The primacy of visual information in the analysis of letter strings

MARTIN H. SINGER

University of Delaware, Newark, Delaware 19711

In Experiment 1, orthographic and phonetic information were separated by using artificial letters to represent English pseudowords and random letter strings. Subjects could learn to distinguish combinations of artificial letters on the basis of (1) orthographic, but not phonetic, information, (2) orthographic and phonetic information, (3) paired-associate verbal labels without orthographic information, and (4) neither orthographic nor phonetic information. By imposing a variety of response deadlines it appeared that subjects quickly exploited orthographic information without any contribution from phonetic correspondences. The only suggestion of a phonetic effect occurred in the absence of orthographic information and at longer latencies. Experiment 3 (using English letters) also suggested that phonetic information influenced the analysis of letter string pairs at only longer latencies, after visual analysis. Experiment 2 provided a demonstration that orthographic rules similar to those exploited in Experiment 1 were useful in visual discriminations regardless of the particular letter position affected by those rules. The results strain phonetic mediation models of performance in word-related tasks (e.g., Spoehr & Smith, 1975) and support models that emphasize visual analysis (Barron & Baron, 1977; Massaro, 1975; Pollatsek, Well, & Schindler, 1975).

Several researchers have demonstrated that the competent reader's knowledge of orthographic regularity facilitates the recognition or detection of letters in words or in pseudowords (Baron & Thurston, 1973; Estes, 1975; Mason, 1975, 1978; Massaro, 1973, 1975; Miller, Bruner & Postman, 1954; Reicher, 1969; Wheeler, 1970). Apparently, intercorrelations among letters (sequential redundancy) or correlations of letters with positions (positional frequency) permits more intelligent guessing or more efficient sampling of information from a letter string.

Differences in orthographic regularity, however, are correlated with differences in the phonetic quality of a letter string. Orthographically legal letter strings are typically pronounceable, whereas irregularly spelled strings are typically nonpronounceable (Neisser, 1967). Smith and Spoehr (1974) and Spoehr and Smith (1975), for instance, have argued that phonetic mediation (i.e., a parsing into vocalic center groups)

accounts for the advantage of words and pseudowords in letter recognition studies. This phonetic mediation hypothesis is supported by other studies reporting phonetic priming effects in lexical decision tasks (e.g., Meyer, Schvaneveldt, & Ruddy, 1974) and in proofreading tasks (Corcoran, 1966, 1967).

Despite the evidence that both phonetic and orthographic information facilitate performance in word-related tasks, the correlation between those two sources of information makes difficult attempts to specify their relative contributions. Models such as Massaro's (1975) and Spoehr and Smith's (1975) differ greatly in the emphasis placed on phonetic and visual analysis, but the available evidence does not yet provide unambiguous support for either hypothesis. Importantly, we also do not yet know the time course with which either type of information becomes available in performing word-related tasks. The confound of visual and phonetic information prevents a clear temporal analysis.

The present study attempted to separate the relative contributions of phonetic and orthographic information in a lexical decision-type task. In doing this, the study attempted to demonstrate how distinctive visual information is the necessary result of underlying phonological constraints. Also, Experiments 1 and 3 attempted to provide a temporal description of the utility of visual and phonetic information. In order to separately characterize the use of phonetic and orthographic information, Experiment 1 employed artificial letter-like characters (after Brooks, 1977). The use of an artificial alphabet (a set of letters not familiar to the subjects) permitted experimental con-

Experiment 1 was part of a doctoral dissertation completed in partial fulfillment of the PhD degree in Psychology at Vanderbilt University and was supported by NSF Grant BNS-75-19103. I am grateful to Joseph Lappin for his continued support and assistance in preparing the present report; to Keith Clayton, John Bransford, Jeffrey Franks, and Robert Fox for useful comments on Experiment 1; and to Melanae Shnurr for programming the displays. Experiments 2 and 3 were completed while the author was supported by a NICHD postdoctoral stipend in Developmental Psychology at the University of Denver. The research was run in the Cognitive Laboratory, which is supported by NSF Grant BNS-76-80005. Clint Rooley provided valuable technical assistance and Robert Keller developed the data analysis programs. Requests for reprints should be sent to Martin H. Singer, Department of Educational Studies, University of Delaware, Newark, Delaware 19711.

trol over the type of information available to subjects. In the four conditions of Experiment 1, subjects could discriminate their artificial words (targets) from the artificial nonwords (foils) on the basis of (1) orthographic information without phonetic information, (2) orthographic and phonetic information, (3) paired-associate verbal labels without orthographic information, and (4) neither orthographic nor phonetic information. Figure 1 displays the four conditions; these conditions are discussed more thoroughly in the Methods section of Experiment 1.

Experiment 1 also attempted a temporal analysis of subjects' performances in the four conditions. Subjects performed the target recognition task in Experiment 1 within various response deadlines to achieve this temporal analysis. Initially, subjects performed the task within 400- and 800-msec deadlines. These deadlines, however, were too liberal. Within 800-msec deadline, all subjects were highly accurate. Although latencies varied across conditions, it could not be determined whether these differences reflected processing factors or disparate response strategies. While the data from the 400-msec deadline were more useful (see Appendix A), they still did not provide a temporal description of subjects' use of orthographic and phonetic information. Thus, the procedure reported in Experiment 1 eliminated these problems by expanding the number of deadline conditions and making them briefer than 400 msec.

Experiments 2 and 3 attempted to clarify certain empirical issues raised in Experiment 1. Those two experiments further explored the effects of positional information provided by orthographic constraints (Experiment 2) and the implication from Experiment 1 that phonetic analysis of letter strings follows visual processing (Experiment 3).

