A parametric investigation of multiletter matches

ROBERT W. PROCTOR and PHILIP W. HURST
Auburn University, Auburn, Alabama

Proctor (1981) presented a theoretical framework that distinguishes factors contributing to disparities in time to classify physical-same, name-same, and different letter pairs as a function of three variables: method of presentation (simultaneous vs. successive), case relationship (same-case vs. opposite-case pairs), and blocking (blocked vs. mixed presentation of same-case and opposite-case pairs). He also argued that these variables were critical in multiletter matches, and performed a between-study comparison of existing data to support his contention. Because comparison across studies is always a tenuous process and because the absence of several relevant conditions precluded a complete analysis of predictions, a within-experiment manipulation of the three relevant variables was desirable. The present study reports such an experiment. In general, the factorial manipulation of variables supported predictions of Proctor's framework and indicated that many phenomena of multiletter matching, including the widely studied fast-"same" phenomenon, are attributable primarily to differences in the rate at which component letter pairs are matched.

Numerous studies during the past decade have examined same-different matches of multiletter strings. Such studies have been popular not only because they allow precise quantitative tests of the manner in which multielement stimuli are compared (e.g., Bamber, 1969; Taylor, 1976b), but also because they provide a baseline for examining the influence that various structural constraints (such as orthographic regularity, phonological regularity, and word structure) have on processing (e.g., Bruder, 1978; Bruder & Silverman, 1974).

In the most common version of the multiletter-matching task, two letter strings are presented that are of the same length, and subjects are required to respond "same" if all letters in corresponding positions are identical (e.g., M D T B; M D T B) and "different" otherwise. The general pattern of results obtained in all studies of this type is that the latencies of both "same" and "different" responses increase as a function of string length and that, within a given string length, the latency of "different" responses increases with the number of positions on which the two strings match.

In the first study of multiletter matching, Bamber (1969) determined that the "different" reaction-time functions were accurately described by an analytical

model in which the individual letter pairs were compared in a serial self-terminating manner. However, "same" reaction times were faster than predicted by the serial self-terminating model, leading Bamber to conclude that "same" judgments were based on a holistic comparison of the two strings.

Studies since that of Bamber (1969) have questioned his conclusions regarding the nature of the comparison process and the basis of the fast-"same" phenomenon. For example, the serial self-terminating model favored by Bamber for "different" judgments has been found to be difficult to distinguish from certain types of models in which the letter pairs are compared in a parallel self-terminating manner (Snodgrass & Townsend, 1980; Taylor, 1976a, 1976b; Townsend, 1974). There is also evidence to suggest that "different" judgments might be based on a holistic comparison rather than on the analytic comparisons that have commonly been assumed (Krueger, 1978; Miller, 1978). In addition, the fast-"same" phenomenon has been attributed to holistic priming for "same" strings (Taylor, 1976b), to the nature of a basic holistic comparison process that occurs for both "same" and "different" strings (Krueger, 1978), and to differences in the rate at which component letter pairs are matched (Proctor, 1981).

The present study is concerned with evaluating Proctor's (1981) claim that the fast-"same" phenomenon and several other phenomena of multiletter matching are attributable to differences in the processing rate for component letter pairs. The analysis is based on a theoretical framework that Proctor developed to account for the name-physical and same-different disparities in reaction time to classify single-

We would like to thank Peter Harzem for allowing us to conduct the experiment on his equipment, Deborah Grantham for assistance in conducting the experiment, Maria Ekstrand-Hurst and Otto Arnoscht for assistance in analyzing the data, and Janet D. Proctor for helpful comments on the manuscript. Requests for reprints should be sent to Robert W. Proctor, Department of Psychology, Auburn University, Auburn, Alabama 36849.

letter pairs. These terms refer to the common findings that physical-same (same letters, same case) pairs are classified as "same" more rapidly than name-same (same letters, opposite case) pairs and that "same" judgments are faster than "different" judgments, respectively. The framework attributes these disparities for single-letter pairs to three factors: The level of processing at which the match is performed (physical code vs. name code); facilitation in the rate at which repeated forms are encoded (priming); and inhibition that occurs when competing name codes are activated (response competition).¹ The former two factors act to decrease reaction time to physical-same pairs relative to name-same and "different" pairs for situations in which they are operative, whereas the latter factor acts to slow reaction time to "different" pairs relative to the others.

According to the framework, the situations in which each of the three factors contributes to the reaction-time disparities varies as a function of the case relationship of the letter pairs (same case vs. opposite case), whether trials are mixed or blocked according to case relationship (blocking), and whether the letters are presented simultaneously or successively (method of presentation). These situations are summarized in Table 1.² The most prominent features of the framework are that (1) the levels factor is relevant only for simultaneous presentation, with all successive matches, including judgments to physical-same pairs, made at the name code level; (2) facilitation is relevant only for successive presentation; and (3) the factors that contribute to the physical same-different disparity for simultaneous presentation vary as a function of blocking (because "different" judgments can be made at the physical code level if no name-same pairs are included, but must be made at the name code level, otherwise), but do not with successive presentation (because levels is not a factor and facilitation is assumed to operate indepen-

dently of blocking). The evidence on which the framework is based is considered in detail in Proctor (1981).

