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Reading Ability and Perception

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READING ABILITY AND PERCEPTION

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ABSTRACT

Skilled reading can be partly understood as a set of interrelated component processes (Perfetti & Lesgold, 1979). The efficiency with which any one of these component processes operates could limit or improve the efficient operation of the other component processes. However, there is some controversy over which of these component processes are important in showing differences in overall reading ability. The processes of interest in this study are those at the perceptual level. The purpose of the existing study was to examine the relationship between perceptual processes involved in reading and individual differences in reading ability among college students. Specifically, the present study assessed whether skilled readers utilized more effectively compared to less skilled readers such perceptual factors as spatial redundancy when tachistoscopicly presented four-letter words. Furthermore, the words were presented at four different rates in order to examine whether certain perceptual factors affect the speed of verbal encoding when performing perceptual tasks.

Thirty-four highly skilled and 36 less skilled college readers were rated on the basis of their scores on a standardized reading test. They were then divided into groups performing one of three perceptual tasks: item location (where a letter appeared in the word), item identification (what the letter is, at a specific letter position in the word), or a

combination of the two tasks (both item location and identification).

Subjects viewed 128 words, 32 at each presentation rate. Subjects responded after each word was presented.

The proportion of errors in responding to the words was computed. A 2 (Ability) x 3 (Condition) x 4 (Exposure Duration) x 2 (Spatial Redundancy) x 4 (Serial Position) ANOVA was computed on this data. Standard significant main effects of duration, spatial redundancy, and serial position were found along with a condition x duration and a spatial redundancy x serial position interaction.

More importantly, a significant ability x duration x spatial redundancy x serial position interaction was observed. This may reflect qualitative differences in the nature in which good and poor readers process words. Good readers did not seem to utilize such factors as spatial redundancy in processing order more than poor readers since a significant ability x condition x spatial redundancy interaction was not found. In addition, it was expected that the condition combining both item location and identification would be more difficult than either of the other two tasks. However, this condition showed smaller errors rates suggesting that a combination of the two processes augmented the efficiency of feature extraction.

The primary result of the present study was that reading ability differences were found in processing at the perceptual level. If reading ability differences exist at the perceptual level, such as in encoding item location (Mason, 1980; Mason et al., 1981), then it follows that this may limit the efficiency of later components of word recognition. A more extensive manipulation of reader ability and perceptual tasks may help elucidate the viability of this interpretation.

INTRODUCTION

The ability to skillfully comprehend printed symbols by the process called reading is a complex task. Perfetti and Lesgold (1979) suggested that skilled reading could be partly understood as a set of interrelated component processes. These component processes include: (1) decoding, i.e. interpretting printed symbols to produce meaning; (2) short term memory operations that allow interconnectedness among word meanings to be made; and, (3) comprehension processes which include identifying main ideas and tying them to prior conceptual structures. In formulating their ideas, Perfetti and Lesgold (1979) argue that the component processes of reading are not necessarily functionally independent but mutually facilitative. Therefore, they suggest that a gain in the efficiency with which one subskill operates would lead to a gain in the efficient operation of other subskills as well. Conversely, an ineffectively operating subskill might limit the efficiency with which other subskills could operate.

The purpose of the present study was to examine the relationship between perceptual processes involved in reading and individual differences in reading ability among college students. A brief review of the experimental studies of the perceptual processes involved in word recognition will be useful before discussing the role of perceptual processes involved in reading.

Nearly a century ago, Cattel (1885-1886) found that subjects can report more letters from a briefly exposed stimulus if those letters formed a word than if they did not. Cattel presented to his subjects letter displays for 10msec and asked them to report as many letters as possible. He found that subjects reported only four or five individual letters correctly if random letter strings were shown but if the display consisted of several words they were able to report three or four entire words (Spoehr & Lehmkuhle, 1982). This phenomenon was titled the word apprehension effect.

Miller, Bruner, and Postman (1954) suggested that the word apprehension effect resulted from the fact that a familiar unit (word) could be reconstructed from a bare minimum of perceptual input because there are only a limited number of ways in which the incompletely perceived portions of the word could be filled in. In other words, Miller et al. (1954) suggested that English language facilitates the rapid perceptual processing of words because of the redundancy involved in the English language. They believed that the closer the stimulus followed the rules of English (implicitly possessed by the subject) the greater the probability of guessing the missing portions (Miller, Bruner, & Postman, 1954).

The prototype for word recognition studies was reported by Reicher (1969). Subjects were briefly presented with one or two letters, four-letter common words, or four-letter random letter strings (nonwords) immediately followed by a visual noise masking field. Two single letters appeared with the mask, and subjects were asked to choose which of the two letters appeared in the stimulus presented. The forced-choice alternatives were chosen such that if a word was presented as a stimulus, both alternatives would make a common word given the other three letters. For example, if the stimulus was WORD then the alternatives could have been D and K. If the stimulus was a nonword, both of the alternatives would complete the stimulus as a nonword.

Three exposure durations were chosen for each subject. The shortest exposure duration was set at the point where the subject achieved 60% report accuracy during a set of sample trials. The longest duration was set at 90% accuracy, with the third duration set at a midpoint between the two extremes. Reicher used three exposure durations for the purpose of probing different stages of the encoding process (Reicher, 1969).

A third variable was introduced into the design in order to minimize the confounding of perceptual effects with memory effects. During one half of the trials, the forced-choice alternatives were shown before the stimulus presentation as well as after.