EXPERIMENT 1

Method

Subjects

Eight male graduate students in the Vanderbilt Psychology Department participated as paid volunteers. Their ages ranged from 22 to 27 years. The subjects were randomly assigned to four conditions (two subjects in each condition), and each subject received a base pay of \$18 plus additional incentives for fast and accurate performance.

Stimuli and Apparatus

Six letters—S, N, P, T, E, and A—were used to generate sets of four-letter strings, with the constraint that no letter occur more than once in any string. The total set of 360 possible combinations was further reduced by eliminating all combinations that represented English words or homophones of English words. The remaining items comprised two categories of meaningless letter strings: pronounceable pseudowords and nonpronounceable random letter strings.

Each of the six letters was paired with an artificial letter. These artificial letters were taken from Brooks (1977) and are displayed in Figure 1. The letters were adapted for presentation by a PDP-8I computer on a cathode ray tube (CRT, Tektronix 604) with rapid decay phosphor (P15). Each letter subtended a visual angle of

.5 × .10 to .15 deg. A four-letter string subtended a visual angle of .5 × 2.2 deg.

Telegraph keys served as response mechanisms, with the computer measuring and recording the speed and accuracy of responses. A Teletype bell provided feedback about accuracy on each trial.

Index cards displaying uniform, stenciled letter strings were used in initial training sessions.

Procedures

Each group of two subjects learned to recognize one set of eight artificial, four-letter target items. In each of the four conditions, the subjects learned specific types of information about their targets. The target sets for each condition are also illustrated in Figure 1. The same set of 24 foil items were used in all conditions. The foil items were all translated from nonpronounceable random letter strings. Appendix B lists the combinations that were translated into artificial foil items.

The experimental design can be understood in terms of the dis-

UN(){} — ARTIFICIAL AEPNST T ENG. CORRELATES			
ARBITRARY TARGETS		ORTHOGRAPHIC	
)(— — ())((— ())(— () — — () (— (() ()		)(())(—)(—)(())(() () ())(— — ()	
PAIRED ASSOCIATE		READING	
)(— (SNEP) — ())((SNET) (— (SNAT) ())(— (NEPS) () — (NESP) — () (SPEN) (— (NAST) () () (TASP)		)(() (SNEP))(— (SNET))(— (SNAT))(() (NEPS))(() (NESP) () () (SPEN))(— (NAST) — () (TASP)	

Figure 1. Targets in the paired associate and arbitrary targets conditions were translations of nonpronounceable letter strings in English. Targets in the reading and orthographic conditions were translations of pseudowords. English-to-Artificial translations were made according to the code listed at the top of the figure. The verbal labels in the paired-associate condition and the translations in the reading condition are enclosed in parentheses.

tinguishing target characteristics in each condition, as described below.

Arbitrary-targets condition. In this condition, the targets and foils were both translations of random letter strings. Thus, the visual structure of targets and foils was similar and there were no verbal labels for the targets. Sounds were not paired with any of the target items, and the subjects were not taught Latin-letter correlates to the artificial letters. Targets were distinguished from foils only by random selection. The initial training procedure in this condition involved only copying the target set, reproducing the target set from memory, and sorting targets from foils. When subjects sorted the index cards, they said either "word" or "nonword."

Paired-associate condition. The same targets and foils used in the arbitrary-targets condition were used in this condition, except that in this condition the subjects learned a paired-associate verbal label for each of the eight artificial targets. The training procedure included naming the members of the target set when sorting the index cards. Furthermore, the subjects were timed on how rapidly they could name the targets to ensure that they learned the paired-associate names of the targets. Figure 1 illustrates the artificial targets and the paired-associate verbal labels.

It must be stressed that the subjects never learned the relationships between English and artificial letters. As in the arbitrary-targets condition, both the targets and the foils were translations of random letter strings in English. Subjects in this condition, however, learned a paired-associate label for each of the targets. Thus, the subjects could name the target items, but the names were unrelated to the visual structure. Also, the visual structure of targets and foils was similar.

Orthographic condition. The targets in this condition were artificial translations of pronounceable pseudowords generated from the six-letter Latin alphabet. In principle, the visual structure of targets and foils should have differed because the targets were translations of pronounceable pseudowords but the foils were translations of nonpronounceable random Latin-letter strings.

The initial training procedure for the subjects in this condition was similar to the procedure in the arbitrary-targets condition. In the orthographic condition, though, subjects were taught positional information about the letters in their targets and were told that this information could be helpful in making discriminations between targets and foils. No phonetic information was provided. As in the arbitrary targets condition, the subjects never learned the correspondences between Latin and artificial letters and were not taught any verbal labels. In the orthographic condition, then, visual structure, but not phonetic information, could facilitate target recognition.

Reading condition. The target items in this condition were the same as in the orthographic condition. In this condition, however, subjects could easily translate the targets, since the sounds associated with each of the artificial letter strings consistently mapped one Latin letter onto one artificial letter and the subjects were informed on this correspondence. That is, the subjects in this condition could easily learn to read the target items.

The training procedure in this condition included naming the targets and learning positional information about the letters in their targets. As in the paired-associate condition, the subjects were timed on naming the targets.

Practice and Pilot Sessions

After 1 h of the initial training procedures, all subjects were asked to take home a copy of their targets and to study them. To ensure that the subjects at least examined the targets, they were asked to bring a duplication of the list the following day. On the 2nd day, all subjects were asked to reproduce their set of targets again and to sort the index cards that displayed either a target or a foil. Subjects sorted these cards until they could perform the task perfectly. In the paired-associate and reading conditions, the subjects also named the cards twice without being timed.

