the screen for 250-500 msec. Then it was erased and the target stimulus was displayed until the subject responded. After the response, the stimulus was erased. If the response was incorrect, feedback was given: For false alarms in response to distortions, the distortion was redisplayed together with the corresponding prototype and an appropriate message; for misses in response to prototypes, the prototype was redisplayed with an appropriate message. The subjects responded to terminate the display. Each trial was followed by a 1-sec interval. After each block of trials, a message told the subject to take a short break and then respond to continue the experiment.

Subjects. Eighteen volunteers from introductory psychology classes at the University of Wisconsin-Madison participated. They received partial course credit for participation.

Results

For the main analyses, the data were collapsed across stimulus sets and organized according to the three blocks of trials with each stimulus set. Thus, the term *first block* refers to the first blocks with all of the stimulus sets.

Errors to manipulated stimuli. Errors in response to the manipulated items (the prototypes and their distortions in the easy and difficult environments) were examined first. As expected, there were few errors in the easy environment, in which the distortions were easy. However, in the difficult environment, in which the distortions were difficult, many errors were made in response to the distortions, especially during the first block with such items. Most, but not all, subjects adjusted to the difficult distortions, as indicated by a decrease in error rates for manipulated items over blocks. Because we were concerned here with the nature of adjustments, the subjects that did not adjust to the difficult items were separated out for the analyses. A 25% error criterion for manipulated items (prototypes and distortions) in the last two blocks of difficult environments was adopted, and, on the basis of this criterion, five subjects were separated out.

The proportions of errors in response to manipulated stimuli for adjusting subjects in each environment are reported in Table 2. There were few errors during the three blocks in the easy environment. As would be expected with the adjustment process, there were many errors in the difficult environment, especially in the first block. There were reliable interactions of block and environment [$F(2,24) = 13.25, p < .001$], and of block, environment, and response [$F(2,24) = 7.67, p < .01$]. The main effects and all remaining interactions were also reliable ($ps < .001$).

Errors for nonmanipulated items. The nonmanipulated items (prototypes and distortions) were identical between environments. Error rates for these items were generally low, and are reported for the adjusting subjects in Table 3. Error rates decreased over blocks [$F(2,24) = 8.13, p < .01$], and there were differences in the rates for the three items [$F(2,24) = 5.54, p < .05$]. The three-way interaction of environment, response, and item was also reliable [$F(2,24) = 4.17, p < .05$]. In general, errors were more frequent for prototypes than for distortions of nonmanipulated letters. Subjects may have attempted to offset the many erroneous "yes" responses to distortions of manipulated items by lowering their criterion for "no" responses, producing errors in responses to prototypes. However, an exception to this general pattern was that errors tended to be more frequent for distortions of the SF items than for PSF and C items in the difficult environment.

Table 2
Error Rates (in Percent) for Prototypes (P) and Distortions (D) of the Manipulated Items in Experiment 1, for Adjusting Subjects ($n = 13$), as a Function of Block and Environment

	Environment			
	Easy		Difficult	
Block	P	D	P	D
1	0	5.1	9.6	69.2
2	0	3.8	3.8	28.2
3	1.9	2.6	3.8	19.2

Table 3
Error Rates (in Percent) for Prototypes (P) and Distortions (D) of the Nonmanipulated Items in Experiment 1, for Adjusting Subjects ($n = 13$) as a Function of Block and Environment

	Shared Feature		Partial Shared Feature		Control	
Block	P	D	P	D	P	D
			Easy Environment			
1	7.7	5.8	3.8	1.9	3.8	5.8
2	5.8	1.9	3.8	0	7.7	3.8
3	1.9	0	0	0	3.8	0
			Difficult Environment			
1	5.8	11.5	7.7	0	9.6	0
2	1.9	11.5	1.9	0	7.7	0
3	5.8	1.9	3.8	0	0	0

Reaction times. Of primary interest were the adjusting subjects' RTs for correct responses to prototypes. Outlying responses over 3 sec were to be eliminated from the analyses, but none exceeded this criterion.

RTs for the easy and difficult environments are shown in the left panel of Figure 2, with a separate graph for each block. Note that the degree to which the critical part is shared by nonmanipulated items decreases from left to right on the abscissa. As can be seen, there is a striking interaction of block, condition, and prototype [$F(6,72) = 2.34, p < .05$]. The results for the easy environment are relatively simple: RTs are generally fast, are equal for all four prototypes, and decrease somewhat across blocks. In contrast, the results for the difficult environment change across blocks, providing evidence in different blocks for each of the three hypothesized classes of adjustments.

In the first block, RTs are inflated (relative to the easy condition) for the manipulated letter and equally inflated for the nonmanipulated, shared-feature (SF) letter. RTs are also inflated for the nonmanipulated, partial shared-feature (PSF) letter, but there is little or no increase for the control (C) letter. The elevation for the SF and PSF letters relative to the C letter illustrates a feature-based adjustment, in that subjects were cautious only with letters that shared the critical feature. The linear trend for RT to increase from the C to the SF letters was reliable in the difficult environment [$F(1,24) = 11.76, p < .01$], and it was reliably stronger than in the easy environment [$F(1,24) = 6.20, p < .05$].

The pattern of data in the second block can be viewed as a transition between the types of adjustments in the first and third blocks. The pattern in the third block illustrates a combination of an identity-based and a decisional adjustment. The identity-based adjustment is limited to the manipulated item, and is indicated by the increase in RT for the manipulated letter relative to all three of the nonmanipulated letters [$F(1,12) = 11.10, p < .01$]. (Among the nonmanipulated letters, similarity to the manipulated letter did not matter.) The decisional adjustment involves all items, and is indicated by the longer RTs for the nonmanipulated letters in the difficult environment relative to the easy environment [$F(1,12) = 17.44, p < .01$].

The changing patterns of results for the difficult environment suggest that subjects initially made adjustments on the basis of features common to manipulated and nonmanipulated items. By the third block, the subjects apparently had learned that only one item was difficult and, accordingly, they restricted most of their adjustments to that specific item. In addition, in the third block, there was also a general but small decisional effect for all items.