Proctor's (1981) theoretical framework provides a good qualitative account of a wide range of data obtained with single-letter pairs. In addition, Proctor has argued that the framework is appropriate for multiletter matching, as well. That is, he contends that the time to match component letter pairs is the primary determinant of many phenomena evident in multiletter matching.

In order to extend the theory to multiletter matching, Proctor (1981) made the additional assumptions (1) that component letter pairs are matched in parallel, with the process being self-terminating (see Taylor, 1976b, for support), and (2) that because "same" matches of component letter pairs are performed more rapidly than "different" matches, the reaction-time functions for one-different strings (strings that differ at only one position) effectively reflect an exhaustive comparison similar to that required for "same" strings. The framework, along with these additional assumptions, predicts that when reaction time is examined as a function of string length, the functions for "same" and one-different strings should be approximately parallel, with the "same" judgments being faster than the "different" judgments by an absolute magnitude determined by the situational factors in the framework.

Existing studies of multiletter matching are categorized in Table 2 according to the variables that are critical in the theoretical framework.³ Proctor (1981, pp. 315-319) performed a qualitative analysis of these existing studies that supported the predictions drawn from the framework as well as the more general premise that disparities in time to match multiletter strings are primarily a function of the time to match component letter pairs.

As is apparent from Table 2, the analysis of existing studies suffers from two major drawbacks. First, with the exception of the mixed-list same-case and opposite-case conditions examined by Beller (1970) and Bruder and Silverman (1974), all of the conditions corresponding to the cells of the three-factor array have been conducted as separate experiments that varied widely in the specific procedures employed. Secondly, as indicated by the blank cells in Table 2, several conditions relevant to the classificatory system have not yet been studied.

Thus, in addition to the relative tentativeness with which conclusions can be drawn from between-study comparisons, the missing conditions prohibit a complete analysis. A complete evaluation of Proctor's (1981) theoretical framework requires that all cells in the array be examined. In particular, one very important prediction that cannot be verified from existing data is that blocking should not influence the physical same-different disparity with successive pre-

Table 1
Processing Components That Contribute to Reaction-Time Differences in Single-Letter Matches

Difference	Presentation Sequence	
	Simultaneous	Successive
Name Instructions		
NS - PS	Levels	Facilitation
Diff - NS	Inhibition	Inhibition
Diff - PS	Levels + Inhibition	Facilitation + Inhibition
Physical Instructions		
Diff - PS	Inhibition (?)	Facilitation + Inhibition

Note—NS = name same; PS = physical same; Diff = different. (From "A Unified Theory for Matching-Task Phenomena" by R. W. Proctor, *Psychological Review*, 1981, 88, 291-326. Copyright 1981 by the American Psychological Association. Reprinted by permission.)

Table 2
Multiletter Matching Studies Classified According to Method of Presentation (Simultaneous vs. Sequential), Case Relationship (Same-Case vs. Opposite-Case Pairs), and Blocking (Blocked vs. Random Presentation of Same-Case and Opposite-Case Pairs)

Blocked		Random	
Same-Case Pairs	Opposite-Case Pairs	Same-Case Pairs	Opposite-Case Pairs
Simultaneous Presentation			
Eichelman (1970), Experiment 1: Nonsense Strings		Beller (1970), Experiment 2	Beller (1970), Experiment 2
Silverman (1973), Experiment 1, Experiment 2		Bruder & Silverman (1974): Nonword Strings	Bruder & Silverman (1974): Nonword Strings
Successive Presentation			
Bamber (1969)	Bamber (1972)		
Taylor (1976b): Standard Condition			

sentation of the two strings, although it does with simultaneous presentation.

Similarly, there is an ambiguity regarding the influence of string length on name-same matches that needs to be resolved. Whereas Beller (1970) and Bruder and Silverman (1974) obtained an increase in reaction time of approximately 150 msec/letter, Bamber (1972) found an increase of only half that magnitude.⁴ Because the former studies differed from the latter in both method of presentation (simultaneous in the former, successive in the latter) and blocking (mixed list in the former, blocked list in the latter), it is unclear which of these two variables is critical. Method of presentation would implicate a difference in the manner in which simultaneous and successive matches are performed, whereas blocking would implicate a difference in the manner in which name codes are accessed as a function of whether or not subjects expect only opposite-case letter pairs to be presented.

To summarize, Proctor (1981) has presented a theoretical framework that accommodates many data for single-letter matches. He has argued that, with some additional assumptions, the framework can also be applied to multiletter matching. A between-study analysis of existing literature provided support for Proctor's position, but suffers from the tentativeness of any such analysis and the lack of relevant data to support a complete analysis. Thus, in order to more strongly assess the position that time to match component letter pairs accounts for many of the phenomena of multiletter matching, the three variables relevant to Proctor's framework (method of presentation, case relationship, and blocking) were manipulated within-subjects in a single experiment.

METHOD

Subjects

The subjects were 12 students enrolled in an undergraduate psychology course. Each student voluntarily participated in eight sessions for extra credit toward his/her course grade.

Apparatus

Stimuli were presented on the display screen of a Radio Shack TRS-80 computer. Stimulus durations, interstimulus intervals, and intertrial intervals were controlled by the computer.