Throughout the next 2 weeks, the subjects performed these training tasks and were exposed to the computer task. The task required

the subjects to discriminate between the targets and foils when they were displayed on a CRT for 2,000 msec. The subjects indicated whether they saw a target or foil by pressing one of two telegraph keys. During this initial training session, the subjects were also required to vocalize their responses. Subjects in the arbitrary target and orthographic conditions merely said either "word" or "nonword" when responding. Later on, they submitted responses only via telegraph key.

The subjects were also taught to respond prior to a "deadline." This response deadline was indicated by stimulus offset. Specifically, the subjects submitted their responses prior to 1,000-, 800-, and 400-msec deadlines. At the end of 2 weeks, each subject had performed 7,680 trials. These sessions were useful in two ways. First, the extensive practice increased stimulus familiarity and reduced task-related variability. The intensive training should have eliminated differences in the initial levels of learning across the four conditions. Indeed, it is hard to imagine any differences in the initial learning of eight items after 7,680 trials. Second, the sessions indicated that briefer response deadlines were necessary to eliminate ceiling effects and differences due to disparate response strategies. Thus, in the subsequent test sessions, the number of deadlines was increased and the deadlines were all briefer than 400 msec.

Test Sessions

The subjects were introduced to four faster response deadline conditions. The deadlines were 375, 325, 275, and 225 msec. They were told that response latencies had been extremely variable in the practice sessions and that they were to respond closer to stimulus offset. To maintain latencies close to the deadline, the subjects practiced on 20 trials prior to each block of trials at a particular response deadline.

After practicing at each deadline condition, the subjects performed three blocks of 80 trials at the four deadlines (a total of 12 blocks, or 960 trials). Twenty practice trials preceded each set of three blocks, and the subjects took short breaks (3-5 min) between the sets of trial blocks representing the deadline condition. The subjects completed all test trials within 1 h.

Three different sets of eight foils were alternated within the test session. This was done to prevent subjects from memorizing the foils. Within a particular block of 80 trials, though, there were only eight targets and eight foils. The presentation of targets and foils was randomized, and the probability of a target display was 50%.

A trial always involved the same sequence. On each trial, a subject viewed the CRT display from a distance of 1 m. Depressing both the left and right response keys initiated the stimulus display sequence: A fixation point followed by the display of an artificial letter string (target or foil). If the subject believed that a target had been presented, he released the left key; for a foil, he released the right key. The speed and accuracy of each response were recorded by the computer. The subjects were asked to respond as accurately as possible, with the constraint that they respond near the stimulus offset. Responses executed after display offset, however, were included in the data analysis.

Results

The major results of Experiment 1 are graphically depicted in Figure 2. The linear functions relating speed to accuracy for each condition, as well as the function for all conditions, are included in this graph. The functions are based on four data points for each block of 80 trials: Accuracy associated with the fastest 20 responses, the next fastest 20 responses, and so on. These functions indicate that the subjects in the reading and orthographic conditions performed more accurately at brief response deadlines than did the subjects in the other two conditions. At longer latencies, subjects in all but the arbitrary targets condition

Figure 2. The linear functions relating speed to accuracy for target recognition are depicted for each condition and for all data.

Figure 3. The four points plotted for each condition represent the average latency and accuracy at each response deadline (225, 275, 325, and 375 msec). Note that the latency at the 225-msec deadline for the reading condition is comparable to the latencies at the 275-msec deadline for all other conditions.

were comparably accurate. The functions suggest that orthographic information was quickly utilized by subjects in the reading and orthographic conditions, but that phonetic information was only useful in recognizing targets at longer latencies and in the absence of orthographic information. The goodness of fit for these linear functions varied across the four conditions (reading: $r = .31$; orthographic: $r = .60$; paired associate: $r = .74$; arbitrary targets: $r = .64$; overall: $r = .60$). Thus, one should not posit a linear relationship between accuracy and response latency. Figure 2 is intended only as a description of the results. Figure 3 plots the average latency and accuracy for each group for each of the four response deadlines.

After first determining that there were no effects due to the type of stimulus (target or foil), an analysis of variance was imposed on the average accuracy

scores¹ for each subject (two per cell) for each block of trials (three) within all response deadlines (four) for each condition (four). The analysis disclosed significant differences in accuracy due to condition type [$F(3,9) = 25.3, p < .05$] and response deadline [$F(3,9) = 41.9, p < .01$]. In addition, the analysis supported the suggestion from Figures 2 and 3 that groups interacted with the response deadline conditions [$F(9,32) = 3.78, p < .05$].

This analysis was somewhat unfair, however, as the subjects in the reading condition submitted longer responses at the 225- and 275-msec deadlines. These longer latencies probably contributed to their high accuracy scores and, consequently, to the group and interactive effects. A second analysis eliminated this advantage by examining the accuracy scores from the 375-, 325-, and 225-msec deadlines for the reading condition and accuracy scores from 375-, 325-, and 275-msec deadlines for the other conditions. This second analysis (2 by 3 by 3 by 4) kept response latencies more constant across the four groups at the three response deadlines. Even with this procedure, there were significant differences in accuracy due to group type [$F(3,6) = 13.94, p < .05$] and response deadline [$F(2,6) = 25.17, p < .05$]. Also, group type again interacted with the three response deadlines [$F(6,24) = 5.46, p < .05$]. Table 1 displays the average latency and accuracy measures for the four groups at the three deadline conditions (i.e., scores at the 375-, 325-, and 225-msec deadlines for the reading condition, and scores at the 375-, 325-, and 275-msec deadlines for all other conditions).