The major result reported by Reicher (1969) was that performance on single words was better than performance on single letters. This word superiority effect was inconsistent with the serial models of information processing and suggested that some early stages of feature extraction must occur in parallel.

Wheeler (1970) proposed five hypotheses to account for the word superiority effect reported by Reicher (1969). Each of the hypotheses centered on the idea that the word superiority effect found by Reicher (1969) resulted from his experimental procedures rather than the fact that letters in words are perceived more rapidly than isolated letters.

The first alternative hypothesis proposed by Wheeler (1970) was the interference hypothesis. This hypothesis suggested that since the two choice alternatives appeared simultaneously with the mask in the Reicher (1969) study, the alternatives interfered with the still proceeding process of recognizing the stimulus. Furthermore, Wheeler (1970) suggested that the degree of interference was greater for letters than words. In an attempt to assess this hypothesis, Wheeler (1970) varied the time interval between the mask onset and the onset of the two choice alternatives by 0, 1, or 2 seconds. At each interval the word superiority effect was observed, thus providing no support for this hypothesis.

The second alternative hypothesis suggested that perception of letters was impaired because they occurred in the same position they would have appeared at had they been in the corresponding word, while words were centered with regards to the fixation point. Possibly, locating the letter within the visual field would take time away from the recognition process and impair performance. In an attempt to assess this hypothesis, Wheeler (1970) presented words and letters either centered on the fixation point or displaced in the visual field. The word superiority effect was always obtained, thus offering no support for this hypothesis.

The third hypothesis of Wheeler (1970) was that there are idiosyncratic properties of individual words that cause the subject to focus on those aspects of a word which contains the most information that distinguishes the presented word from other words. This hypothesis was tested by presenting target words in which the critical letter appeared in all positions across subjects. The word superiority effect was again found in all conditions, therefore, providing no support for this hypothesis.

In a fourth hypothesis, Wheeler (1970) suggested that in the Reicher (1969) study, subjects performed well on word stimuli because they were more frequent than the alternative word the incorrect letter choice alternative formed. Therefore, subjects may have been able to guess correctly more often on word stimuli in the Reicher (1969) study. In an attempt to examine this issue, Wheeler (1970) balanced the words used as targets and distractors across subjects. For example, if one subject was presented with the word READ with choices of R and H, another subject viewed HEAD with the same choice alternatives. The results fail to support this hypothesis as the word superiority effect was still obtained.

Finally, Wheeler (1970) suggested that the word superiority effect may have resulted from the fact that words are more frequent than letters in the English language. Wheeler (1970) examined this assertion by comparing word perception with the perception of the letters A and I which appear in the language as high frequency words. Wheeler (1970) found that performance on the four-letter words was still better than performance on the single letters of A and I.

Wheeler's dismissal of these attempts to explain the word superiority effect as a methodological artifact led other investigators to attempt to ellucidate the cause of the word superiority effect.

Johnston and McClelland (1973) examined some of the boundary conditions of the word superiority effect. Furthermore, they sought to rule out some alternative interpretations of the word superiority effect. For example, the perception of letters in a word may be facilitated by the presence of adjacent contours. In order to assess this possibility, they presented subjects with four-letter words, single letters, and single letters with number signs ("#") filling the three empty positions. This symbol was used because it is not easily confused with any particular letter. A second alternative interpretation of the word superiority effect is that single letters are hard to find in the visual field since their position varies as to where they would appear if they were part of a four letter word. If positional uncertainty of the letters is the basis of the word superiority effect, Johnston and McClelland (1973) argue that precuing subjects as to the position of the target letter should eliminate the word superiority effect (WSE). Therefore, subjects were precued to the position of the target letter on half of the letter and letter # stimuli.

Twenty-four subjects performed the task with a pre- and postexposure field consisting of a white card with black curved and jagged contours in an irregular pattern, referred to as a pattern mask. For the other 24 subjects, the pre- and post mask consisted of a plain white field. Following each trial, subjects were asked to respond to two forced-choice alternatives, consisting of letters for the single letter and letter # stimulus type or two words differing in only the critical letter for the word stimulus type.

They found that the word-letter difference was virtually unchanged when the subjects were precued to letter position. Johnston and McClelland (1973) saw this as demonstrating the robustness of the WSE since letters should be favored during a position-uncertainty condition. Furthermore, performance was no better on letter # stimuli than on letter stimuli, providing no support to the notion that the WSE is due to single letters being harder to see because the stimulus field contains fewer contours as a whole or because a single letter lacks adjacent contours (Johnston & McClelland, 1973). Finally, Johnston and McClelland (1973) found a WSE with the pattern mask but not when subjects performed under the white mask condition. Thus, Johnston and McClelland (1973) reported some interesting boundary conditions of the word superiority effect and rule out some alternative explanations of its source.

Juola, Leavitt, and Choe (1974) found additional support for the necessity of using a patterned mask in order to produce the word superiority effect. In this experiment, the stimuli consisted of four-letter words, four-letter orthographically regular nonwords, and single letter displays. Immediately after the stimulus was presented the stimulus field darkened but no patterned mask was used. After a one second delay, subjects were presented with two letters and asked to choose which one was in the stimulus just viewed. No word superiority effect was found, similar to the white mask condition in Johnston and McClelland's (1973) study. Juola et al. (1974) attribute their inability to produce the WSE to their failure to use patterned masking. They concluded that effective masking is apparently more detrimental for the perception of letters than words (Juola et al., 1973).