Responses for the matching task were made by pressing one of two response keys on the computer's keyboard (a standard typewriter keyboard). For half of the subjects, "same" responses were indicated by pressing the Z key with the left index finger, whereas "different" responses were indicated by pressing the ? key with the right index finger. For the other half of the subjects, this pairing was reversed. Reaction times were recorded to the nearest millisecond by the computer.

Stimuli

Stimuli were pairs of letter strings composed from the set B, D, F, G, H, L, M, N, R, and T. Both upper- and lowercase versions of the letters were employed. Only consonants were used to minimize the probability that strings of two or more letters could be given a monosyllabic name. In addition, the specific consonants used in the experiment were chosen because they were clearly identifiable on the computer display and because the upper- and lowercase versions of each were physically dissimilar.

The strings were 1, 2, or 4 letters in length. All strings were constructed such that no letters were repeated within a string and the letters within a string were either all uppercase or all lowercase. The letters within the strings of length 2 and 4 were presented in a horizontal row. Each letter subtended a visual angle of approximately 36 min square as viewed by the subject. The space separating the letters in multiletter strings was approximately 6 min. Thus, the visual angle subtended by the 2-letter and 4-letter strings was approximately 1 deg 18 min and 2 deg 7 min, respectively. The pair of strings on each trial was centered both horizontally and vertically around a small fixation spot. The gap between the top and bottom strings was approximately 1 deg 30 min.⁵

Conditions and Procedures

Each subject received four sessions in which the pair of strings was presented simultaneously and four sessions in which the pair was presented successively. All four sessions of one presentation type were conducted before the sessions of the other type, with the order of presentation counterbalanced across subjects. For successive presentation, the string above fixation was presented for a duration of 1 sec. After an interstimulus interval of 350 msec, the string below fixation was presented for 150 msec. For simultaneous presentation, both strings were presented for the entire 1.5-sec interval.⁶ For both presentation conditions, a warning interval of .5 sec (as indicated by a flicker of the fixation point) preceded presentation of the letter strings, and an intertrial inter-

val of 3 sec separated successive trials. Reaction time was measured from the onset of the pair of stimuli with simultaneous presentation and from the onset of the second stimulus with successive presentation.

Within both the simultaneous and successive presentation conditions, the first of the four sessions was a practice session in which both same-case (upper-upper; lower-lower) and opposite-case (upper-lower; lower-upper) pairs were presented. The three experimental sessions differed in terms of the case relationship (same case, opposite case) of the pairs and whether pairs of only one (blocked) or both (random) case relationships could occur. That is, in the blocked same-case and blocked opposite-case sessions, only pairs with the respective case relationship occurred, whereas in the random session, both same-case and opposite-case pairs occurred, randomly intermixed. The order of the three experimental sessions was counterbalanced across subjects, with each subject receiving the same order of sessions for both the simultaneous and successive presentation conditions.

Within each session, subjects received 186 trials, the first 6 of which were practice. Of the remaining 180 trials, 90 pairs were "same" and 90 were "different." An equal number of the "same" and "different" pairs (30) were of each string length. Within each string length, the 30 "different" trials were divided equally between strings that differed at all positions (all-different) and strings that differed at only one position (one-different). To the extent possible, the position at which the one letter differed was varied approximately equally across all positions for the two and four letter strings. For the random-list sessions, each of the trial types (same, one-different, all-different at each string length) was divided approximately equally between same-case and opposite-case pairs.⁷ The trials within a session were presented in pseudorandom order with the restriction that no more than three "same" or three "different" pairs occur in a row.

At the beginning of the experiment, the subjects were given instructions regarding the nature of the matching task. The instructions stressed that strings should be classified as same only if they matched at all positions, that case relationship was irrelevant (name-matching instructions), and that responses should be made as rapidly as possible without making many errors. Prior to each session, the subjects were also instructed regarding the case relations of stimulus pairs (same-case, opposite-case, or both) that could occur. Only correct responses were included in the reaction-time data.

RESULTS AND DISCUSSION

Reaction-Time Data

Median reaction times were obtained for each subject as a function of string length (1, 2, 4), method of presentation (simultaneous vs. successive), case relationship (same, opposite), blocking (random, blocked), and type of pair (same, one-different, all-different).⁸ Means were obtained by averaging across subjects, and these data are presented in Table 3. Reaction time varied as an approximately linear function of string length, so least square regression lines were obtained. These functions are plotted in Figure 1 because they illustrate clearly the major aspects of the data. Three sets of data analyses were performed. The first was on single-letter pairs alone, the second on same and one-different strings of all lengths, and the third on all-different strings.