The effects due to group differences most likely reflected the more accurate performance of subjects in the orthographic and reading conditions. Another analysis, contrasting those two groups against the

Table 1
Accuracy (Percent Correct) and Response Latency
(in Milliseconds) at Various Response Deadlines
in Experiment 1

Stimulus Condition	Response Deadline		
	1	2	3
Orthographic	94,331	91,306	83,265
Reading	98,326	93,306	78,263
Arbitrary Targets	77,335	76,315	66,279
Paired Associate	94,324	83,308	69,264
Average	91,329	86,309	74,268

Note—Response Deadline 1 = 375-msec response deadline for all conditions. Response Deadline 2 = 325-msec response deadline for all conditions. Response Deadline 3 = 275-msec response deadline for the orthographic, arbitrary targets, and paired associate conditions and 225-msec response deadline for the reading condition. Responses at the 225-msec response deadline in the reading condition were comparable in speed to those at the 275-msec deadline in all other conditions. Their responses at the 275-msec deadline were very accurate but averaged 298 msec—much longer than in the other conditions.

paired-associate and arbitrary-targets conditions (across only three deadlines), supported this interpretation. There were significant accuracy differences due to group type [$F(1,6) = 388, p < .05$]. Again, in this analysis, group effects reflected the disparity in accuracy scored between the four subjects in the reading and orthographic conditions and the four subjects in the paired-associate and arbitrary-targets condition. This analysis further disclosed significant effects due to response deadline [$F(2,6) = 297, p < .05$].

One of the more intriguing suggestions from Figures 2 and 3 was that paired-associate verbal labels facilitated target recognition at longer latencies. A comparison of accuracy scores from the paired-associate and arbitrary-targets condition at the four response deadlines indicated that these groups did interact differently with response deadline [$F(3,16) = 5.76, p < .01$]. This interaction almost certainly reflects the increased disparity between the two groups at longer latencies. Consistent with this interpretation, a subsequent comparison of these two groups at the longest deadline (375 msec) produced significant group differences in target recognition accuracy [$F(1,2) = 226.6, p < .05$]. This analysis used trial blocks (three) as a factor. These two groups were indistinguishable at brief latencies.

Finally, as in the pilot and practice sessions, it was impossible to discriminate the performance of the subjects in the reading and orthographic conditions at any of the response deadlines. One might conclude that the contribution of orthographic information to accurate target recognition made superfluous any contribution of phonetic information in the reading condition.

Discussion

The advantage for subjects in the reading and orthographic conditions suggests a primary role for orthographic information in the word-related target recognition task. Orthographic information contributed more to rapid and accurate target recognition than did phonetic information. The difference between accuracy scores in the orthographic and reading conditions and accuracy in the paired-associate and arbitrary-targets conditions indicates the positive and rapid influence due to orthographic information.

This result is important for two reasons. First, orthographic information in Experiment 1 simply reflected the visual distinctions between a set of pronounceable pseudowords and nonpronounceable nonwords. Only 74 of the four letter combinations (generated from the letters A, E, P, N, S, and T) were pronounceable, and 54 of these had a vowel in the second position and 15 began with ST, SN, or SP. These combinations were apparently visually distinct from the nonpronounceable letter strings—even when represented by the artificial letters. The ability of subjects

in the orthographic and reading conditions to exploit the visual distinctiveness of the pronounceable combinations supports models of word processing, such as Massaro's (1975), that emphasize the use of visually stored orthographic knowledge.

Second, the results from Experiment 1 suggest a temporal ordering of orthographic and phonetic effects. Subjects in the reading and orthographic conditions more accurately recognized targets at the briefest response deadlines. The only suggestion of a phonetic effect was at longer latencies (375 msec), where the subjects in the paired-associate condition were more accurate than the subjects in the arbitrary-targets condition. Although the small number of subjects and stimuli decrease the generality of Experiment 1, this description of the temporal utility of orthographic and phonetic information strains phonetic mediation models of word-related tasks (i.e., Spoehr & Smith, 1975). It is of interest to note that phonetic interference effects reported in a lexical decision task (Meyer et al., 1974) occur at latencies longer than those described here. Those phonetic effects occur (with judgments concerning a single word) between 600 and 700 msec. The suggestion that phonetic operations are secondary to (occur after) a visual analysis is further explored in Experiment 3, using Latinic letter strings and more subjects.

One could claim that the high accuracy in the reading and orthographic conditions reflects only the greater visual dissimilarity between targets and foils in those conditions relative to the dissimilarity in the other conditions. This criticism might point out that the sequence $\square \square$ (which represented SN) occurred often at the beginning of items in the reading and orthographic target set. This criticism, though, only emphasizes that certain visual patterns underlie pronounceable combinations of letters. For example, the sequence $\square \square$ could not occur at the end of the target items in the reading and orthographic conditions simply because the sequence SN is not pronounceable when in the final two positions of a letter string. Although the information available in the initial letter position did provide orthographic and reading subjects with a distinctive cue, this advantage is not artifactual or unfair. It represents the legitimate outcome of an orthographic structure that distinguishes pronounceable from nonpronounceable letter strings. The features of these targets were so distinctive because the underlying rules of pronunciation drastically constrain permissible combinations and positions of letters. Nonetheless, to demonstrate that orthographic or structural rules facilitate target recognition independent of the particular letter position affected by those rules, a second experiment was run.

EXPERIMENT 2

Experiment 1 indicated that subjects could quickly

deploy orthographic information in distinguishing target from foil items. A possibility exists that "orthographic information" in Experiment 1 only meant information regarding letter occurrence in a particular position. While this criticism is not serious (i.e., orthographic constraints *should* provide positional information), the present experiment attempted to demonstrate that orthographic constraints are useful in target/foil discriminations, regardless of the particular position affected by the constraints and that this information is learned quickly.