Once the validity and the boundary conditions of the word superiority effect were reasonably established, researchers began to investigate the properties of words that might be responsible for producing the WSE. One idea was that subjects were more familiar with whole word units than single letter units. Unfortunately, this explanation is incomplete because studies using nonwords clearly indicate that the accuracy of perceptual encoding varies with the degree to which a letter string embodies the structural regularities of English. For example, subjects perform better on orthographically regular pronounceable nonwords (pseudowords) than unrelated character strings (nonwords).

The above empirical relationships led McClelland and Johnston (1977) to suggest that the perceptual encoding of letter strings may be influenced by the familiarity of the letter groups, including whole words, component letter clusters in words, and single letters. Therefore, McClelland and Johnston (1977) predicted that subjects should perform better on letter strings composed of more familiar letter clusters, and should perform better on words than pronounceable orthographically regular pseudowords.

In their first experiment, McClelland and Johnston (1977) tachistoscopically presented subjects with words, pseudowords, and single letters and were asked to choose which of two forced-choice letter alternatives they had seen in the display. On half the trials, subjects were required to give a full report of all the letters they saw in the display before they were presented with the two letter alternatives. Letter cluster familiarity for the words and pseudowords was defined by the sum of the bigram (two-letter combinations) frequencies for each word or pseudoword. In other words, the frequency with which each two-letter combination occurred in their particular position in a four letter string was computed and summed for each word and pseudoword. Words and pseudowords high in single letter frequency were encoded faster than words low in single letter frequency.

In the second experiment, McClelland and Johnston (1977) tachistoscopicly presented subjects with words, unrelated letter strings (nonwords), and single letters, and required subjects to give a full report of the letters they saw followed by a two-letter forced-choice test of which letter was seen in the display. The forced-choice report accuracy was better on the words than on nonwords or letters, 86%, 76%, and 72% respectively, with accuracy on the nonwords and letters being nondifferential. On the full report measure, performance on words was much better than performance on nonwords.

McClelland and Johnston (1977) concluded that familiarity with whole word units facilitates encoding but the orthographic regularity of the unit greatly contributes to this facilitation. Furthermore, they also suggest that perception of all types of letter strings involves a position-specific letter analysis process sensitive to the frequency of occurrence of letters in different positions (McClelland & Johnston, 1977).

Later work by Johnston and McClelland (1980) presented a hierarchical model of word perception to attempt to account for the perceptual advantage of whole word units and letter strings that are high in their orthographic regularity. The theory posits the existence of a hierarchy consisting of (in ascending order) letter position pre-processors, feature detectors, letter detectors, and word detectors. Detectors can receive excitatory input that will activate them or inhibitory input that will deactivate them. Activation of certain feature detectors send excitatory input to letter detectors consistent with those features and inhibitory input to letter detectors inconsistent with those features. When a patterned mask appears after a word stimulus, deactivation of the feature detectors of the word occurs while the detectors for the mask are being activated. All the letter detectors should be deactivated by the pattern mask because it contains elements inconsistent with all letters. Yet at the word level, detectors should receive neither excitatory nor inhibitory input because all of the letter detectors are inactive. Therefore, a word detector should remain active longer than a letter detector (activated by a letter stimulus) when both are followed by a patterned mask (Johnston & McClelland, 1980). Furthermore, if a mask composed of unrelated letters or a word was used, the word level detectors should be deactivated by the mask and thus, the word superiority effect should disappear. In three experiments, Johnston and McClelland (1980) provide complete support for these predictions. For example, in Experiment 1, with words and letters as the target displays, a feature mask produced a 15.6% WSE while a word mask resulted in a 6.2% effect. In Experiment 2 with word and letter target displays, word and nonword masks produced word superiority effects of 2.4% and 2.2%, respectively. Finally, in Experiment 3 with word and letter target displays, feature masks and nonword masks produced word superiority effects of 26.6% and 7.5%, respectively.

The theoretical model of Johnston and McClelland (1980) along with the empirical data on word perception clearly suggest that subword components and whole-word components are important aspects of rapid word recognition. These empirical and theoretical advances provide a framework for applied researchers to investigate the sources of individual differences in the proficiency of word recognition. One such area that has received considerable attention is reading ability differences in the speed and accuracy of word recognition.

Perfetti and Lesgold (1979) argue that rapid word recognition is important in distinguishing good and poor readers. Adequate reading comprehension depends in part on the proficiency with which certain subskills have been developed, including the ability to convert printed symbols into a language code. If a reader requires a considerable amount of processing capacity to decode a single word, less processing capacity will be available for higher order comprehension processes (Perfetti & Lesgold, 1979). For example, memory for the just previously coded word or phrase may decrease, and therefore the subject's ability to integrate successive clauses in working memory may be impaired.

In one of the first examinations of reading ability differences in word recognition speed, Perfetti and Hogaboam (1975) separated third and fifth grade students into skilled and less skilled reading groups and measured their vocalization latencies for high frequency words, low frequency words, and pseudowords. They found that the skilled reader vocalization latencies were faster than less skilled readers, but the reading ability groups differed to a large degree for pseudowords and for low frequency words, and displayed smaller differences for high frequency words. Perfetti and Hogaboam (1975) suggest that since good readers invest less processing capacity to decode words, more capacity should be available for higher level comprehension processes and thus facilitate comprehension performance.