Single-Letter Pairs

A four-factor analysis of variance was performed on the reaction-time data for strings of length 1. Three main effects were significant: method of presentation [$F(1,11) = 50.27$, $p < .001$], type of pair [$F(1,11) = 14.03$, $p < .01$], and case relationship [$F(1,11) = 36.83$, $p < .001$]. The main effect for method of presentation represents the common finding that simultaneous matches are slower than successive ones. The more critical effects are those for type of pair and case relationship, which reflect the same-different disparity ("same" judgments faster than "different") and name-physical disparity, respectively. That the latter effect is attributable primarily to the name-physical disparity is evident in

Table 3
Mean Proportion of Errors and Mean Reaction Time as a Function of the Five Independent Variables

	Blocked									Random								
	Same			One Different			All Different			Same			One Different			All Different		
	1	2	4	1	2	4	2	4		1	2	4	1	2	4	2	4	
Simultaneous Presentation: Same Case																		
RT	539	610	907	588	696	952	650	725	557	640	896	644	778	1087	704	786		
Error	.025	.028	.036	.028	.084	.139	.023	.006	.006	.012	.012	.051	.089	.201	.011	.023		
Simultaneous Presentation: Opposite Case																		
RT	643	814	1228	686	862	1225	752	950	643	808	1206	671	910	1116	720	852		
Error	.023	.031	.086	.036	.040	.205	.028	.023	.034	.105	.089	.051	.122	.300	.011	.023		
Successive Presentation: Same Case																		
RT	356	397	454	383	415	520	389	397	390	432	459	420	487	600	442	429		
Error	.023	.042	.053	.017	.040	.139	.023	.012	.006	.023	.023	.039	.067	.133	.000	.033		
Successive Presentation: Opposite Case																		
RT	424	471	604	444	511	644	440	468	420	486	590	436	483	695	453	441		
Error	.017	.022	.058	.034	.094	.177	.023	.017	.046	.061	.040	.023	.056	.201	.000	.023

Figure 1. Least square regression lines for reaction time as a function of string length, method of presentation, case relationship, blocking, and type of pair. Open circles indicate simultaneous presentation and filled circles indicate successive presentation.

the significant interaction of type of pair $\times$ case relationship [$F(1,11)=6.79$, $p < .025$], which reflects a greater influence of case relationship on "same" than on "different" pairs. Although blocking had no main effect, it did interact reliably with case relationship [$F(1,11)=6.58$, $p < .05$], indicating that whereas it made little difference whether opposite-case pairs were blocked or randomized, same-case pairs were classified more rapidly under blocked than under random presentation conditions.

The theoretical framework proposed by Proctor (1981) makes several predictions for responses to single-letter pairs. The first of these is that the name-physical disparity should be obtained for all situations. As can be seen in Table 3, this finding was obtained. Although no specific prediction is made for the relative magnitude of the name-physical disparity for simultaneous and successive presentation conditions, the disparity is usually greater with simultaneous presentation. This relationship was evident in the present study, as indicated by a significant case relationship $\times$ method of presentation interaction when only "same" pairs were examined [$F(1,11)=6.41$, $p < .05$]. The theory does predict, however, that blocking should not influence the magnitude of the name-physical disparity for either simultaneous or successive presentation conditions. In the analysis of "same" pairs, there was no interaction of blocking $\times$ case relationship [$F(1,11)=2.29$, $p > .05$] or blocking $\times$ case relationship $\times$ method of presentation ($F < 1.0$), indicating that within chance limits

the blocking variable had no influence on the name-physical disparity.

Proctor's (1981) theory also predicts that "same" judgments should be faster than "different" judgments for all situations. As is evident in Table 3, this common finding was also obtained in the present study. More importantly, the theory predicts that the magnitude of this same-different disparity should be greater with random than with blocked presentation for simultaneous same-case pairs, but not for simultaneous opposite-case pairs or for either same- or opposite-case pairs with successive presentation (see the introduction). The four-way interaction that would support this prediction approached, but did not attain, the .05 significance level [$F(1,11)=3.25$, $p < .10$]. However, as predicted, separate analyses of the successive and simultaneous presentation conditions showed no sign of a three-way interaction for the former method of presentation ($F < 1.0$), with a nonsignificant trend toward such an interaction for the latter method [$F(1,11)=4.33$, $p < .10$]. Thus, although the results are not conclusive regarding this important prediction, the pattern of outcomes is as predicted. In the analysis of multiletter strings that follows, this interaction attains the .05 significance level.

Same and One-Different Strings

A five-factor analysis of variance, with repeated measures on all factors, was performed on the reaction-time data for same and one-different pairs. In addi-

tion, more specific analyses were performed to clarify critical relationships. The presentation of results that follows centers around a discussion of the relevant issues, with the *F* ratios that are cited coming from the five-factor analysis unless otherwise noted.

Four of the five main effects in the analysis were significant: string length [$F(2,22)=123.08$, $p < .001$], method of presentation [$F(1,11)=202.63$, $p < .001$], case relationship [$F(1,11)=54.08$, $p < .001$], and type of pair [$F(1,11)=12.31$, $p < .005$]. The only nonsignificant main effect was that of blocking [$F(1,11)=1.14$]. The main effect of string length reflects increases in reaction time as a function of increases in string length. The remaining significant effects indicate that successive pairs of stimuli were responded to more rapidly than simultaneous ones, that same-case pairs were responded to more rapidly than opposite-case pairs, and that responses to "same" pairs were faster than those to one-different pairs, respectively. All of these findings are commonly obtained outcomes.

The remainder of this section focuses on a more detailed analysis of the role of each of the independent variables. Although they cannot be considered entirely in isolation, each subsection will focus around one or two particular variables.