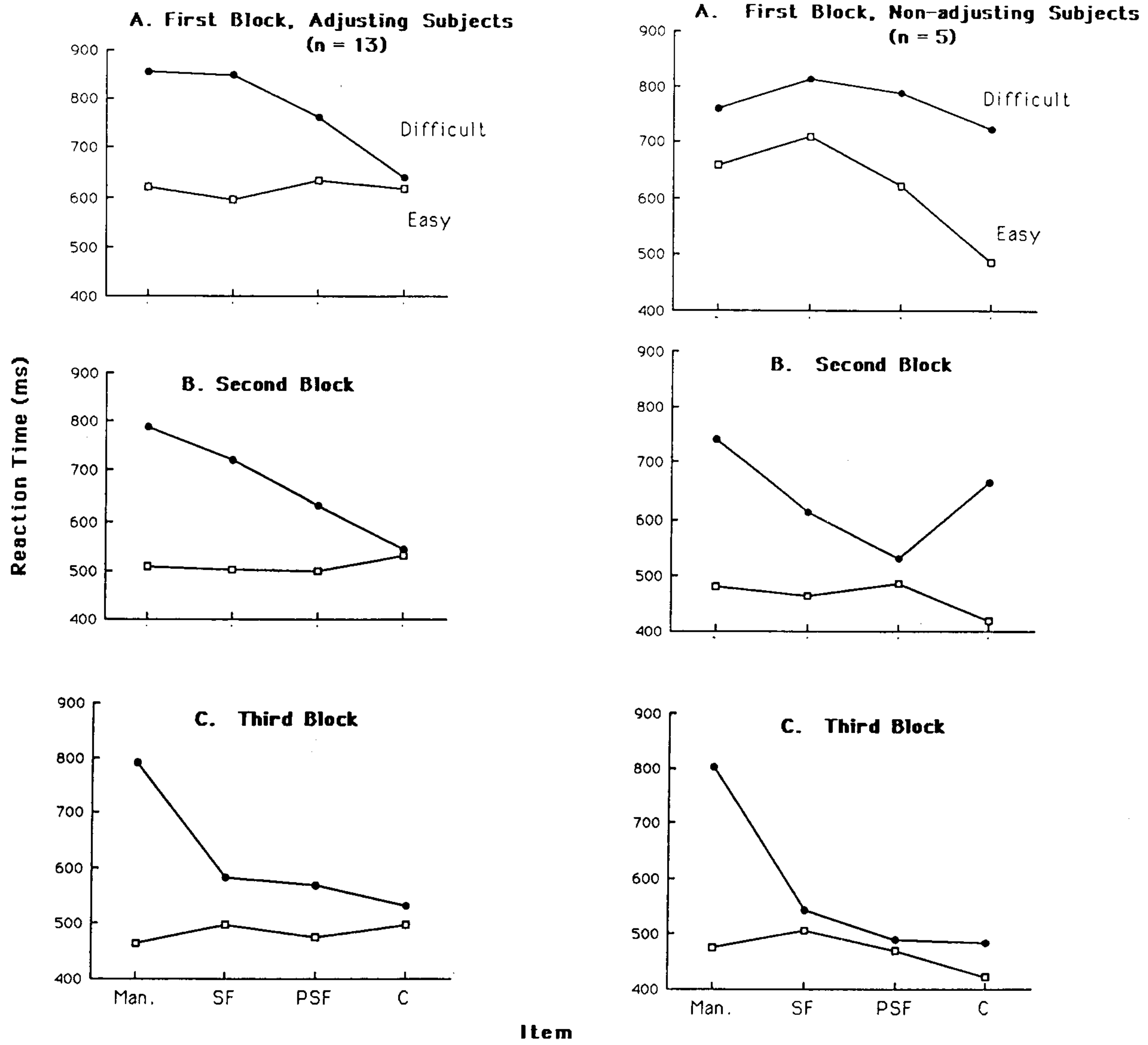

Figure 2. Reaction times to prototypes for adjusting (left panel) and nonadjusting (right panel) subjects in Experiment 1, as a function of prototype, block, and environment.

Reaction times for nonadjusting subjects. RTs for correct prototype responses by these 5 subjects are shown in the right panel of Figure 2. Their results are similar to those for the adjusting subjects except on the first block in the difficult environment, in which there is little or no gradient indicative of a feature-based adjustment. Apparently, during the first block, most of these subjects were not attending to the aspects of letter structure crucial for distinguishing between the manipulated prototype and its distortions. As a result, they continued to make errors in later blocks. However, they did learn that there was only one difficult item, and consequently, their later adjustments were similar to those of the adjusting subjects. There were main effects of environment [$F(1,4) = 36.53$, $p < .01$], block [$F(2,8) = 5.21$, $p < .05$], and prototype [$F(3,12) = 7.86$, $p < .01$]. The three-way interaction of these factors was not reliable [$F(6,24) = 2.09$, $p > .05$].

Effects for each letter set. Because different groups of subjects received different assignments of stimuli, the analyses above contained error due to items, permitting generalization across items. However, examination of the RTs for each letter set suggested that although the identity-based and decisional adjustments in Block 3 were generally consistent across letter set, there was inconsistency in the feature-based adjustments in Blocks 1 and 2. These data should be interpreted with caution, because relatively few observations contributed to each datapoint. Nevertheless, the trends in the data support an explanation discussed below. The data for each letter set are shown in Figure 3, in the same manner as in Figure 2. (For these data, subjects were eliminated for each letter set on the

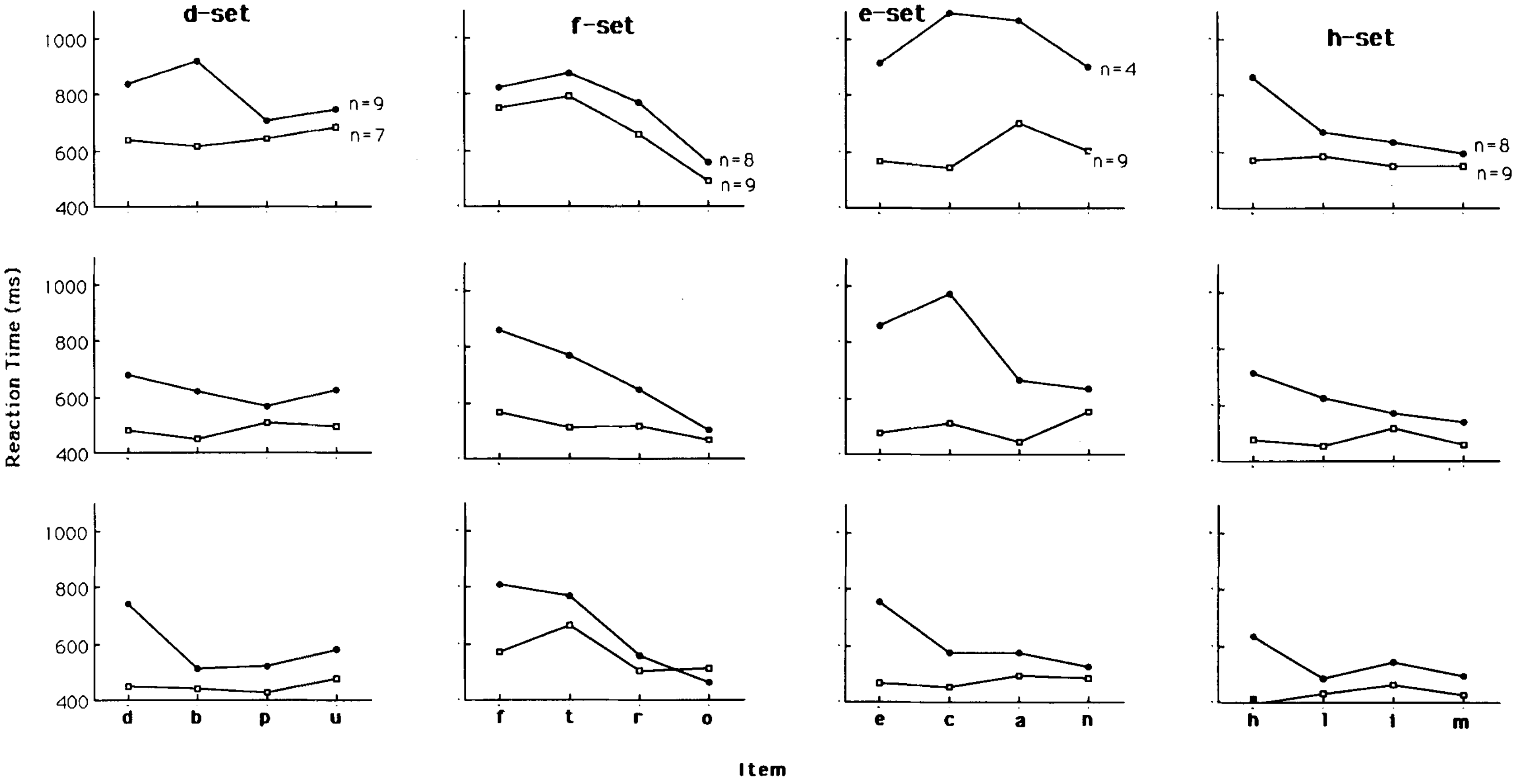

Figure 3. Reaction times to prototypes by adjusting subjects in Experiment 1 for each letter set, as a function of block and environment. Note that the first letter listed on each abscissa is the manipulated letter, the second the SF letter, the third the PSF letter, and the fourth the C letter. (Closed symbols, difficult environment; open symbols, easy environment.)

basis of the 25% error criterion, resulting in different *n*s for each letter set, as shown in the figure.)