In Experiment 2, six typewriter symbols (*, #, !, /,], <) comprised an alphabet. Sixteen four-symbol targets were generated using two simple sequential constraints and two positional constraints. Three sets of 16 foils were also developed, with each set violating the orthographic principles in various ways. One foil set violated two constraints, the other foil sets only one constraint. In the second two foil sets, the violation affected the constraints concerning either the first or second position in the four-symbol combination. The first foil set affected both positions. The target and three foil sets are displayed in Figure 4.

It was reasoned that the number of orthographic violations would facilitate subjects' abilities to distinguish target from foil items. Thus, an advantage for discriminating the foils in Foil Set I was predicted. It was also predicted that, with sufficient practice, manipulations affecting either the first or second position would equally facilitate subjects' discriminations. In other words, the contribution of orthographic structure to target and foil discrimination would be independent of the specific letter position affected by the violation.

Targets	Foil Set I	Foil Set II	Foil Set III
1 * / <]	#] * !	# * !	* # / <
2 * / < #	#] * /	# * /	* # ! #
3 * / #]	#] / *	# / !	* ! ! #
4 * / # <	#] * !	# /] *	* # /]
5 * ! # <	#] / !	# ! < *	*] / <
6 * ! <]	# * /	# ! /	* # !]
7 * ! < #	# * / !	< / ! !	/ < !]
8 * ! #]	# < / *	< * /	/ # *]
9 / ! # <	< # * !	< / # *	/ < * #
10 / ! < #	< # * /	< ! # /	/ ! ! #
11 / ! #]	< # / !	< ! ! *	/] * #
12 / * # <	< # / *	] * !	! # *]
13 / * #]	<] * /	] * # /	! # / <
14 / * # <	<] / !	] ! # /	! < /]
15 / * #]	<] / *	] ! < /	!] / #
16 / ! # <	<] * !	] / < *	!] * #

Figure 4. The combinations of the six symbols (*, /, <,], #, and !) used as targets and foils are listed. Items in Foil Set I differ from the targets in each position; those in Foil Set II differ from the targets in the first and third positions; and those in Foil Set III, from the second and fourth positions.

Method

Subjects

Three adult subjects participated in the experiment. All were associated with the University of Denver Psychology Department. Their ages were 26, 27, and 27 years.

Materials and Apparatus

Six symbols (-, /, !, #,], <) were used to generate four-symbol combinations. In generating combinations for the target set, the following rules were used: (1) Only the symbols *, /, and ! could occur in the first two positions. (2) Only the symbols #,], and < could occur in the second two positions. (3) The symbol ! had to follow the symbols * and /. (4) The symbol < had to follow the symbols # and]. Sixteen combinations were possible given these constraints. They are listed in Figure 4.

In addition to these target sets, three foil sets were developed. In the first foil set, Rules 3 and 4 were preserved, but Rules 1 and 2 were violated. Thus, symbols #,], and < occurred in the first two positions and symbols *, /, and ! occurred in the second two positions.

In the second foil set, the constraints regarding the first and third positions were violated. Thus, the symbols #,], and < could occur in the first and fourth positions and the symbols *, /, and ! could occur in the second and third positions.

In the third foil set, the constraints regarding the second and fourth positions were violated. Thus, the symbols *, /, and ! occurred in the first and fourth positions and the symbols #,], and < occurred in the second and third positions. The foil sets are also listed in Figure 4. All three foil sets contained 16 four-symbol combinations.

A Consul 980 terminal was used to display both target and foil items. Buttons were pressed to deliver responses, two small lights above the buttons provided trial-by-trial feedback, and a PDP-1130 computer controlled display parameters and collected response measures (latency and accuracy). The display screens and response mechanisms were situated in a room adjoining the computer room, and the subjects performed the task while seated in a booth .31 m from the display screen. Each item subtended a visual angle of 2.22 deg and was presented at a rate of 9,600 characters/sec.

Procedures

The subjects were told that displays of four symbol strings would be presented on the display screen. Their task, they were instructed, was to learn which combinations were targets and which were foils. The subjects were not taught any of the orthographic rules that distinguished targets from foils. Instead, they were instructed to press one of two buttons: the right one if they guessed the display to be a target, the left one for a foil. After each response, a light over the correct response button indicated the correct response. The subjects were told that if they paid attention to the light feedback they would learn which combinations were targets and which were foils.

Targets and foils were randomly presented in blocks of 32 trials (16 targets and 16 foils). The foils in each block were from only one of the three foil sets and the order of blocks within sessions was randomized. A session included three blocks (96 trials) and, thus, all three foil sets. The subjects were asked to complete three sessions the first 2 days and four sessions on the 3rd day.

The subjects were further instructed to concentrate on accuracy, decreasing response latency only when they had mastered their target sets. The subjects performed in a total of 10 sessions.

A session began with the warning "trials about to start." After this display was erased, a four-symbol combination appeared. The item was displayed until the subjects responded and light feedback was provided. A 500-msec interval followed the feedback, and then another item was displayed. After 32 trials, there was a brief rest followed by two more sets of 32 trials.

Results and Discussion

The results of Experiment 2 were as anticipated. As described in Figure 5, the subjects quickly learned

Figure 5. The above figure describes the accuracy and latency changes in recognizing foils across days. Performance on each foil set is separately depicted.

to discriminate the foils from their target items. By the 3rd day, accuracy was near perfect in all foil set conditions, but the subjects could more quickly discriminate the items in Foil Set I, than they could those in Foil Set II or Foil Set III. Foil Set I, it will be recalled, violated more of the orthographic constraints than did the other two foil sets. Even with extensive practice (576 trials), the advantage for discriminating items in Foil Set I was significant ($z = 3.87$, $p < .001$). At the same time, extensive practice eliminated any differences between the speed of responses to items in Foil Sets II and III. Table 2 displays the latency and accuracy data for the 3rd day (i.e., after 576 trials).