Type of pair. One major prediction from Proctor's (1981) analysis of multiletter matching is that the "same" and one-different functions should be approximately parallel. The type of pair $\times$ string length interaction was nonsignificant [$F(2,22) < 1.0$]. However, two three-way interactions involving these two factors along with method of presentation [$F(2,22)=3.74$, $p < .05$] and case relationship [$F(2,22)=5.34$, $p < .025$] were significant, as was the five-way interaction of all factors [$F(2,22)=3.64$, $p < .05$]. As is evident in Figure 1, these interactions reflect a systematic deviation from predictions for the simultaneous opposite-case conditions. Whereas all other conditions show either approximately equivalent slopes for the "same" and one-different functions or slightly greater slopes for the one-different function, the simultaneous opposite-case conditions show greater slopes for the "same" than for the one-different functions. More specifically, because the difference in slopes with blocked presentation was a nonsignificant one attributable primarily to one subject, the greater influence of string length on "same" than on one-different judgments was clearly evident only when the opposite-case pairs were randomly intermixed with same-case pairs. The reliability of this latter outcome for the simultaneous, random presentation situation is evident in that similar results were obtained by Bruder and Silverman (1974), as well as apparently by Beller (1970), although he did not report separate functions for one-different pairs of the same and opposite case.

Rather than the greater slope for name-same strings in the simultaneous, random presentation condition reflecting a fundamental distinction in the nature of processing for this condition relative to all others, the result apparently only reflects an influence of response criterion. That is, the proportion of errors (incorrect "same" responses) to one-different strings of length 4 was greatest for the simultaneous opposite-case strings under random presentation conditions. Thus, reaction time to these strings is likely underestimated due to the tendency to initiate a "same" response if a "different" letter pair is not recognized relatively quickly. This bias most likely occurs as a consequence of the relative rarity of trials with one-different stimuli of the opposite case when random presentation conditions are in effect, combined with the very long time required to complete such comparisons for simultaneous strings. Evidence supporting the bias interpretation is apparent in the fact that if the reaction-time functions for the simultaneous opposite-case strings in the random presentation condition are plotted on the basis of the data from strings of lengths 1 and 2 only, the function for one-different pairs is steeper than that for "same" pairs.

A comment is necessary regarding the tendency toward slightly greater slopes for one-different functions as compared with "same" functions that was evident for most of the conditions. This outcome is also commonly obtained. The deviation from the parallel relationship predicted by Proctor (1981) apparently reflects an influence of response competition that occurs at longer string lengths for one-different strings. That is, because the matching of the "same" component letter pairs will tend to be completed prior to that of the one pair of letters that is "different," a "same" response will be primed. Evidence supporting this interpretation is apparent in Beller's (1970) study. He included "same" strings composed of one name-same letter pair, with the remaining pairs being physical-same. Thus, these strings are similar to the one-different strings in that all component letter pairs except one are physical-same. However, because these one-name-same strings require a "same" response, response competition would not be a factor. As would be expected, the one-name-same responses were slower than the all-physical "same" responses by a constant amount; that is, the functions were parallel.

Method of presentation and case relationship. The relative influence of string length as a function of method of presentation and case relationship that was obtained in the present experiment was in accord with the between-experiment analysis performed by Proctor (1981). The influence of string length was greater on simultaneous matches than on successive matches, as indicated by a significant method of pre-

sentation $\times$ string length interaction [$F(2,22)=66.72$, $p < .001$]. String length also influenced opposite-case matches more than it did same-case matches [$F(2,22)=12.36$, $p < .001$].

The question raised in the introduction as to whether the much greater effect of string length on opposite-case matches reported by Beller (1970) and Bruder and Silverman (1974) as compared with that reported by Bamber (1972) was due to a difference in method of presentation or the blocking factor is clearly answered in the present study. Method of presentation is the critical factor. The three-way interaction of method $\times$ case-relationship $\times$ string length was marginally significant [$F(2,22)=3.36$, $p < .06$; or $F(1,22)=5.01$, $p < .05$, when only the linear component of the string length variable is considered], indicating that the relative influence of string length on opposite-case pairs as opposed to same-case pairs is greater for simultaneous than for successive matches. Furthermore, when responses to opposite-case pairs alone are analyzed, the interaction of string length with method of presentation is highly significant, as well [$F(2,22)=43.54$, $p < .001$]. On the other hand, blocking plays only a limited role in the effect that string length has on match reaction time, as indicated by a nonsignificant interaction of blocking $\times$ string length [$F(2,22)=1.20$] and a nonsignificant three-way interaction of these two variables with case relationship [$F(2,22)=.88$].⁹

The interaction of method of presentation and case relationship with string length is similar to the pattern of interaction that the two variables have for single-letter pairs. This relationship is most clearly apparent in a comparison of the name-physical disparity for single-letter pairs with the corresponding difference in slopes of the reaction-time functions for name-same and physical-same matches. For simultaneous stimuli, the difference in reaction time to opposite-case and same-case single letter pairs is 95.5 msec (when averaged across blocked and random presentation), and the corresponding difference in slopes is 72 msec/item. Similarly, for successive stimuli, the name-physical disparity for single-letter pairs is 39.9 msec, and the difference in slopes is 34.3 msec/item.