There are two important features of these data (discussed below). First, in Blocks 1 or 2, there were feature-based effects for three sets but not for the fourth (the "h" set). Second, the feature-based adjustments for two of the three affected sets involved the SF letter but not the PSF letter (only in the "f" set was there an effect for the PSF letter).

Discussion

The differences between the adjusting and nonadjusting subjects, in both patterns of errors and RTs, provide strong evidence that adjustments to the difficult stimuli were implemented by adjusting subjects. Of primary interest were the RTs for prototypes. With the adjusting subjects, the data indicate that the adjustments were initially based on similarities (shared features) between manipulated and nonmanipulated items. However, as the subjects gained experience with the stimuli, the adjustments became restricted mainly to the manipulated items, and shared features were no longer important.

The patterns of RT effects in the first two blocks were not consistent across letter sets. Although this may be due to the small numbers of observations, the data suggest two qualifications with respect to the preceding conclusions about effects on features. First, for most of the letter sets, no evidence indicated that feature-based adjustments affected the PSF letters relative to the C letters. Therefore, adjustments may generally be limited to letters that share the critical component to a high degree.

A second qualification concerns the assumption, used in creating the stimuli, that features correspond to local parts of letters. The fact that expected effects did not occur in one case suggests that subjects may not have always used such features in their adjustments. Specifically, it seems that "h" and "l" share the critical part *ascender* to a high degree; however, there was no evidence that the adjustment to the ascender of the "h" extended to the "l" (see Figure 3, panel 4). An alternative hypothesis about the features is that they correspond to parts *within specific types of relational contexts*. According to this hypothesis, the relation between the ascender and body was quite different in "h" as opposed to "l." In contrast, the relational contexts of critical parts were more consistent for the three letter sets that yielded feature-based effects (see Table 1).

EXPERIMENT 2

The initial adjustments obtained in Experiment 1 have been interpreted in terms of shared features. However, an alternative explanation is that they depend on overall similarity between letter prototypes. According to this hypothesis, adjustments affect letters that have high overall similarity to the manipulated letter. In this alternative hypothesis, it is assumed that the overall similarity between letters remains constant. Therefore, the relative degree of similarity between letters should remain constant as the environment changes.

In contrast to the similarity-based explanation, feature models (based on independent features or relational networks) assume that similarity is based on shared features and that the features can change with the environment. Therefore, if two different features of a single letter prototype are each used as the critical part in two separate difficult environments, then differing feature-based adjustments should be made in the two cases. Thus, a nonmanipulated prototype sharing the critical feature of Environment A should be affected in that environment more than in Environment B, whereas the opposite should occur for a second nonmanipulated prototype sharing the critical feature of the B environment. In contrast, since the relative degrees of similarity should remain constant in the similarity-based explanation, the degree to which the shared-feature letters are affected should not change.

Method

There were four sets of letter prototypes. As in Experiment 1, each set of prototypes had two versions; however, in both versions, the one manipulated letter had difficult distortions. The distortions were of one critical part in the A environment and of another critical part in the B environment. In each set, the SFA letter shared the critical part of the A environment, whereas the SFB letter shared the critical part of the B environment. The fourth letter (Type C) did not share either critical part. As in Experiment 1, the distortions of the three nonmanipulated letters were always easy and remained constant across environments. Critical parts were chosen to be consistent with traditional feature models. The stimulus sets are summarized in Table 4.

Half of the subjects received Sets 1 and 3 in the A environment and Sets 2 and 4 in the B environment; the other half received the opposite assignment. Orders were counterbalanced. Stimulus presentation and procedural details were similar to those in Experiment 1. There were 24 new subjects from the same population as before.

Results

Two subjects exceeded the 25% error criterion and were eliminated from the analyses. For the main analyses, the data were collapsed across letter sets. The pattern of er-

Table 4
Four Letter Sets and Critical Parts Used in Environments A and B of Experiment 2

Letter Set	M	SFA	SFB	C	Critical Part
"h"	h	l	n	x	(A) Height of ascender (B) Size of upper notch at juncture
"j"	j	i	t	u	(A) Dot-body separation (B) Extent of terminator at bottom
"*a*"	a	r	o	z	(A) Notch size at juncture (B) Height of body
"g"	g	f	p	k	(A) Extent of curved terminator (bottom or top) (B) Height of body

Note—Each set includes a manipulated letter (M), shared-feature A letter (SFA), shared-feature B letter (SFB), and a control letter (C).

rors was generally similar to that in the previous experiment and will be reported after the RT results.

Reaction times. The 3-sec limit was exceeded by five responses to prototypes (0.2% of the data), which were omitted from the analyses. The means are shown in Figure 4. The changes from block to block are generally similar to those in Experiment 1; RTs decreased considerably for the three nonmanipulated prototypes, but much less for the manipulated prototype. Of particular interest is the relation between the nonmanipulated SFA and SFB prototypes in the first block. The SFA prototype shared the critical feature in Environment A, whereas the SFB shared the critical feature in Environment B. As can be seen, RTs were inflated much more for the SFB prototype than they were for the SFA prototype in Environment B, and there was much less of a difference in Environment A. This interaction between prototype and environment is consistent with the feature-based models, but not with the similarity-based explanation. In the similarity-based explanation, the relative degree of similarity between letters should not change as a function of environment, so the RT gradient for the SFA and SFB prototypes should not change.

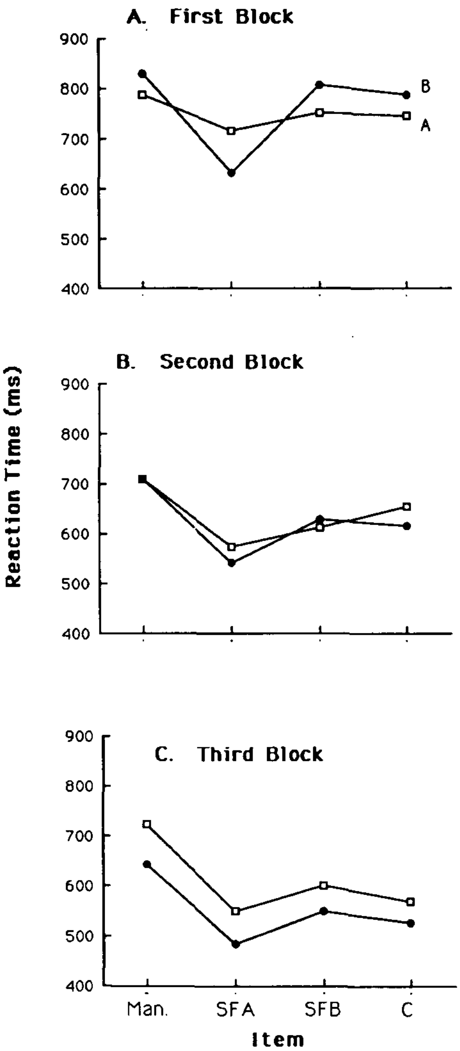

Figure 4. Reaction times to prototypes in Experiment 2 as a function of prototype, block, and environment.