Later work by Perfetti, Finger, and Hogaboam (1978) found that vocalization latency differences between good and poor readers were only found when the stimuli were words but were not found when the stimuli were colors, digits, or pictures. Perfetti et al. (1978) suggest that the slower decoding speed of poor readers is specific to alphabetic stimuli and rule out a general deficit in retrieval of any name from long term memory.

Perfetti and Lesgold (1979) state that skilled reading comprehension depends on a highly refined facility for generating and manipulating language codes. They see reading capacity limitations as largely the result of limitations in the decoding process. Therefore, if the process of accessing word meaning from memory requires more processing capacity in poor readers, less capacity will be available for working memory operations and comprehension will be impaired.

The importance of rapid verbal coding as contributing to reading ability differences was clearly indicated by Perfetti's work; however, several components are involved when accessing word meanings from long term memory. The relative importance of each of these components to reading ability differences was not addressed by Perfetti's work. Recently, Chabot, Zehr, Prinzo, and Petros (1983) argued that decoding involves the perceptual process of extracting the word features, lexical access (locating the name of the word in memory) and semantic access (accessing meaning and other properties beyond the name). In order to estimate the relative importance of these three subprocesses to reading ability differences in decoding speed, subjects were presented with two words and asked to decode whether the two words were the same, as quickly as possible. In some trials, subjects would be presented with the same word and thus could base their decisions soley on the physical features of the word. On some trials, the two words would be the same but would be presented in different type (upper and lower case letters). Finally, some of the trials presented two different words and the subjects had to decide whether they were from the same semantic category. Their results suggest that semantic access is the most important process in producing reading ability differences in word recognition speed and that no perceptual factors contribute to these ability differences (Chabot et al., 1983).

Jackson and McClelland (1979) found that university undergraduates differing in reading ability did not differ on sensory tests involving identification of letter pairs within a string of nonletter characters. On each trial, subjects were presented with two letters (200msec) that were separated by a varying number of nonletters within a field of 35 characters. After each trial, the subjects were asked to write down which letter was presented on the right and which letter was on the left of the fixation point. The largest number of nonletter characters separating the two target letters that still led to accurate performance constituted the primary dependent measure. The results indicated no significant effects of reading ability. The results of Jackson and McClelland (1979) and Chabot et al. (1983) led to the assertion that perceptual factors are not a source of reading ability differences in word recognition speed.

The work of Mildred Mason suggests that perceptual factors are an important component of reading ability differences in word recognition speed. Mason (1978a) had good and poor readers perform a single word naming task with latency to vocalization onset as the primary dependent variable. Subjects were presented with 4 and 6 letter words and pseudowords that were high and low in spatial redundancy. Single letter spatial redundancy is a measure of orthographic regularity that reflects the frequency with which single letters appear in certain positions in words (Mayzner & Tresselt, 1965). The spatial frequency of each letter is summed for each word to reflect its average level of spatial redundancy. The results indicated that good readers were faster than poor readers, four letter arrays were named faster than six letter arrays, arrays high in spatial redundancy were named faster than arrays low in spatial redundancy, and words were named faster than pseudowords. More importantly, reading ability interacted with array length and spatial redundancy while ability was additive with lexicality (words vs. pseudowords). Employing additive factors logic (Sternberg, 1969), Mason (1978a) suggested that since reading ability interacted with variables that influence the speed of visual code formation (i.e., array length, spatial redundancy) then ability differences in this task must be due to slower visual code formation on the part of the less skilled readers (Mason, 1978a).

In a subsequent study, Mason (1978b) examined whether spatial redundancy restricts the number of valid alternatives at each serial position, or serves a perceptual function by keeping visually confusable graphemes from appearing in the same array and/or maximizing the distance between such graphemes when they do occur in the same array. The results of two experiments suggest that spatial redundancy serves the function of improving feature extraction by keeping visually confusable graphemes separated. That is, letters that share visual features are constrained at opposite ends of words (b in the first serial position and d in the sixth position) or are constrained in the same serial position (b and p in the first position, d and t or g and y in the last position) (Mason, 1978b). Such letters are highly spatially redundant for those specific serial positions. This is a logical concomitant with the nature of the retina, the fovea has a high concentration of retinal cells and the middle of the word has less constraint, while the ends of the word have more constraint and are more likely to appear in the lesser concentrated areas of the retina. Thus, an implicit understanding of spatial redundancy and the frequencies of certain letter placements for each serial position in a word can facilitate the encoding process at this level. Utilization of spatial redundancy allows faster item location resolution by knowing the most likely serial position that any certain letter will appear.

Another study concerning perceptual subprocesses done by Mason, Pilkington, and Brandau (1981) found no differences in naming times for nonlinguistic stimuli between good and poor readers when naming did not require order to be processed. Subjects were given paired-associate training in which each stimulus was a string of three symbols from the set #, $, %, &, @, and *. Highly skilled readers were superior in naming nonlinguistic stimuli only when the correct response depended on the order of the symbols. This raised the question of whether the requirement to process order information affects memory retrieval as well as visual code formation (Mason et al., 1981).

In later work, Mason (1980) sought to more carefully examine the importance of processing order information to reading ability differences in word recognition. Mason (1980) required subjects to identify a letter or the location of a letter in a 4 character display. She used uppercase X's superimposed on dollar signs as nonletter characters. One of the four characters presented was a letter while the other three were nonletters. With the item perception task (the WHAT condition), subjects were required to make a forced-choice response on each trial from four letters. The serial position was precued with this condition. With the location perception task (the WHERE condition), subjects were required to identify the serial position in which a letter occurred regardless of the identity of the letter. Mason found that less skilled readers seem to require more time than highly skilled readers to encode location information (WHERE). Her results refute the notion that there are no peripheral sensory differences between good and poor readers. This suggests that both highly skilled and less skilled readers extract the same amount of visual information during the time course of an eye fixation, but highly skilled readers make better use of linguistic structure to augment the visual code formation.