The obvious implication of the close relationship between differences in reaction time to single-letter pairs and differences in slope as a function of string length is that multiletter strings are compared in an analytic manner in which the time to match strings is determined by the time required to compare the single-letter pairs. Thus, the factors that contribute to the disparities in reaction time to single-letter pairs (see Table 1) also are primarily responsible for the slope disparities with multiletter pairs.

Blocking. Although blocking does not have the general effect that method of presentation does in multiletter matches, it does have a more limited one.

The two-way interactions of blocking with type of pair and with case relationship were significant [$F(1,11)=9.36$, $p < .025$, and $F(1,11)=7.25$, $p < .025$, respectively], as was the three-way interaction involving these variables [$F(1,11)=15.09$, $p < .01$]. These analyses indicate that randomly intermixing same- and opposite-case pairs had little influence on opposite-case matches, while slowing same-case matches, and that this effect was greater for "different" pairs than for "same" pairs.

The outcome indicated by the preceding analyses is further clarified by a significant four-way interaction of those variables with method of presentation [$F(1,11)=5.22$, $p < .05$]. Separate analyses of the simultaneous and successive presentation conditions indicated that whereas, for the former method of presentation, there was a significant interaction of blocking $\times$ case relationship $\times$ type of pair [$F(1,11)=13.49$, $p < .01$], for the latter there was not [$F(1,11)=2.26$, $p > .05$] (for successive presentation, all other terms involving blocking were nonsignificant). Thus, the influence of blocking occurs primarily for simultaneously presented "different" pairs of the same case. Responses to these pairs are considerably slower when randomly intermixed with opposite-case pairs than when not.

As indicated previously, Proctor's (1981) theoretical framework predicts this outcome. No significant effect of blocking is predicted for successive presentation because both same- and opposite-case matches are considered to be performed at the name-code level under both random and blocked presentation conditions and because the factors that contribute to reaction time are assumed to be equivalent for the two methods of presentation. An effect of blocking is predicted for simultaneous presentation that is limited primarily to "different" pairs of the same case because matches for these pairs can be performed at the physical code level when only same-case pairs are possible, but must be performed at the name-code level when opposite-case pairs can also occur. Thus, the obtained outcome provides confirmation of an important prediction from Proctor's (1981) theory.

All-Different Pairs

A four-factor analysis of variance was performed on the reaction-time data for all-different pairs. "Different" pairs with a string length of one that were included in the previous analysis as one-different pairs were also included in the present analysis of all-different pairs. Although, as commonly found, the influence of string length on reaction time was substantially less for all-different pairs than for "same" and one-different pairs, the basic pattern of results was similar.

The main effects of method of presentation, case relationship, and string length were all highly signif-

icant [$F(1,11)=59.62$, $p < .001$; $F(1,11)=17.69$, $p < .005$; and $F(2,22)=28.8$, $p < .001$, respectively]. As in the previous analysis, only the main effect of blocking was nonsignificant ($F < 1.0$). The significant main effects reflect the same general findings as in the analysis of "same" and one-different pairs: Reaction-time was slower to simultaneous matches than to successive matches, slower to opposite-case pairs than to same-case pairs, and increased as a function of string length.

As in the previous analysis, both method of presentation and case relationship interacted with string length, as well as with each other [$F(2,22)=18.3$, $p < .001$; $F(2,22)=6.38$, $p < .01$; and $F(1,11)=28.8$, $p < .001$, respectively]. The three-way interaction of these variables was also significant [$F(2,22)=3.96$, $p < .05$]. These interactions indicate that the effects of string length and case relationship were located almost entirely on simultaneous matches. For simultaneous matches, the effect of string length was greater for opposite-case pairs than for same-case pairs, resulting in responses to opposite-case pairs being slower overall than responses to same-case pairs. These outcomes are all in agreement with the primary analysis of "same" and one-different strings.

Of the remaining terms, only the blocking $\times$ string length and blocking $\times$ case interactions were significant [$F(2,22)=4.07$, $p < .05$; and $F(1,11)=6.86$, $p < .025$, respectively]. The blocking $\times$ string length interaction is due to the fact that the effect of string length on reaction time is greater for blocked than for random presentation. The blocking $\times$ case interaction reflects the fact that the difference in reaction time to opposite-case and same-case pairs was greater with blocked presentation than with random presentation. The three-way interaction of blocking $\times$ case $\times$ method of presentation was of borderline significance [$F(1,11)=4.43$, $p < .06$], indicating that the effect demonstrated by the blocking $\times$ case interaction was stronger for simultaneous than for successive presentation.

In general, the findings for all-different strings are in agreement with those from the analysis for "same" and one-different strings. As in the previous analysis, the influence of all variables is greater with simultaneous than with successive presentation. In fact, there is very little influence of any variable, including string length, with successive presentation. Because correct responses to all-different strings can be emitted whenever a single mismatch is obtained, the time to complete the first mismatch is relatively independent of string length when the strings are presented successively.

Error-Rate Data

The overall proportion of errors committed in the experiment was .036. The mean proportion of errors

as a function of the five independent variables is shown in Table 3. Error rate was positively correlated with mean reaction time for the 64 conditions in the five-factor design ($r = .53$), indicating that the conditions that yielded longer reaction times generally yielded higher error rates, also.