Table 5
Error Rates (in Percent) for Prototypes (P) and Distortions (D) of the Manipulated Items in Experiment 2, as a Function of Block and Environment

	Environment A		Environment B	
Block	P	D	P	D
1	8.0	54.5	6.8	43.9
2	4.6	31.1	4.6	19.7
3	3.4	22.0	5.7	12.1

Table 6
Error Rates (in Percent) for Prototypes (P) and Distortions (D) of the Nonmanipulated Items in Experiment 2, as a Function of Block and Environment

	Shared Feature A		Shared Feature B		Control	
Block	P	D	P	D	P	D
			Environment A			
1	2.3	1.2	2.9	0	3.2	1.9
2	1.1	1.1	3.1	1.1	1.1	2.1
3	1.9	1.1	0	0	1.1	1.6
			Environment B			
1	3.9	1.6	1.9	1.1	3.0	1.1
2	2.1	2.5	1.9	0	2.1	2.1
3	1.9	1.1	1.6	1.1	1.9	2.1

There were main effects of block [$F(2,21) = 49.11$, $p < .01$] and prototype [$F(3,21) = 12.87, p < .01$], but not of environment [$F(1,21) > 1$]. None of the interactions were reliable. However, the interaction between the SFA and SFB prototypes and environment during the first block was reliable [$F(1,21) = 4.47, p < .05$], supporting the feature-based explanation.

Error rates. For the manipulated items (Table 5), there were the expected effects of environment [$F(1,21) = 5.52$, $p < .05$], block [$F(2,42) = 38.95$, $p < .001$], and response [$F(1,21) = 160.92, p < .001$], as well as the interactions of environment and response [$F(1,21) = 7.46$, $p < .05$] and block and response [$F(2,42) = 27.24$, $p < .001$]. For nonmanipulated items (Table 6), error rates were generally low (less than 4%), although there were numerous small effects, of block [$F(2,42) = 6.18$, $p < .01$], response [$F(1,21) = 21.73, p < .001$], and item [$F(2,42) = 4.32, p < .05$], as well as the interaction of environment, block, and item [$F(4,84) = 2.86, p < .05$]. As in Experiment 1, errors were more frequent for prototypes than for distortions of nonmanipulated items. However, the higher rate of errors for distortions of the SF prototypes in the difficult environments of Experiment 1 was not replicated.

Effects for each letter set. The crucial finding in this experiment was the interaction between the SFA and SFB

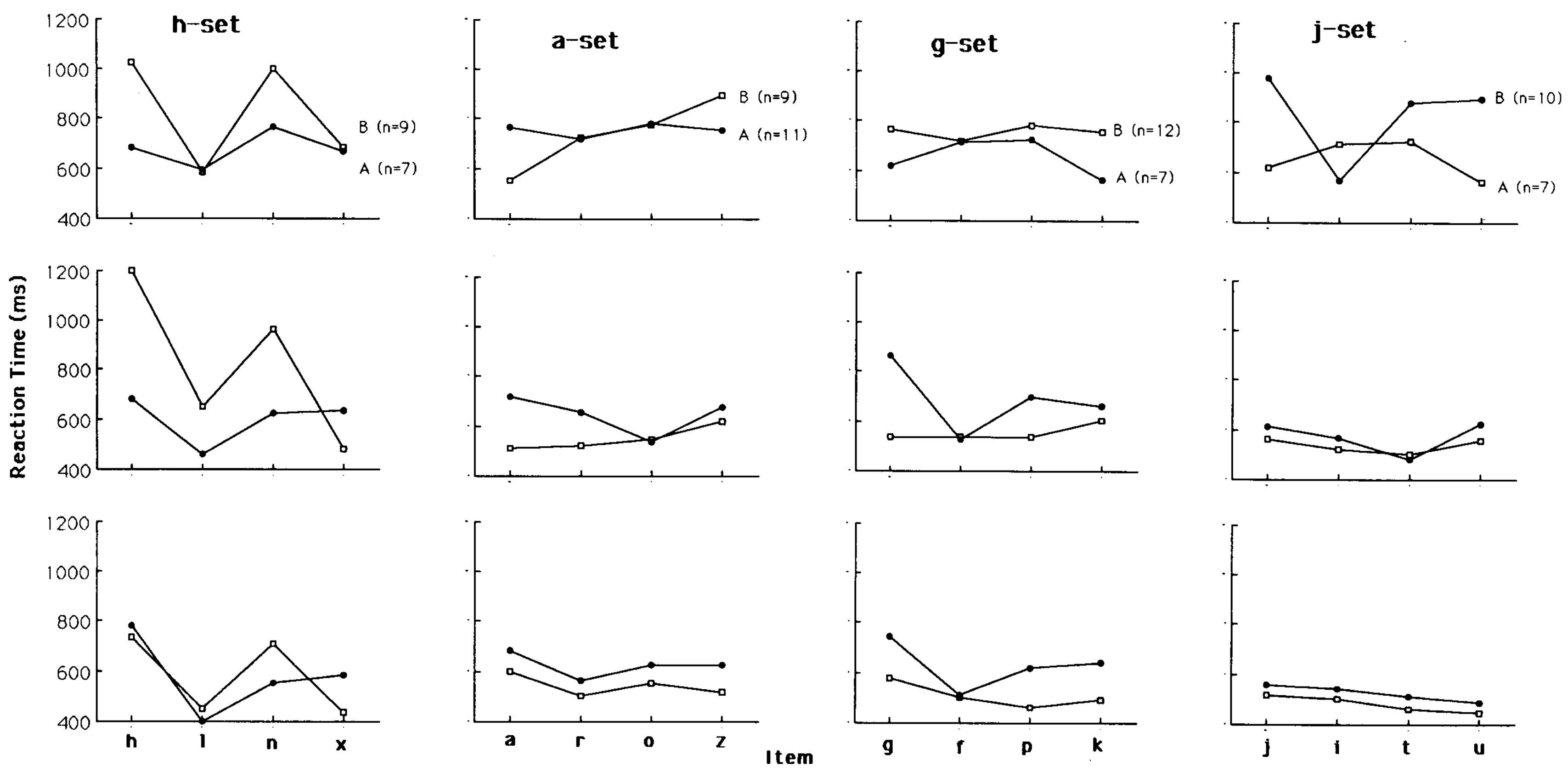

Figure 5. Reaction times to prototypes for each letter set in Experiment 2 as a function of prototype, block, and environment. Note that the first letter listed on each abscissa is the manipulated letter, the second the SFA letter, the third the SFB letter, and the fourth the C letter. (Open symbols, A environment; closed symbols, B environment.)

prototypes in the first block. As in Experiment 1, the crucial effect varied with letter set, in this case ranging from zero with the "*a*" set to quite large with the "j" set. The data for each letter set are shown in Figure 5.