She states that more than any other visual activity, reading involves a continuous integration of both the absolute spatial location (WHERE) and the identities of the letters (WHAT) contained in the words (Mason, 1980).

In Mason's (1980) work, she dealt with single letter stimuli and, therefore did not allow spatial redundancy to operate naturally. Spatial redundancy is most effective when it serves to prevent visually confusable letters from appearing in adjacent positions in the array. Therefore, it speeds the rate of visual code formation if the letters appear in highly redundant positions. Since Mason (1980) dealt with only single letters, she did not create conditions in which spatial redundancy is most effective. In order to improve on what is already known, the present study used four-letter words as stimuli. It included the conditions of item identification (WHAT) and item location (WHERE) as in Mason's (1980) work and added the condition combining the two (the BOTH condition) in order to simulate more closely natural word recognition processes. The summed single letter spatial redundancy was calculated for each word. The subjects' report accuracy for the various conditions of WHAT, WHERE, and BOTH were examined as a function of spatial redundancy and reading ability. The questions addressed by this study are whether there are perceptual differences in item location and identification between good and poor readers.

METHOD

Subjects

All subjects were administered the Nelson-Denny Reading Test (1973). The subjects were native English-speaking undergraduate psychology students at the University of North Dakota who received class credit for their participation. All subjects were required to have normal or corrected to normal vision. Thirty-four highly skilled and 36 less skilled readers were then rated on the basis of the reading rate, comprehension, and vocabulary subscores on the Nelson-Denny. Normative data is given for a combined total reading score obtained by weighing the comprehension subscore twice as heavily as the vocabulary subscore. These total reading scores were utilized to classify each subject as a skilled or less skilled reader. Less skilled readers were those who scored between the 10th and 45th percentiles and skilled readers between the 65th and 99th percentiles.

Materials

Sixty-four pairs of four letter words were used. The words in each pair differed from one another by one letter only. The forced-choice letter alternatives for each stimulus complete either of the words in a particular pair. The words from each pair were divided into two blocks of 64 trials. Half the words in each block were designated as high in spatial redundancy and half were designated as low in spatial redundancy. Summed spatial redundancy was calculated by adding over serial positions with the Mayzner and Tresselt (1965) single-letter frequency counts for four-letter words. The average summed spatial redundancy is presented in Table 1 as a function of exposure duration and spatial redundancy. Within each block, words were presented for 20, 35, 50, and 65msec. Within each block 8 high and 8 low spatially redundant words appeared at each exposure duration. The mean summed spatial redundancy for the high and low conditions are approximately equal for each exposure duration. Across subjects each word appeared in each exposure duration equally often.

Stimuli were presented on a Model T-2B-1 Harvard Tachistoscope which has a two-field exposure cabinet. The tachistoscope controlled the exposure duration as set by the experimenter. The stimuli were typed on 4" x 6" white cards using an IBM-100 Memory Typewriter with a carbon ribbon. The individual letters subtended a visual angle of .43 degrees in height and .21 degrees in width. The four element arrays subtended approximately 1.02 degrees. The mask was composed of 4 uppercase X's superimposed on 4 uppercase O's.

Procedure

After the Nelson-Denny was completed a short break was given after which the experiment began. Subjects were randomly assigned to one of three conditions (WHAT, WHERE, or

Table 1

Mean Summed Spatial Redundancies for Each Serial Position and Exposure Duration for High and Low Spatially Redundant Words

High Spatially Redundant Words				
Serial	Exposure Duration			
Position	20msec	35msec	50msec	65msec
1	2669	2717	2487	2576
2	2307	2670	2563	2450
3	2955	2216	2586	2520
4	2199	2532	2498	2586
Low Spatially Redundant Words				
1	1310	1799	1846	1732
2	1555	1439	1464	1514
3	1452	1163	1416	1489
4	1844	1811	1469	1460

BOTH). In the WHAT condition, subjects were precued as to the position where the target letter would appear and were only required to identify the correct letter from the forced-choice alternatives. In the WHERE condition, subjects were precued with the target letter. After the presentation of the word, they were required to indicate in which of the four serial positions the target letter appeared. In the BOTH condition, subjects were required to resolve both item location and identity. They had to select one of the two forced-choice alternatives after the presentation of the word without being precued to identity or location of the target letter.

Before the presentation of each word, a premask appeared on the screen. After the subject was cued, this was immediately replaced by the stimulus for the specific exposure duration after which the postmask immediately appeared. Each subject received 32 practice trials, and 2 block of 64 trials. There was a 5 minute break after the practice trials and between the 2 blocks of experimental trials.

RESULTS

The average number of correct responses made as a function of exposure duration, spatial redundancy, and serial position of the probed letter was calculated for every subject according to the number of alternatives possible in each condition. A correction for guessing model was applied by subtracting from the number of correct responses a fraction of the number of incorrect responses (this fraction utilizes the number of alternatives minus 1 as its denominator). This was applied due to the fact that 2 alternatives were possible in the BOTH and WHAT conditions while 4 responses were possible in the WHERE condition. Therefore, chance level was 50% in the BOTH and WHAT conditions while chance level was 25% in the WHERE condition. A 2 (Ability) x 3 (Condition) x 4 (Exposure Duration) x 2 (Spatial Redundancy) x 4 (Serial Position) ANOVA was computed on this corrected data. All subsequent tests utilized Newman-Keuls procedures, with alpha set equal to .05.