The advantage for discriminating the foils in Foil Set I juxtaposed with the similar performance across the other two sets suggests that (1) the number of violated orthographic rules facilitates target/foil discrimination, but that (2) the facilitation is independent of the particular letter position affected by the violations. The subjects reported that in Foil Sets II and III they simply learned which letter positions were critical for successful discrimination (Position 1 in Set II; Position 2 in Set III) and focused their attention on those positions. In Experiment 1, subjects in the reading and orthographic conditions probably adopted a similar strategy, utilizing the particular spatial information related to the orthographic distinctions between the pronounceable and nonpronounceable letter strings. Again, this is not an unfair strategy advantage, but only the legitimate effect of structural differences between targets and foils. The results of Experiment 2 expand the generality of those in Experiment 1 as a different set of structural rules and symbols again facilitated target/foil discriminations. Furthermore, Experiment 2 indicates that structural rules are acquired quickly. This is consistent with Barron and Baron's (1977) report that first

graders quickly learn to access their lexicon directly from visual information.

Finally, the subjects were comparably fast and accurate in recognizing target items independent of which foil set was represented in a trial block. By the 3rd day, average accuracy for recognizing targets was 99%, 97%, and 100% in Blocks 1, 2, and 3, respectively; correct latencies were 581, 627, and 637 msec. None of these differences was significant, but any suggestion of a latency difference was in the same direction as the differences in recognizing foils. Apparently, targets became so well learned that performance reached ceiling levels.

EXPERIMENT 3

These results of Experiment 1, as pointed out earlier, also suggested that phonetic information only affected target recognition at longer latencies. The subjects who learned a paired-associate verbal label more accurately recognized targets at longer latencies than did the subjects in the arbitrary-targets condition. Importantly, these four subjects performed comparably at rapid response latencies (see Figures 2 and 3).

It has been suggested to me (by an anonymous reviewer) that the slower use of phonetic information might not occur with highly familiar letter strings (i.e., combinations of English letters). This argument might be that, with highly familiar letters, a phonetic analysis would automatically accompany visual analysis. Thus, with familiar letters, phonetic information would influence the analysis or recognition of letter strings during the same time period as visual information.

Pollatsek, Well, and Schindler (1975) already have demonstrated that *different* responses to homophonic word pairs (CITE vs. SITE) take no longer than do those to nonhomophonic pairs (COLD-SOLD). This suggests that a phonetic analysis follows a visual analysis even with familiar letters. The stimuli in the Pollatsek et al. study, however, may have engaged a time-consuming lexical access that obscured differences between decisions regarding the homophonic

Table 2
Correct Latencies (in Milliseconds) and Percent Correct for Recognizing Foils

Subject	Correct Latency			Percent Correct		
	Foil Set			Foil Set		
	1	2	3	1	2	3
1	571	620	607	100	97	98
2	474	512	504	95	100	92
3	488	596	623	100	95	89
Average	511	576	578	98	97	93

Note—Values are for Day 3 (e.g., after 576 trials) of the experiment.

and nonhomophonic pairs. Experiment 2 examined the possibility that phonetic information would influence decisions regarding pseudowords. Like the Pollatsek et al. task, subjects were required to determine if pairs of letter strings were the same or different. In Task 1, the subjects based their decisions on only visual qualities. Thus, given the pair NERS-NERS, the correct response was "same." The pairs NIRS-NERS, NARS-NERS, and NXRS-NERS warranted "different" responses. It was reasoned that if a phonetic analysis automatically accompanied a visual analysis, the "different" responses to NIRS-NERS would reflect some interference (because of their phonetic similarity) and be longer or less accurate than the responses to NARS-NERS. If, however, phonetic information could be ignored, or its use occurred after a visual analysis, then responses for NIRS-NERS and NARS-NERS should be similarly fast and accurate.

In Task 2, subjects examined the same pairs but were instructed to ignore visual dissimilarity and base their decisions on phonetic similarity. In this task, both NERS-NERS and NIRS-NERS require a "same" response. It was reasoned that if subjects first sampled visual information, the "same" responses to NIRS-NERS should be longer than those to NERS-NERS. Also, if a phonetic analysis followed visual operations, responses (both "same" and "different") should be longer in Task 2 than in Task 1. If responses in Tasks 1 and 2 were similarly fast, it would suggest that phonetic operations occur during the same time period as visual analysis.

Method

Subjects

Twenty-four students from an introductory psychology course at the University of Denver participated in the experiment. Twelve students performed Task 1 and Task 2.

Materials and Apparatus

A PDP-1130 computer controlled the presentation of stimuli on a Consul 980 model terminal. The subjects viewed the displays from a distance of .32 m and submitted their responses via push buttons. Displays were simultaneously presented pairs of letter strings, subtending a visual angle of approximately 7 deg. The letter strings were presented on the same line, separated by 2.54 deg. The speed of display presentation was 9,600 characters/sec.

The pairs of letter strings used in both Tasks 1 and 2 are listed in Appendix C.

Procedures

The two tasks both required a same-different judgment. Since the subjects determined similarity on different dimensions in the two tasks, the tasks are described separately.