Discussion

The crucial result of the present experiment was the interaction of environment and prototype (SFA or SFB) in the first block. The fact that such interactions occurred in any cases is inconsistent with the similarity-based explanation, because the relative amounts of interletter similarity in that explanation (and thus, the relative size of adjustment effects) should remain constant from environment to environment.

Although the results were inconsistent with the present similarity-based explanation, the results do not rule out other models that incorporate the idea of similarity between items. For example, similarity relations might be affected by what is known about the stimulus set (see, e.g., Crist, 1981) and therefore might change, depending on the subject's knowledge of critical features or relations. The latter type of model is difficult to distinguish from a feature model, in that shared features or shared relations determine adjustments within both types of model.

There was variation between letter sets in the size of the crucial interaction. The reasons for this are not obvious. Again, the variation could be due to the small numbers of observations for each set. Another possibility is that subjects were using relational features, rather than features based on independent, local parts. Indeed, note that the strongest first-block interaction was found for the "j" set (fourth panel). In this set, one critical relation would have been the dot's height above the body, which was shared by the SFA letter "i." The other critical relation was the extent of the tail, which was shared by the SFB letter "t." In some other cases, subjects may attend to general relations that apply to many letters such as "fatness" or overall "height" (see below).

EXPERIMENT 3

When they were obtained, the feature-based adjustments in the first two experiments generally lasted for only one block, raising questions about their longevity. Our purpose in carrying out Experiment 3 was to examine whether longer feature-based adjustments could be obtained. Because there had been only one manipulated letter in each set of the previous experiments, it might have been easy for subjects to learn a distinction between that letter and the nonmanipulated letters; this distinction would have supported identity-based adjustments. To make it more difficult to learn such a distinction in Experiment 3, the number of manipulated letters was increased to four. There were four nonmanipulated letters; two shared the critical feature (SF letters), and two were controls (C letters) that did not contain the critical feature. Feature-based adjustments would be indicated by an increase in response times for the SF letters, relative to the C letters.

In a pilot study, two stimulus sets were used, and across subjects each set appeared in an easy and difficult environment. As in the previous experiments, the letters and the critical parts were motivated by models based on local part features. Evidence of a feature-based adjustment was obtained for only one set. In the "k" set, for which a feature-based effect was *not* obtained, the critical part was the ascender, which varied in height. RTs were inflated in the difficult environment for the manipulated letters ("k," "l," "d," and "t"), and for the SF letters ("b" and "h"), but also for the Type C letters ("x" and "r"). It is possible that the functional feature was not the ascender, but perhaps a general relation such as the relative height of the entire letter. Since height pertains to all letters, adjustments based on height would have affected all of the letters.

An emphasis on feature relations would be consistent with relational network models (e.g., those of Oden, 1979, and Palmer, 1975), and it provides a different perspective on what subjects are doing in the task. Briefly (this idea is elaborated below), the idea is that subjects attend to relations between parts. In the present case, where the size of parts is especially important, subjects may attend to relations involving the sizes of the critical parts and neighboring parts. When the manipulated and SF letter(s) share those relations, adjustments will be based on them. However, when the relations are not shared, or when relations vary between manipulated letters, alternative strategies may be used.

In the pilot study, the set for which a feature-based effect was obtained had as a critical part (the extent of) a terminating segment (for "g," "a," "c," and "j"). The part was shared by the Type SF letters ("e" and "y"), but not the Type C letters ("n" and "o"). In this case, the functional feature might involve the curved terminator, *in relation to* the middle part of the letter. Although the orientation of the relationship varies from letter to letter, the relationship between terminator and letter body exists in each letter. For this set, the feature-based adjustments lasted throughout the relevant portion of the session. In the present experiment, both letter sets were selected, in a manner consistent with relational feature models, around critical parts that had fairly consistent intraletter relations across the manipulated and SF letters.

Method

There was one block in the easy environment, followed by four blocks of trials in the difficult environment. Two sets of prototypes were used, and for different halves of the subjects, each set was used once in the easy environment and once in the difficult environment. The "g" set contained four manipulated letters ("g," "t," "c," and "j"), two SF letters ("e" and "y"), and two C letters ("o" and "n"). Four distortions of each letter were used in the easy environment; these distortions were obvious violations of the letter's structure. In the difficult environment, three distortions of each manipulated letter were replaced by difficult distortions that involved small extensions or contractions of the terminating segments at the bottom of the letter, as in Figure 6 (top row). For "c," both terminating segments were distorted, resulting in symmetrical distortions. The other set was the "b" set, which also contained

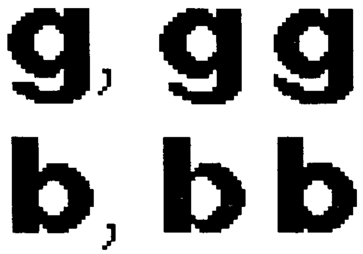

Figure 6. Examples of prototypes (first item in each row) and distortions (second two items) in Experiment 3.

four manipulated letters ("b," "*a*," "q," and "h"), two SF letters ("d" and "p"), and two C letters ("i" and "x"). In this set, the difficult distortions involved either an enlargement or a shrinking of the portions of the loops that join the vertical stroke, also as in Figure 6 (bottom row).

The apparatus and procedure were similar to those in Experiment 1, except for the following changes. During the one block in the easy environment, there were 8 practice trials with randomly selected stimuli, followed by four subblocks of 16 trials each. In each subblock, each prototype appeared once, as well as one distortion of each prototype. In the difficult environment, the four blocks each had four subblocks of 16 trials each. Each prototype appeared once during a subblock, as did one distortion of each prototype. The stimuli were randomly selected on each trial; there were no buffer trials in this experiment. The intertrial interval was the same as before, but no warning signal was used. Twenty-six new subjects from the same population served.

Results

No subjects in this experiment exceeded the 25% error criterion for the last two blocks in the difficult environment.

Reaction times. There were 51 responses to prototypes that were longer than the 3-sec limit (1.2% of the data), and they were omitted in the analyses. In the main analyses, data were collapsed within the three types of prototypes. Means are shown in Figure 7, with each of the four blocks in the difficult environment plotted. As can be seen for the easy environment, there were no differences between the three types, as was expected. In the difficult environment, RTs were longest for the manipulated prototypes, a bit shorter for the SF prototypes, and much shorter for the C prototypes. The most important result is that RTs are slowed considerably more for the SF prototypes in the difficult environment than for the C prototypes, indicating a feature-based adjustment. Furthermore, this pattern held across all four blocks, indicating that feature-based adjustments can be long-lasting under the appropriate conditions.

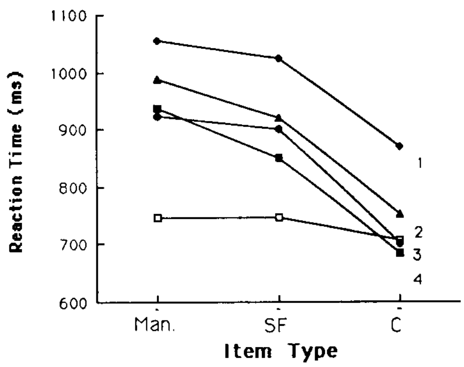

Figure 7. Reaction times for each type of prototype in the easy environment (open squares) and in each block of the difficult environment (filled symbols) in Experiment 3.