A five-factor analysis of variance similar to that performed on the reaction-time data was performed on the error-rate data for the "same" and one-different pairs. The main effects of string length [$F(2,22)=47.79$, $p < .001$], case relationship [$F(1,11)=11.97$, $p < .01$], and type of pair [$F(1,11)=12.62$, $p < .005$] were significant. These three terms reflect increasing error rates as a positive function of string length, higher error rates for opposite-case strings than for same-case strings, and higher error rates for one-different pairs than for "same" pairs, respectively.

The only other terms that were significant were the string length $\times$ type of pair interaction [$F(2,22)=15.70$, $p < .001$], the method of presentation $\times$ blocking interaction [$F(1,11)=10.45$, $p < .01$], and the string length $\times$ case relationship $\times$ method $\times$ blocking interaction [$F(2,22)=3.47$, $p < .05$]. The first of these terms indicates that error rate increased with string length to a greater extent for one-different pairs than for "same" pairs. The method $\times$ blocking interaction shows that error rate was unaffected by blocking with sequential presentation, but was greater for random conditions than for blocked conditions with simultaneous presentation. The four-factor interaction indicates that this effect was due primarily to an increase in error rate for opposite-case pairs at the longer string lengths.

A four-factor analysis of variance performed on the proportion of errors to all-different pairs showed only a significant influence of string length [$F(2,22)=8.69$, $p < .005$]. Post hoc comparisons revealed that this effect was due to a higher error rate for pairs of length 1 than for pairs of lengths 2 and 4.

FINAL DISCUSSION

One important outcome of the present study that has not been emphasized to this point is that it replicates a large part of the literature on multiletter matching. This replication includes not only manipulations that were performed within previous experiments, but also those evident in the between-study analysis performed by Proctor (1981). Thus, this study confirms the conclusion suggested by the orderliness of data across existing studies that the phenomena of multiletter matching are consistent and robust.

A second general outcome of importance is that the study provides strong evidence to support Proctor's (1981) claim that many phenomena of multiletter matching, including apparently the fast-same phenomenon, are attributable to the time required to match component letter pairs. In general, the factors

that Proctor (1981) has shown to be critical at influencing the time to judge single-letter pairs as same or different have similar effects on the time to match multiletter strings. The clearest indication of the importance of the time required to match component letter pairs is the close relationship between the magnitude of the name-physical disparity for single-letter pairs and the disparity in slopes between physical-same and name-same strings. That is, each additional pair adds a relatively constant amount to the reaction time disparity.

Although the relationship between the name-physical disparity for single-letter pairs and the name-physical disparity in slopes for multiletter pairs provides strong evidence regarding the analytic nature of the comparison process, it also raises a dilemma regarding the manner in which multiletter strings are compared. That is, the similarity between the difference in slopes and the corresponding difference in time to match single-letter pairs strongly suggests that "same" judgments are based on a serial comparison process. Although certain parallel models yield predictions that are similar or equivalent to those of the serial model (Taylor, 1976b), it seems highly unlikely that with parallel processing the increment in reaction time for each additional letter would be so similar to the reaction-time difference for single-letter pairs. Because evidence from "different" matches clearly favors self-terminating rather than exhaustive processing (Taylor, 1976b), the problem of the relative slopes for "same" and "different" reaction-time functions arises again, without solutions that have previously been proposed apparently being applicable.

That is, the basic problem around which most studies of multiletter matching have been centered is why the slope of the "same" reaction-time function is less than predicted by the serial self-terminating model that accounts well for the "different" functions. The alternative ways of dealing with the problem have been to argue (1) that although "different" judgments are based on a serial self-terminating comparison, "same" judgments are based on a holistic comparison (Bamber, 1969), (2) that both "same" and "different" judgments are based on parallel self-terminating comparisons, with the relative advantage for "same" pairs being due to a holistic priming effect (Taylor, 1976b) or the faster rate at which the comparisons are completed for matching letter pairs (Proctor, 1981), or (3) that the matching process is holistic for both "same" and "different" strings, with the reaction-time functions reflecting the nature of this process (Krueger, 1978). In providing support for a serial comparison process underlying "same" judgments, the name-physical disparity in slope for multiletter matching functions provides evidence against the operation of all of these proposed mechanisms.