Task 1. The subjects were required to determine the visual similarity of various types of letter-string pairs. The pairs could be visually and phonetically similar (e.g., NERS-NERS), visually dissimilar and phonetically similar (e.g., NIRS-NERS), or visually and phonetically dissimilar (NARS-NERS, NXRS-NERS). The subjects could correctly judge as similar only pairs such as NERS-NERS. There were 24 such pairs and 12 instances of the other three pair types. Thus, there were 60 trials with 40%

chance of a "same" display. The order of pair type within the block of 60 trials was randomized.

Task 2. The same stimulus pairs were presented in Task 2. In this task, though, subjects were instructed to respond "same" to NIRS-NERS as well as to NERS-NERS. That is, phonetic similarity was relevant in determining similarity. The probability of a "same" display was 60%.

In both tasks, the subjects practiced on a lexical decision task and a same-different task prior to participating in this experiment. The subjects were instructed to perform accurately, but rapidly. Before the onset of the first stimulus pair, the subjects were alerted by a warning message, "Trials about to start."

A trial sequence was as follows: A pair of letter strings appeared on the display screen. The subjects determined if the strings were identical or not and submitted their responses by pressing one of two buttons. They pressed the left button for a "different" response, the right button for a "same" response. Stimuli were presented for 2,000 msec or until the subject responded, whichever occurred first. The session took approximately 5 min.

Results and Discussion

The results of Experiment 3 are depicted in Figure 6. First, response latencies in Task 2 were significantly longer [$t(22) = 2.59, p < .01$] but comparably accurate to those in Task 1. That is, judgments concerning phonetic similarity took longer than those pertaining to visual similarity. This was true for pronounceable pairs (e.g., NERS-NERS), and nonpronounceable pairs [e.g., NXRS-NERS: $t(22) = 4.5, p < .0005$].

Second, phonetic similarity did not interfere with judging the pair types NERS-NIRS as "different" in Task 1. Responses to NERS-NIRS and NARS-NIRS were comparably fast and accurate in Task 1 ($t = .341$). Apparently, subjects were able to ignore phonetic information. A phonetic analysis of the

Figure 6. Accuracy in the visual task (Task 1) and the phonetic task (Task 2) is displayed for each stimulus pair type. The figure also shows the appropriate response and accuracy for each pair in both tasks.

letter strings did not automatically accompany the visual analysis of stimuli. This result is compatible with the Pollatsek et al. study.

In Task 2, however, visual dissimilarity did interfere with judging NERS-NIRS as similar. The "same" responses to NERS-NERS were faster [$t(11) = 3.896$, $p < .005$] and more accurate [$t(11) = 2.89$, $p < .01$] than responses to NERS-NIRS. The interference of visual information in Task 2, coupled with the longer latencies in Task 2, suggests that visual analysis of the stimulus pairs preceded or was completed prior to any phonetic operation. The subjects' ability to ignore phonetic information in Task 1 is also consistent with the hypothesis that phonetic operations occur or are completed after a visual analysis.

One might argue that the failure of phonetic information to interfere with "different" responses to NERS-NIRS only reflects an attentional strategy. That is, given the prior knowledge that phonetic qualities were irrelevant in determining similarity, subjects ignored phonetic qualities. It must be noted, though, that this strategy (of ignoring a stimulus dimension) was not available to the subjects in Task 2. Visual dissimilarity interfered with certain "same" judgments (e.g., NIRS-NERS) despite the prior knowledge that visual dissimilarity was irrelevant. Thus, even if an attentional strategy accounted for the absence of interference in Task 1, one must still explain why that same strategy failed to eliminate the interference of visual similarity in Task 2. Again, a model which posits a primary visual analysis and a secondary or longer phonetic operation is consistent with subjects' ability to ignore phonetic similarity but not visual dissimilarity.

GENERAL DISCUSSION

Experiments 2 and 3 support the findings of Experiment 1 in two ways. First, Experiment 2 demonstrated, with a different set of symbols and rules, that structural constraints contribute to a subject's ability to discriminate symbol combinations. In other words, there was nothing special about the constraints in Experiment 1; another set of constraints produced a similar advantage in Experiment 2. Second, Experiment 3 showed that, with highly familiar letters, visual analysis preceded any phonetic contribution. This result was consistent with the earlier Pollatsek et al. findings as well as with Experiment 1.

The results from all three experiments support models of letter analysis (or recognition) which posit (1) a primary visual analysis capable of utilizing orthographic information (Massaro, 1975) and (2) a secondary phonetic operation. The results are consistent with Stanovich and Bauer's (1978) finding that speed stress eliminated phonetic effects (i.e., letter-to-

sound irregularity) in a lexical decision task. Experiment 1, in particular, suggests that the primary visual analysis is sensitive to the distinct patterns that reflect pronounceable letter combinations, without any direct contribution from phonetic information. More sophisticated procedures that manipulated the degree of difference between targets and foils could provide a detailed analysis of what visual information is useful in the recognition of letter combinations. Experiment 1 of the present study only attempted to demonstrate that a simple distinction between letter combinations (i.e., pronounceable or nonpronounceable) manifests as very distinct sets of letter strings. The utility of these differences in a simple recognition task should apply to the rapid visual recognition of words as meaningful letter combinations must also reflect phonological constraints.