Separate analyses were conducted for the easy and difficult environments, with letter type, letter set, and (for the difficult environment) block as factors. In the easy environment, there were no reliable effects of type or letter set [for the main effect of type, $F(2,48) = 2.14$, $p > .10$]. In the difficult environment, there were main effects of block [$F(3,72) = 13.54, p < .001$] and of letter type [$F(2,48) = 41.81, p < .001$], but no interaction of block and type [$F(6,144) < 1$]. There was an interaction of block and letter set [$F(3,72) = 3.39, p < .05$], which stemmed from the fact that the "g" set was initially more difficult, but showed more improvement over time. The interaction of block, letter type, and letter set was not reliable [$F(6,144) = 1.87, p > .05$].

As noted, the crucial finding is that RTs in the difficult environments were longer for the nonmanipulated, SF prototypes than for the C prototypes. Planned comparisons indicated that in the difficult environment, RTs were reliably slower for the SF prototypes than for the C prototypes [$F(1,25) = 35.80, p < .001$]. There was also a difference between SF prototypes and manipulated prototypes [$F(1,25) = 6.67, p < .05$], with responses to manipulated prototypes being somewhat slower. This implies that in addition to feature-based adjustments, there were some additional identity-based adjustments. Clearly, however, the major effect in this experiment was a feature-based adjustment.

The nonmanipulated letters in each letter set are shown in Table 7, together with their RTs in the difficult environment. As can be seen, within each set, the RTs for each SF letter are inflated considerably, relative to those for the C letters. This provides further evidence that the present effects were consistent across stimulus sets and letters.

Error rates. Errors were analyzed separately for the easy and difficult environments, and separately for manipulated and nonmanipulated letters. Error rates for manipulated and nonmanipulated stimuli in both environments are shown in Table 8. In the easy environment, error rates were generally low and there were no reliable effects. In the difficult environment, effects were as expected. For manipulated items, there were effects of block [$F(3,75) = 24.49, p < .001$] and response [$F(1,25) = 95.38, p < .001$], and there was an interaction of these factors [$F(3,75) = 9.55, p < .001$]. For nonmanipulated items, there were effects of block [$F(3,75) = 6.67$], and response [$F(1,25) = 28.38, p < .001$], and there was an interaction of these factors [$F(3,75) = 9.94, p < .001$]. There was no effect of type of letter (SF vs. C) [$F(1,25) = 2.02, p > .10$], and there were no interactions involving this factor. As in previous experiments, errors were more frequent for prototypes than for distortions of nonmanip-

Table 7
Reaction Times (in Milliseconds) for Nonmanipulated Prototypes in the Difficult Environment of Experiment 3

Letter Set	Shared Feature	RT	Control	RT
"g"	e	851	o	693
"g"	y	790	n	699
"b"	d	976	i	818
"b"	p	1,088	x	798

ulated items. As in Experiment 2, the increased error rate for SF distortions in Experiment 1 was not replicated.

Discussion

Experiment 3 indicates that when it is difficult for subjects to learn the distinction between manipulated and nonmanipulated letters, feature-based adjustments can be long lasting. Furthermore, the fact that strong feature-based effects were obtained when the critical parts were within consistent intraletter contexts provides support for the idea that the features are relational in nature. We will now restate the relational feature hypothesis in a more general way.

The hypothesis is based on the idea that parts of letters are represented and processed in relation to each other. The relations may vary in generality, from very specific relations such as the relative positions and sizes of specific, neighboring parts, to general relations pertaining to all letters, such as relative height or height–width ratio. We assume that subjects make specific adjustments when possible—that is, when the critical part has an adjacent part (or parts) that can be used in perceiving the critical part's relative size. This will produce effects on SF letters if those letters contain similar relations. Otherwise, the manipulated item will be the only one affected, because only it has the critical relation; this would produce an effect similar to identity adjustments (as in the "h" set of Experiment 1). In one other case, a specific local relation is not available; for example, in the "k" set of the pilot study mentioned above, the context of the critical part ascender changed from manipulated letter to manipulated letter (e.g., "k," "l," or "d"). In such cases, adjustments may be based on general relations such as height. Adjustments based on general relations affect many letters, producing the same effects as a decisional adjustment.

In sum, feature-based effects seem most likely to occur for parts occurring in consistent intraletter contexts. In cases in which feature-based effects were not obtained, the critical parts but not the critical relations were shared by the manipulated and SF letters. In these cases, adjustments appear to have been restricted to the manipulated letter, or to have affected all letters because they involve general relations.

EXPERIMENT 4

The results from the first three experiments indicated that feature-based adjustments occur, and that they can be rather long lasting under certain conditions. However, the initial assumption that features correspond to functionally independent, local parts of letters was not strongly supported by the data for individual letter sets, nor by the pilot study mentioned above. As an alternative, we suggested that features might be relational in nature, corresponding to relations within specific intraletter contexts. This assumption receives some support from post hoc explanations of the effects for each letter set in Experiments 1 and 2, and from the fact that robust feature-based effects were obtained in Experiment 3 with stimuli selected on the basis of this assumption.

An essential difference between the two hypotheses about features is that in the local features hypothesis, parts are processed independently of each other, whereas in the relational features hypothesis, parts are processed within networks. As noted above, the assumption that parts should be functionally independent is similar to the idea of separable dimensions (see, e.g., Garner, 1974), which implies that the features can be attended to independently of other features, and that their processing is not facilitated by additional, redundant information. In contrast, a nonseparable feature or dimension (e.g, an integral dimension) cannot be selectively attended to with complete success, but its processing can be facilitated by additional, redundant information. If features correspond to local parts and are functionally independent of each other, they should function as separable dimensions. In contrast, the relational features hypothesis implies that different parts of a stimulus should not be entirely separable, because they are interrelated within the network.

The purpose of Experiment 4 was to examine the functional independence of letter parts in the present task.

Table 8
Error Rates (in Percent) for Prototypes (P) and Distortions (D) In Experiment 3, as a Function of Block and Environment

		Manipulated		Shared Feature		Control	
Environment	Block	P	D	P	D	P	D
Easy		2.7	4.8	2.5	2.4	4.8	3.4
Difficult	1	8.9	36.9	13.8	1.0	9.1	0.5
Difficult	2	5.5	24.6	6.4	1.0	3.9	1.4
Difficult	3	3.9	20.7	4.3	1.9	1.9	3.4
Difficult	4	4.5	17.8	3.5	1.0	2.9	1.9

There was again an easy condition, followed by a difficult condition. (These are referred to as conditions, rather than environments, because all of the items had difficult distortions in the difficult condition.) In the difficult condition, subjects were directed to base their responses on one critical part, which changed subtly in size in all distortions. The critical part appeared in the same position from item to item, and existed in three types of contexts (three types of prototypes), which varied in the amount and type of additional, irrelevant information they contained. The stimuli are shown in Figure 8. The control prototype consisted *only* of the one, critical part, and is referred to as Type O (in order to distinguish it from Type C in the previous experiments). The consistent-feature, Type CF prototype, was similar to the O prototype, except that a second, irrelevant part was added to the critical part (see Figure 8). This part remained constant throughout the experiment, and thus provided a consistent context, although the part per se did not provide useful information. The inconsistent-feature, Type IF prototype was similar to the consistent-feature prototype except that a third, irrelevant part was added to the stimulus. This third part varied irrelevantly in size across versions of the prototype, and therefore provided an inconsistent, potentially interfering context (see Figure 8).