REFERENCES

- BAMBER, D. Reaction times and error rates for "same-different" judgments of multidimensional stimuli. *Perception & Psychophysics*, 1969, **6**, 169-174.
- BAMBER, D. Reaction times and error rates for judging nominal identity of letter strings. *Perception & Psychophysics*, 1972, **12**, 321-326.
- BELLER, H. K. Parallel and serial stages in matching. *Journal of Experimental Psychology*, 1970, **84**, 213-219.
- BRUDER, G. A. Role of visual familiarity in the word-superiority effects obtained with the simultaneous matching task. *Journal of Experimental Psychology: Human Perception and Performance*, 1978, **4**, 88-100.
- BRUDER, G. A., & SILVERMAN, W. Effects of familiarity and sequence length on analog matches in the simultaneous matching task. *Journal of Experimental Psychology*, 1974, **102**, 875-880.
- EICHELMAN, W. H. Familiarity effects in the simultaneous matching task. *Journal of Experimental Psychology*, 1970, **86**, 275-282.
- KRUEGER, L. E. A theory of perceptual matching. *Psychological Review*, 1978, **85**, 278-304.
- KRUEGER, L. E., & SHAPIRO, R. G. A reformulation of Proctor's unified theory for matching-task phenomena. *Psychological Review*, 1981, **88**, 573-581.
- MILLER, J. Multidimensional same-different judgments: Evidence against independent comparisons of dimensions. *Journal of Experimental Psychology: Human Perception and Performance*, 1978, **4**, 411-422.
- PROCTOR, R. W. A unified theory for matching-task phenomena. *Psychological Review*, 1981, **88**, 291-326.
- SILVERMAN, W. P. The perception of identity in simultaneously presented complex visual displays. *Memory & Cognition*, 1973, **1**, 459-466.
- SNOODGRASS, J. G., & TOWNSEND, J. T. Comparing parallel and serial models: Theory and implementation. *Journal of Experimental Psychology: Human Perception and Performance*, 1980, **6**, 330-354.
- TAYLOR, D. A. Stage analysis of reaction time. *Psychological Bulletin*, 1976, **83**, 161-191. (a)
- TAYLOR, D. A. Effect of identity in the multiletter matching task. *Journal of Experimental Psychology: Human Perception and Performance*, 1976, **2**, 417-428. (b)
- TOWNSEND, J. T. Issues and models concerning the processing of a finite number of inputs. In B. H. Kantowitz (Ed.), *Human Information Processing: Tutorials in Performance and Cognition*. Hillsdale, N.J.: Erlbaum, 1974.

NOTES

1. Krueger and Shapiro (1981) have recently argued that the inhibition factor proposed by Proctor (1981) be replaced by an internal noise factor. Although the issue regarding the role of inhibition vs. the role of internal noise is important, it is independent of the predictions examined in the present article. Internal noise could be substituted for inhibition without altering the nature of the arguments presented in this article.

2. Table 1, which is taken from Proctor (1981), does not directly indicate the case relationship and blocking factors. Case relationship is distinguished by whether the particular disparity involves name-same or physical-same pairs, whereas the influence of blocking is indicated by the distinction between physical instructions (that allow only physically identical forms to be classified as "same") and name instructions (that also allow physically distinct forms with the same name to be classified as "same").

3. Only studies that manipulated string length from 1 to at least 4 letters are included in Table 2. Studies that did not vary string length are excluded because of the primary role that factor plays in most analyses of multiletter matching, whereas studies

that employed longer string lengths (e.g., Bruder, 1978; 3-6 letters) are excluded because patterns beyond the length of 4 appear to require multiple glances, and, as a consequence, yield different patterns of results (Krueger, 1978; Silverman, 1973).

4. The estimate from Bruder and Silverman's (1974) study is based on the increase between the string lengths of 1 and 3. The increase between lengths 3 and 5 was much less, but was apparently underestimated due to criterion factors (see the discussion of this problem later in the article).

5. Although the visual angle subtended by the letter strings was a bit greater than optimal, and the separation between letters was a bit less than optimal, the entire display was clearly visible within a single glance. The fact that the data correspond closely to those obtained in previous multiletter matching experiments indicates that the display characteristics were not a problem.

6. The 150-msec duration of the second stimulus with successive presentation was chosen because of its use in previous studies to minimize eye movements (Bamber, 1969, 1972; Taylor, 1976b). Because this duration was too brief for subjects to clearly perceive the two strings with simultaneous presentation, a longer duration had to be employed for that condition. The decision to make the simultaneous duration equivalent to the total presentation time of the two-string sequence with successive presentation was made in order to maintain a constant rate of occurrence of trials for the two conditions. It has been suggested that this difference in the physical availability of the critical strings might confound the simultaneous-successive comparisons (particularly those involving interactions with string length). Recently, we have repeated the blocked-physical match conditions using a procedure in which the second string for successive presentation and both strings for simultaneous presentation offset with the subject's response. Because instructions emphasized accuracy, the slopes of the func-

tions were slightly greater than in the present study. However, the average difference in slopes (56.5 msec for successive and 132.7 msec for simultaneous, averaged across "same" and one-different functions) were roughly equivalent, indicating that the successive-simultaneous comparison in the present study is not confounded with exposure duration.

7. In the mixed-list sessions, there were 15 one-different pairs and 15 all-different pairs at the string lengths of 2 and 4 that were divided into same-case and opposite-case pairs. Within a single list, eight pairs were of one of the case relationships, and seven were of the other. The particular case relationship receiving the extra trial was varied between lists so that across subjects an equal number of same-case and opposite-case pairs occurred for these conditions. For the one-different pairs in the case relationship that occurred eight times, the position at which the strings differed was distributed equally across all positions. For those that occurred seven times, one of the positions was randomly selected to have one fewer occurrences, and this position was also varied across lists.

8. The term "type of pair" will be used to refer to this factor, although the reader should be aware that in the primary analysis of "same" and one-different pairs, response covaries with type of pair.

9. The one particular outcome suggested by between-experiment comparisons (Proctor, 1981) that was not evident in the present study was a similarity between the functions for successive opposite-case matches (when blocked) and simultaneous same-case matches. This apparent similarity had led Proctor to suggest that blocking, rather than method of presentation, might be critical.

(Manuscript received March 27, 1981;
revision accepted for publication March 24, 1982.)