A main effect of duration was observed, $F(3,192) = 191.554$ $p < .001$, with mean correct responses of 1.579, 2.769, 3.336, and 3.624 for the 20, 35, 50, and 65msec exposure durations, respectively. Subsequent tests indicated that the proportion of errors increased significantly with each reduction in the amount of time that the stimulus was presented. There was also a main effect of spatial redundancy, $F(1,64) = 9.438$

p = .004, which showed that more correct responses were made (M = 2.915) to high spatially redundant words than to low spatially redundant words (M = 2.739). A main effect of serial position was also found, $F(3,192) = 21.808$ $p < .001$, with means of 3.159, 2.886, 2.662, and 2.602 for the first, second, third, and fourth serial positions in the word, respectively. Subsequent tests indicated that the proportion of errors increased significantly between the first, second, and third letter positions, but did not increase significantly between the third and last letter positions.

A significant ability x duration interaction, $F(3,192) = 2.615$ $p = .053$, was observed and is depicted in Table 2. Subsequent tests of this interaction indicated that good readers performed significantly better than poor readers only at the 35msec exposure duration. At both levels of ability, performance was significantly better with each increase in exposure duration.

A significant spatial redundancy (SR) x serial position interaction, $F(3,192) = 7.444$ $p < .001$, was found (see Table 3). Subsequent tests found significant differences in performance between high and low spatially redundant words at the second and last serial positions, with no spatial redundancy differences observed at the first and third serial positions. On the high SR stimuli, performance did not differ between the first two serial positions but significantly decreased in number correct at the third and fourth positions,

Table 2

Mean Number of Correct Responses as a Function of Reading Ability and Exposure Duration

		Exposure Duration			
Reading Ability		20msec	35msec	50msec	65msec
Poor	Mean	1.613	2.546	3.218	3.531
	SD	1.987	1.609	1.154	.901
Good	Mean	1.544	2.991	3.455	3.717
		1.717	1.384	.957	.548

Table 3

Mean Number of Correct Responses as a Function of Spatial Redundancy and Serial Position

	Serial Position			
Spatial Redundancy	1	2	3	4
High	3.145	3.093	2.609	2.812
Low	3.172	2.679	2.715	2.391

with the third position showing the lowest number of correct responses. On the low SR words, performance was significantly better when the probe was at the first position, compared to the second and third positions which were similar. Performance on these was significantly better compared to words in which the probe appeared at the last position.

A significant condition x duration x spatial redundancy x serial position interaction, $F(18,576) = 1.676$ $p = .04$, was found (see Table 4). Subsequent tests indicate significant differences in performance between the conditions only at the 20msec and 35msec exposure durations. At 20msec, on highly spatially redundant words, subjects performed better on the WHERE task compared to the WHAT task for words probing the second position, while with words at the third position WHAT was better than BOTH. For low SR words at this duration, WHERE and BOTH was better than WHAT at the first position, WHERE was better than WHAT and BOTH at the second position, and BOTH was better than WHAT and WHERE at the third position. The only significant difference in performance at 35msec for high SR words was BOTH showing better responding over WHAT at the first position. Similarly, at the same duration for low SR words, the only difference was again BOTH better the WHAT task at the second position. Despite the complexity of these comparisons, the most consistent pattern indicated is the the WHERE task was easiest at the fastest exposure duration (20msec) and the first two serial positions. Also, performance on high SR words was

Table 4

Mean Number of Correct Responses as a Function of Spatial Redundancy and Serial Position at Each Exposure Duration for Each Condition

WHERE Condition

Exposure Duration	Spatial Redundancy	Serial Position 1	2	3	4
20msec	High	2.100	2.533	1.355	1.689
	Low	2.600	2.122	.956	.739
35msec	High	2.911	3.467	2.611	2.756
	Low	3.278	2.533	2.856	2.620
50msec	High	3.645	3.689	3.356	3.367
	Low	3.633	3.211	3.189	3.314
65msec	High	3.833	3.756	3.367	3.767
	Low	3.889	3.533	3.411	3.186

Table 4--continued

WHAT Condition					
Exposure Duration	Spatial Redundancy	Serial Position 1	2	3	4
20msec	High	2.000	1.583	1.750	1.833
	Low	1.081	1.000	1.083	1.083
35msec	High	2.500	3.000	2.167	2.250
	Low	3.417	2.000	2.500	1.917
50msec	High	3.500	3.333	2.667	3.083
	Low	3.667	2.917	3.000	2.833
65msec	High	3.833	3.667	3.500	3.667
	Low	3.917	3.667	3.167	3.000

Table 4--continued

BOTH Condition					
Exposure	Spatial		Serial Position		
Duration	Redundancy	1	2	3	4
20msec	High	2.417	2.083	.583	1.167
	Low	2.000	1.167	2.000	.959
35msec	High	3.500	3.750	2.750	2.833
	Low	3.250	3.000	3.000	2.583
50msec	High	3.750	3.417	3.417	3.667
	Low	3.667	3.250	3.500	3.000
65msec	High	3.750	3.833	3.583	3.667
	Low	3.667	3.750	3.917	3.458

significantly better than low SR words scattered across conditions and serial positions but only at the 20msec and 35 msec presentations.