If different parts of letters are perceived independently, as in the local features hypothesis, it should be possible for subjects to selectively attend to the critical part; irrelevant information from neighboring parts should have no effects. In contrast, if the critical parts are perceived in relation to the neighboring parts, ostensibly irrelevant information should have negative and perhaps also positive effects in the task. In particular, the most important prediction of the relational hypothesis is that inconsistent information in the IF prototype should have negative effects because the changing context should interfere with the perception of the critical part. A further possibility is that the CF prototype may have facilitative effects on RT, because it provides a consistent context for the critical feature.

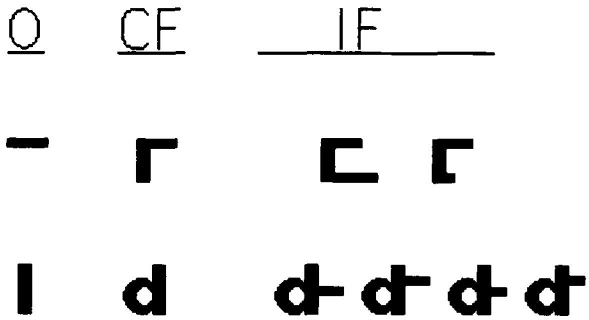

Figure 8. Prototypes in Experiment 4. In each row, there are the C and CF items, followed by the IF items.

Method

There was one block of trials in the easy condition, followed by four blocks in the difficult condition. There were two letter sets, and across subjects, each set was used equally often in both conditions. In the easy condition, the distortions were all easy, created by erasing a portion of each prototype, leaving a gap. In the difficult condition, the distortions were all difficult, created by subtly increasing or decreasing the length of the critical part. There were three types of prototypes in each set, as described above: control (O), consistent-feature (CF), and inconsistent-feature (IF). There were two (in the "r" set) or four ("d" set) versions of the IF prototype, generated by varying the width and (in the "d" set only) the vertical position of the irrelevant part. Each stimulus is shown in Figure 8. Each *type* of prototype appeared with equal frequency, meaning that each version of the IF prototype appeared less frequently than the O and CF prototypes.

The blocks consisted of 48 trials each, with breaks given at the beginning and middle of each block. The relevant prototypes were displayed for subjects to examine at the beginning of a condition, and the nature of the distortions was explained (although no examples were shown). In the difficult environments, the critical part of the prototypes was pointed out to subjects. The stimulus display and procedure were similar to those in Experiment 3. Ten new subjects served; they were from the same population as before.

Results

No subjects exceeded the 25% error criterion during the last two blocks of trials. Analyses were conducted separately for the easy and difficult conditions.

Reaction times. There were 16 outliers (in which RT exceeded 3 sec) in the data for prototypes (1.3% of the data), which were omitted from the analyses. Of main interest is the pattern of differences between the three types of prototypes. In the easy condition, there were no differences between types. In the difficult condition, the main prediction of the relational feature hypothesis was that the irrelevant variation of the inconsistent-feature prototype (IF) would increase RTs relative to the control prototype (O). Indeed, the mean of 933 msec for the IF prototype was reliably longer than the mean of 833 msec for the O prototype [$F(1,8) = 16.25$, $p < .01$]. The effect was consistent across the two stimulus sets [$F(1,8) = 2.00$, $p > .10$, for the interaction of prototype and letter set]. This indicates that features are not entirely independent of each other; variation of one feature can interfere with responses based on another feature. A secondary prediction of the relational feature hypothesis was that the consistent but irrelevant feature of the consistent-feature prototype (CF) would facilitate processing. However, the mean for this prototype (831 msec) was not different from that for the O prototype, indicating that in the present case, an added consistent context was not helpful.

An overall analysis was conducted with letter set, type, and (in the difficult condition) block as factors. As noted above, there were no effects in the easy condition. In the difficult condition, there were main effects of type [$F(2,16) = 9.71$, $p < .01$], and block [$F(3,24) = 10.71$, $p < .001$]. In addition, letter set interacted with block [$F(2,16) =$

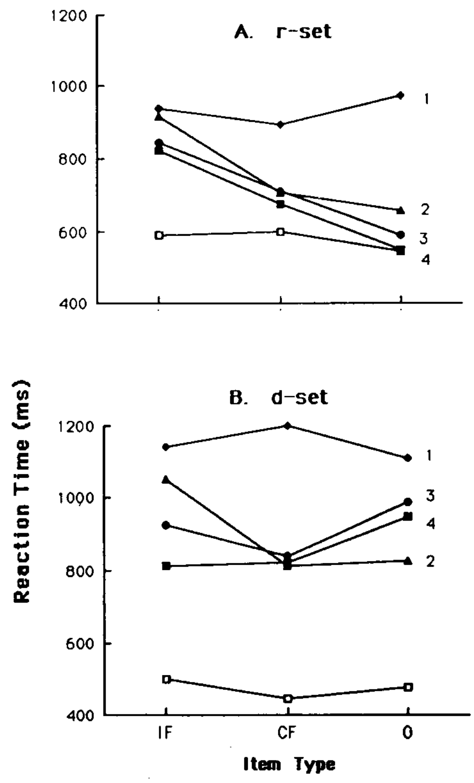

Figure 9. Reaction times to prototypes of each type and in each block in Experiment 4; data for the "r" set are shown in the top panel and for the "d" set in the bottom panel. (Open squares are for the easy condition; filled symbols are for each block of the difficult condition.)

5.45, $p < .05$], and with type and block [$F(6,48) = 2.36$, $p < .05$]. The interaction involving letter set and type appears to stem mainly from the CF prototype (there was no interaction involving letter set when the O and IF types were compared, as reported above). For the CF prototype, responses were faster than for the O prototype in some blocks with the "d" set, but slower than for the O prototype in some blocks with the "r" set. The data for each set are shown in Figure 9. For the "r" set, RTs decrease considerably by the second block for the O and CF prototypes, but not for the IF prototype. For this set, there was an effect of type [$F(2,8) = 10.01$, $p < .01$] and a block × type interaction [$F(6,24) = 2.69$, $p < .05$]. For the "d" set, the only reliable effect was that of block [$F(3,12) = 6.84$, $p < .01$].

Error rates. Error rates are shown in Table 9. In the easy condition, error rates were generally low. The only effect was an interaction of letter set and response [$F(1,8) = 6.74$, $p < .05$]. In the difficult condition, error rates were higher, especially for distortions of the IF prototype. There were effects of block [$F(3,24) = 4.77$, $p < .01$], response [$F(1,8) = 32.67$, $p < .001$], and letter set [$F(1,8) = 9.43$, $p < .05$], and interactions of letter set and item [$F(2,16) = 7.68$, $p < .01$], response and item [$F(2,16) = 12.26$, $p < .001$], and letter set, response, and item [$F(2,16) = 11.04$, $p < .001$].

Discussion

The main result of this experiment was that irrelevant variation of an added feature interfered with perceptual processing. This supports the idea that the functional features in the present situation involve relations between critical parts and their intraletter contexts. The results are inconsistent with the idea that each component part of the stimulus is perceived independently of the other parts.