REFERENCES

- BARON, J., & THURSTON, I. An analysis of the word-superiority effect. *Cognitive Psychology*, 1973, **4**, 207-228.
- BARRON, R. W., & BARON, J. How children get meaning from printed words. *Child Development*, 1977, **48**, 587-594.
- BROOKS, L. Visual pattern in fluent word identification. In A. S. Reber & D. L. Scarborough (Eds.), *Toward a psychology of reading: The proceedings of the CUNY conference*. New York: Wiley, 1977.
- CORCORAN, D. W. J. An acoustic factor in letter cancellation. *Nature*, 1966, **210**, 658.
- CORCORAN, D. W. J. An acoustic factor in proof reading. *Nature*, 1967, **214**, 851-852.
- ESTES, W. K. The locus of inferential and perceptual processes in letter identification. *Journal of Experimental Psychology: General*, 1975, **104**, 122-145.
- MASON, M. Reading ability and letter search time: Effects of orthographic structure defined by single-letter positional frequency. *Journal of Experimental Psychology: General*, 1975, **104**, 146-166.
- MASON, M. From print to sound in mature readers as a function of reader ability and two forms of orthographic regularity. *Memory & Cognition*, 1978, **6**, 568-581.
- MASSARO, D. W. Perception of letters, words, and non-words. *Journal of Experimental Psychology*, 1973, **100**, 349-353.
- MASSARO, D. W. *Understanding language: An information-processing analysis of speech perception, reading, and psycholinguistics*. New York: Academic Press, 1975.
- MEYER, D. E., SCHVANEVELDT, R. W., & RUDDY, M. G. Functions of graphemic and phonemic codes in visual word-recognition. *Memory & Cognition*, 1974, **2**, 309-321.
- MILLER, G. A., BRUNER, J. S., & POSTMAN, L. Familiarity of letter sequences and tachistoscopic identification. *Journal of General Psychology*, 1954, **50**, 129-139.
- NEISSER, U. *Cognitive psychology*. Englewood Cliffs, N.J.: Prentice-Hall, 1967.
- POLLATSEK, A., WELL, A. D., & SCHINDLER, R. M. Familiarity affects visual processing of words. *Journal of Experimental Psychology: Human Perception and Performance*, 1975, **1**, 328-333.
- REICHER, G. M. Perceptual recognition as a function of meaningfulness of stimulus material. *Journal of Experimental Psychology*, 1969, **81**, 275-280.
- SMITH, E. E., & SPOEHR, K. T. The perception of printed English: A theoretical perspective. In B. Kantowitz (Ed.),

Human information processing: Tutorials in performance and cognition. Potomac, Md: Erlbaum, 1974.

SPOEHR, K. T., & SMITH, E. E. The role of orthographic and phonotactic rules in perceiving letter patterns. *Journal of Experimental Psychology: Human Perception and Performance*, 1975, 104, 21-34.

STANOVICH, K. E., & BAUER, D. W. Experiments on the spelling-to-sound regularity effect in word recognition. *Memory & Cognition*, 1978, 6, 410-415.

WHEELER, D. D. Processes in word recognition. *Cognitive Psychology*, 1970, 1, 59-85.

NOTE

1. The average accuracy scores were modified. First, latencies longer than 410 msec were omitted from the analysis (all of these belonged to subjects in the reading and orthographic conditions).

Since the average accuracy of these responses was high (95%), they were not particularly diagnostic, as subjects in these two conditions performed with comparable accuracy at latencies of 310 msec. Also, deleting these trials kept response latency more constant across conditions. Second, latencies faster than 150 msec (these belonged to subjects in the paired associate and arbitrary targets condition) were dismissed as response-related errors (inadvertently releasing a response key). Since these responses were very inaccurate (50%), this modification inflated somewhat the accuracy for subjects in the paired-associate and arbitrary targets condition. Finally, latencies exceeding the deadline in a trial block by over 100 msec were also dismissed, as such responses clearly violated the instructions for that trial block. A total of 8% of the responses were dismissed according to these criteria.

(Received for publication September 3, 1979;
revision accepted November 26, 1979.)

APPENDIX A

Figure 7 displays the linear function relating speed to accuracy for target recognition within a 400-msec deadline. Each point represents approximately 600 trials, and there are three points for each of the two subjects per condition. The figure suggests that, at a given latency, subjects in the reading and orthographic conditions performed more accurately than other subjects. These data were treated as preliminary because (1) of clear ceiling effects in the reading and orthographic condition, and (2) the lack of any information regarding the temporal utility of orthographic and phonetic information.

APPENDIX B

Nonpronounceable nonwords translated into foils in Experiment 1.

List 1: nspa, atsn, tsep, npte, aetp, enpt, pstn, tpsn

List 2: stne, espn, pnas, tnes, ptsn, ntas, psta, epns

List 3: spta, esnt, ptas, ntep, pnst, sepn, tsan, etap

APPENDIX C

Phonetically and Visually Identical

ners-ners; neek-neek; purd-purd; meam-meam; birf-birf; sirt-sirt; terb-terb; leab-leab; peem-peem; yurd-yurd; clirb-clirb; mirp-mirp; sherf-sherf; keam-keam; durs-durs; preen-preen; kerf-kerf; perf-perf; blurk-blurk; dirn-dirn; ferp-ferp; burm-burm; lurf-lurf.

Phonetically Identical But Visually Dissimilar

neak-neek; purd-perd; meem-meam; sirt-surt; berf-birf; terb-turb; peem-peam; leeb-leab; yerd-yurd; klirb-klerb; shirf-sherf; ners-nirs.

Phonetically and Visually Dissimilar (Pronounceable)

klirb-klarb; ners-nars; nelk-neek; purd-pord; meum-meam; sirt-sart; borf-birf; terb-torb; lemb-leab; pelm-peam; yord-yurd; shorf-sherf.

Phonetically and Visually Dissimilar (Nonpronounceable)

nxrs-nirs; neek-nexk; pxrd-purd; meam-mexm; sxrt-sirt; birf-bxrf; txrb-terb; leab-lexb; pesm-peem; yurd-yxrd; clxrb-clirb; mirp-mxrp.