A significant ability x spatial redundancy x serial position interaction, $F(3,192) = 3.140$ $p = .027$, was observed and the means are reported in Table 5. Subsequent tests of this interaction indicated that only one significant ability difference (good better than poor) was at the first serial position for words high in spatial redundancy. Also, good readers were significantly more accurate than poor readers for words low in spatial redundancy only at the third and fourth serial positions. The pattern of this ability x spatial redundancy x serial position interaction depends upon the exposure duration of the stimulus as indicated by a significant ability x duration x spatial redundancy x serial position interaction, $F(9,576) = 1.896$ $p = .051$ (see Table 6). Subsequent tests found that at 20msec poor readers performed significantly better than good readers on high SR words when the probed letter appeared at the fourth serial position. At the same duration, good readers performed better than poor readers for low SR words at only the last serial position. At 35msec, good readers displayed significantly higher number of correct responses on high SR words at the third serial position, and on low SR words at the third and fourth serial positions.

Table 5

Mean Number of Correct Responses as a Function of Spatial Redundancy and Serial Position for Good and Poor Readers

Good Readers					
		Serial Position			
Spatial Redundancy		1	2	3	4
High	M	3.308	3.139	2.708	2.758
	SD	1.162	1.183	1.359	1.126
Low	M	3.219	2.719	2.911	2.650
	SD	.932	1.289	1.136	1.497
Poor Readers					
High	M	2.981	3.046	2.509	2.866
	SD	1.234	1.303	1.520	1.350
Low	M	3.125	2.639	2.519	2.132
	SD	1.587	1.396	1.541	1.497

Table 6

Mean Number of Correct Responses as a Function of Ability and Serial Position for High and Low Spatially Redundant Words at Each Exposure Duration

20msec

Spatial Redundancy	Reading Ability		Serial Position 1	2	3	4
High	Good	M	2.400	2.078	.978	.978
		SD	1.426	1.644	2.020	1.673
	Poor	M	1.944	2.056	1.481	2.148
		SD	2.000	1.977	1.685	1.575
Low	Good	M	1.789	1.378	1.489	1.261
		SD	1.961	1.579	1.468	1.958
	Poor	M	2.000	1.481	1.204	.593
		SD	1.831	1.928	1.765	1.803

35msec

Spatial Redundancy	Reading Ability		1	2	3	4
High	Good	M	3.200	3.311	2.833	2.800
		SD	1.199	1.184	1.770	1.341
	Poor	M	2.741	2.833	2.185	2.426
		SD	1.528	1.577	1.911	1.860
Low	Good	M	3.444	2.411	3.144	2.783
		SD	.822	1.993	1.233	1.530
	Poor	M	3.185	2.611	2.426	1.963
		SD	3.142	1.337	1.774	1.576

Table 6--continued

50msec						
Spatial Redundancy	Reading Ability		Serial Position 1	2	3	4
High	Good	M	3.744	3.422	3.422	3.522
		SD	.639	1.047	.923	.829
	Poor	M	3.519	3.537	2.870	3.222
		SD	.754	.909	1.679	1.245
Low	Good	M	3.756	3.233	3.367	3.172
		SD	.559	1.203	1.196	1.257
	Poor	M	3.556	3.019	3.093	2.926
		SD	.788	1.159	1.386	1.313
65msec						
High	Good	M	3.889	3.744	3.600	3.733
		SD	.385	.858	.723	.659
	Poor	M	3.722	3.759	3.500	3.667
		SD	.653	.750	.804	.720
Low	Good	M	3.889	3.856	3.644	3.383
		SD	.385	.380	.649	1.010
	Poor	M	3.759	3.444	3.352	3.046
		SD	.587	1.160	1.238	1.297

DISCUSSION

The results of this study replicate previous work (Mason, 1978a; 1980) in suggesting that there are perceptual differences between skilled and less skilled readers in the speed and efficiency of the perceptual process involved in feature extraction. That is, at brief exposure durations good readers are able to extract more information from a word than poor readers. The magnitude of reading ability differences in perceptual processing may have been underestimated by the present study as our different ability groups were not as extreme as in other investigations (Mason, 1975, 1978a, 1980; Mason, Pilkington, & Brandau, 1981). For example, subjects in the present study who scored within the 65th - 99th percentiles on the Nelson-Denny Reading Test were designated good readers, while those within the 11th - 45th percentiles were designated as poor readers. However, Mason (1980) defined skilled readers as those who scored between the 90th and 99th percentiles and poor readers as those who scored between the 11th and 40th percentiles. Nevertheless, differences in performance between the reading groups were found in the present study, again suggesting that perceptual processes may contribute to the widely documented reading ability difference in decoding speed (Perfetti & Lesgold, 1979).

The findings of the present study and those of Mason conflict with the assertions of Jackson and McClelland (1979) and Chabot et al. (1983) that perceptual processes are not a source of reading ability differences in memory access speed. The occurrence of these conflicting results may in part be due to differences in tasks used in the two studies. The tasks used by Jackson and McClelland (1979) and Chabot et al. (1983) bypassed the need for subjects to process the location of the letters and primarily required item identification.