The negative effects of irrelevant variation can be explained in at least two ways. First, the IF prototypes could have been viewed by subjects as a single prototype with parts varying in apparent size; this variation could have interfered with classifications. An alternative explanation involves the assumption that subjects used whole stimuli in processing, and viewed each version of the IF prototype as a separate stimulus. Since each *version* of the IF prototype appeared with less frequency than versions of the O and CF stimuli (see Experiment 4, Method section), frequency may have contributed to lower performance in the IF condition. Like the relational features hypothesis, this explanation implies that subjects were not selectively attending to the critical part; the critical part is perceived in relation to the entire stimulus. Therefore, the explanation is not inconsistent with the main conclusion of this experiment. However, note that this explanation would have problems if applied to Experiment 2, because the interaction of environment and prototype indicated that adjustments were based on components of the stimuli, rather than overall similarity between whole letters. Also, note that in the card-sorting task used to diagnose separability, stimuli appear with less frequency in irrelevant variation conditions than in control or correlated conditions; however, if the dimensions are separable, there is no effect of frequency (Garner, 1974).

Table 9
Error Rates (in Percent) for Prototypes (P) and Distortions (D) in Experiment 4, as a Function of Block and Environment

		Control		Consistent		Inconsistent	
Environment	Block	P	D	P	D	P	D
Easy		3.8	2.5	0	0	1.2	2.5
Difficult	1	10.5	22.8	15.0	26.0	8.8	32.5
Difficult	2	10.8	11.4	8.8	19.1	1.2	26.2
Difficult	3	7.5	7.5	2.5	13.8	3.8	25.0
Difficult	4	7.5	17.7	5.0	11.2	5.0	21.2

Although the relational features hypothesis was supported by the negative effects of irrelevant variation, the prediction that a consistent context would facilitate processing was not borne out. This suggests that the role of feature relations in the present situation is not completely understood. Also, note that the lack of separability of features does not necessarily imply integrality of features. Features could be asymmetrically integral, or perhaps configural in nature (see Garner, 1978). Indeed, further research will be necessary to more precisely define relational features and their role in perceptual processing (see also Pomerantz & Pristach, 1989).

GENERAL DISCUSSION

The goals of the present investigations were to develop a method for systematically examining several possible types of perceptual adjustments at varying points in time, and to pinpoint the nature of feature-based adjustments. With regard to the first goal, we obtained evidence at different times for feature-based, identity-based, and decisional adjustments. For example, in Experiment 1, adjustments were initially based on similarities between letters (shared features), but with experience, adjustments became restricted to the manipulated item. However, feature-based adjustments can be relatively permanent when the distinction between manipulated and nonmanipulated letters is less clear (Experiment 3).

In pursuing the second goal, our initial hypothesis was that features would correspond to functionally independent parts of the letters. However, in the first three experiments, there was some evidence against the hypothesis; in analyses of individual sets of items, feature-based effects did not occur in cases in which they should have (Experiments 1 and 2). In addition, a feature-based effect was not obtained in the pilot study reported in the introduction to Experiment 3. On the other hand, the same observations were consistent with the idea that features are relational in nature, and that adjustments based on shared features occur only when the manipulated and shared-feature items share critical parts within similar intraletter contexts. Experiment 4 provided direct evidence for the relational features hypothesis and against the independent features hypothesis: Subjects were unable to selectively attend to one critical part when ostensibly irrelevant contextual parts varied in size.

Implications for Some Models

The variety of adjustments obtained presents a serious challenge for some types of models. For example, the logogen model is based on the idea of abstract detectors that represent items across variations from instance to instance (see, e.g., Morton, 1969). Such a model has problems with the adjustments in terms of features obtained in Experiments 1, 2, and 3, because perceptual information is processed internally by the detectors, and is not available for adjustment. Therefore, adjustments in such a model would be limited to either the manipulated (difficult) items or all items, but they would not occur for items that shared features, since information about shared features would not be available. Modification of the model to make available information about an item's underlying structure would seem inconsistent with the general spirit of the model.

As noted, the results are inconsistent with the assumption that features correspond to functionally independent parts (see, e.g., Keren & Baggen, 1981; Townsend & Ashby, 1982). Models that include this assumption could be modified by including features that correspond to relations between parts; such a change would make them similar to relational network models (e.g., those of Oden, 1979, and Palmer, 1975).

Network models are based on the idea that knowledge is represented in terms of interrelated propositions (see, e.g., Oden, 1979; Palmer, 1975). There are propositions representing identities of items, and these propositions are linked to lower level propositions representing features and relations, and through them eventually to primitive sensory features. Because a proposition may represent any relevant relationship between its components, the resulting interconnected networks can be arbitrarily rich.

Adjustments of evidence criteria have been accounted for within a fuzzy propositional framework, in which propositions can be true to varying degrees about a stimulus (Oden, 1984). In this case, propositions can include modifiers such as "very" or "slightly," to indicate the salience of a component value within some particular context (see, e.g., Massaro & Oden, 1980; Oden, 1981; Oden & Massaro, 1978). For example, if the exact length of a segment is important, then the proposition that a segment "is length x" could be modified to "is *very* (length x)." This would sharpen the function relating stimulus values to internal evidence for the component and its relations. That is, the "very" modification would increase the drop-off in evidence as the apparent size deviates from x. Such modifiers can be applied at any level within the propositional hierarchy, and they can be tuned on the fly as a result of local experience (Oden, 1991). Thus, this approach is well suited to account for the variety of effects from the present studies, as well as the change in adjustments with experience.

Implications for Pattern Recognition

In general, the tradition in pattern recognition research has been to make minimal assumptions about features while emphasizing the generality of the features assumed. For example, the observation is often made that readers can recognize letters in a wide variety of type fonts, and this observation is used to support the argument that recognition may be accomplished by general-purpose feature detectors that work for a variety of fonts. The present conclusions have contrasting implications that have been recently supported in further research. One implication is that letters have rich, relational perceptual structures. A second implication is that subjects can use fairly detailed relational information in perceptual processing, since such information was necessary for discriminations between prototypes and difficult distortions (see, e.g., Figures 1 and 6).

If letter representations can be rich and fairly precise, it follows that certain details of letters can be relevant to recognition. Since details are specific to the letters' font, it follows that font-specific information can be important. In fact, there is an obvious benefit for a perceptual system that is able to use precise, font-specific information. Since the information within a font is highly systematic (e.g., there are similar shapes and systematically related sizes), it lends itself to a precise, economical representation, and it can be used to increase the efficiency of letter recognition. Thus, this view predicts that when there is a consistent, regular font, perceptual representations can become optimally tuned for that font, resulting in more efficient recognition than when the font is not consistent. Indeed, recent experiments have indicated that there is an advantage in letter recognition for conditions with target sets of *n* letters of one font relative to conditions with sets of *n* letters of two fonts (see, e.g., Sanocki, 1987, 1988). These experiments involved both a letter-nonletter task that required fairly complete processing of each item (Sanocki, 1987), and a backward masking task that required rapid recognition while preventing prolonged perceptual processing (Sanocki, 1988). Therefore, the effects seem quite general. In further backward masking experiments, recognition efficiency has been shown to depend on the extent to which the letters have relations typical of common letters (Sanocki, in press-a), although there are limits on how "relational" the letter representations are (Sanocki, in press-b). Thus, relational information does appear to be important in speeded identification tasks, and there are some potentially useful constraints on the definition of relations.

In sum, the present experiments support the idea that letter representations are fairly rich, potentially precise, and relational in nature. Much remains to be learned about the details of these representations and their role in perception; this provides many interesting challenges for future research.

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NOTE

1. RTs for "no" responses to distortions are not of particular interest here, because the crucial questions concern differences between prototype letters, rather than between responses. Also, "no" RTs would be expected to differ with the degree of distortion, which was not strictly controlled apart from the difficult-easy distinction.

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