As mentioned earlier, Jackson and McClelland (1979) required subjects to resolve the identity of two letters in a field of nonlinguistic characters, one on the right and the other on the left of the fixation point. The larget number of nonletter characters separating the two target letters that still led to accurate performance constituted the primary dependent measure. Since the nonletter characters were not easily confusable with actual letters and the presentation time was 200msec, the target letters were easily located. Chabot et al. (1983) presented subjects with two words and asked them to respond as quickly as possible, indicating whether the words were identical or the same but in different type (upper and lower case letters). Other trials asked subjects to decide whether the words were from the same semantic category. Only when the subjects were asked to decode whether the two words were the same was reading ability differences sampled at the perceptual level. During these trials the subjects could base their decisions solely on the physical features of the word.

The conditions administered by Jackson and McClelland (1979) and Chabot et al. (1983) are essentially the same as the WHAT condition in the present study. However, item identification tasks were not found as the major peripheral sensory differences in reading ability, the differences seem to be involved with the encoding of location information (Mason, 1980; Mason et al., 1981). It seems that resolving where the items appear in the stimulus array requires more processing time for poor readers the good ones.

One interesting pattern of results, not involving reading ability, was the performance differences observed between the WHAT, WHERE, and BOTH conditions. According to Mason (1980) and the hierarchical model of Johnston and McClelland (1980) recognizing what a letter is and where it is are important components of word recognition. We had assumed that the BOTH condition should be more difficult than the WHAT or WHERE conditions since it involved both letter identification and location. However, performance differences between conditions were scattered across serial positions for both high and low spatially redundant words presented at 20msec and 35msec exposure durations, with some indication of WHERE being easier than the other tasks at 20msec and the first two serial positions.

Resolving where each item is located within the array was the primary task for subjects performing under the WHERE condition. It was predicted that utilization of spatial redundancy would aid performance in resolving the location of the letters in the stimulus. Yet, a significant condition x spatial redundancy interaction was not found in the present study. These results are contrary to the assertions of Mason (1978b) that spatial redundancy serves the function of improving feature extraction by eliminating or minimizing competition for the same set of feature detectors. Letters that share visual features are constrained at opposite ends of words or are constrained in the same serial position. According to these notions, utilization of spatial redundancy in encoding should allow faster resolution of where each letter is located in the array.

As mentioned earlier, the speed of resolving the order of the letters plays a large part in reading ability differences, therefore spatial redundancy may be utilized differently between the reading groups. However, this is not supported in the present study since a significant ability x condition x spatial redundancy interaction was not found. The investigations of Mason and her colleagues (1980, 1981) concerning ability differences in resolving order did not use words as stimuli. Possibly, spatial redundancy does not facilitate processing order information in words. For example, in the present study a significant condition x duration x spatial redundancy x serial position interaction was found but subsequent tests failed to show spatial redudancy aiding performance in resolving the location of letters (the WHERE task).

On the other hand, reading ability differences were found in the processing of serial position. This was supported by a significant ability x duration x spatial redundancy x serial position interaction. Good readers differed from poor readers only at the last two serial positions. This may reflect qualitative differences in the nature in which good and poor readers process the words such that good readers may encode features in parallel while poor readers may sometimes revert to serial processing of the letters. This is partially supported by subsequent tests of this interaction which found that good readers performed significantly better than poor readers on the low SR stimuli at 20msec and on both the high and low SR stimuli at 35msec. However, this explanation is challenged by an anomolous situation which inexplicably occurred at 20msec on the high SR words with the poor readers performing significantly better than the good readers. The efficiency with which items are processed at these last two serial positions may play an important role in the efficiency of feature extraction.

In summary, reading ability differences in the efficiency of perceptual processing were found in the present study. These results are conservative compared to those found by Mason (1980) because of differences in critereon for assignment to the reading groups. Delineation of the perceptual differences between the reading groups may also have been limited by the choice of exposure durations. Significant differences in performance between good and poor readers were found only at the 35msec duration. The 20msec proved too short a presentation to differentiate between the reading groups and may have resulted in near chance level error rates, while performance at 50 and 65msec possibly reflects the ceiling effects of providing too much time to process the stimuli.

Reading ability differences in processing at the perceptual level are important in understanding decoding differences between skilled and less skilled readers. As mentioned earlier, Chabot et al. (1983) argued that decoding involves the perceptual process of extracting the word features, lexical access, and semantic access. Chabot et al. (1983) and Jackson and McClelland (1979) found no ability differences at the perceptual level with tasks involving the subprocess of item identification. Chabot et al. (1983) found support for the notion that semantic access is an important process in producing reading ability differences. But as Perfetti and Lesgold (1979) suggested, skilled reading can be partly understood as a set of interrelated component processes. If a reader requires a considerable amount of processing capacity to decode a single word, less processing capacity will be available for higher order comprehension processes. Therefore, if reading ability differences exist at the perceptual level, such as in encoding item location (Mason, 1980; Mason et al., 1981), then it follows that this may limit the efficiency of later components of word recognition.

Future directions for this study may delineate further the perceptual significance in reading ability differences in decoding speed by tightening the critereon for good and poor readers, having the exposure durations set at smaller intervals between 20msec and 50msec, and having the stimuli differ by more than one variable (which was only spatial redundancy in this study). The stimulus materials could consist of words, pseudowords, and nonwords in order to investigate the role of spatial redundancy in the extraction of features that cannot be accessed semanticly. Four and six letter stimuli could be used to investigate further any interaction with serial position. But regardless of any future directions with this work, the present study again suggests that perceptual processes may contribute to the widely documented reading ability differences in decoding speed.

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