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The development of word recognition mechanisms: Inference and unitization

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Adult, third-grade, first-grade, and kindergarten subjects searched for target letters through fields of six types. The six fields were formed by factorially combining the two variables wordness (words vs. nonwords) and case (upper, lower, and mixed). The adults and third-graders showed word superiority effects when searching through upper- and lowercase fields, but not when searching through mixed-case fields. First-grade subjects displayed a similar pattern, but the wordness effects in their data failed to reach statistical significance. The kindergarten subjects showed no word superiority effects in any of the three field conditions. The results are interpreted as indicating that the extraction of supraletter features is responsible for the word superiority effects shown by adults and third-graders, that this unitization process begins to develop in the first grade, and that by the third grade it is similar to that of an adult.

Several studies employing adult subjects have found that the perceptual recognition of words is superior to that of nonwords. Word superiority effects have been demonstrated in a wide variety of experimental paradigms, including tachistoscopic recognition (Reicher, 1969), letter search (Krueger, 1970), and same-different classification (Barron & Pittenger, 1974). The theoretical explanations of the word superiority effect fall into two major classes. One explanation is that features are extracted and matched to individual letter units in both word and nonword displays, but that perception of letters in words is facilitated due to an inference process that makes use of the sequential redundancy inherent in the words of a natural language (Thompson & Massaro, 1973). The alternative conceptualization, sometimes termed the unitization hypothesis, is that when a word is presented, features are extracted and matched to units of larger than letter size (e.g., familiar spelling patterns). These supraletter perceptual units are processed in parallel with letter-size units. According to this type of model, word superiority effects obtain because words simply contain more information (in the form of supraletter perceptual units) relevant to any given letter discrimination.

Both major models of the word superiority effect have received some empirical support. Inference explanations are supported by experiments showing word superiority effects with mixed-case stimuli (McClelland, 1976). Since mixed-case stimuli (words printed in the manner of cHaIr) presumably break up supraletter perceptual units, any word superiority effects observed with such stimuli must be due to the use of sequential redundancy. On the other hand, word superiority effects have been reported in experiments that completely controlled for inference processes (Purcell, Stanovich, & Spector, 1978). The processing of supraletter perceptual units seems to be the only viable explanation of such results. It now appears most likely that both inferential and unitization processes are operating in word recognition when the visual angle of the stimuli approximates that found in most reading situations (see Purcell, Stanovich, & Spector, 1978, for a fuller discussion).

Little work has been done on how the ability to use sequential redundancy and supraletter perceptual units develops with age. Most investigations have focused on uncovering developmental trends in the word superiority effect rather than on the question of what processing mechanisms are responsible for the effect at different ages. For example, Krueger, Keen, and Rublevich (1974) found that both fourth-graders and adults searched for a letter faster through word than through nonword displays. The magnitude of the effect, however, did not increase with age. Similarly, Stanovich, West, and Pollak (1978), employing third-grade, sixth-grade, and adult subjects, found no increase with age in the effect of orthographic structure in a word search task. Finally, Juola, Schadler, Chabot, and McCaughey (1978) found letter search to be faster through words

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and pronounceable pseudowords than through nonwords for second- and fourth-graders. The search times of the kindergarten subjects did not differ across stimulus types. These studies, although all focusing on aspects of the word superiority effect, have not addressed the question of which psychological mechanisms are involved. This is attempted in the present investigation, which employs an age range (kindergarten, first grade, and third grade) over which one would expect marked changes in the ability to use orthographic structure to facilitate word recognition. Changes with age in the ability to use sequential redundancy and supraletter perceptual units will be investigated by using uppercase, lowercase, and mixed-case stimuli in a letter search task. Word superiority effects observed in uppercase and lowercase conditions might be due to both inference and unitization. However, the existence of the effect in mixed-case conditions is an indication that inference processes are mainly responsible (see McClelland, 1976).

METHOD

Subjects

Eighty-four subjects participated in the experiment, 60 children and 24 adults. The 20 kindergarten children (8 males and 12 females) had a mean age of 5 years 11 months (range 5-6 to 6-4). The 20 first-graders (12 males and 8 females) had a mean age of 7 years 2 months (range 6-2 to 8-1). The 20 third-graders (9 males and 11 females) had a mean age of 9 years 3 months (range 8-10 to 10-4). The children were tested at the end of the school year. The 24 adults were recruited from a subject pool of Oakland University students.

Stimuli and Materials

Each of the six conditions of the experiment (formed by the 2 by 3 orthogonal combination of word vs. nonword and uppercase, lowercase, and mixed-case stimuli) consisted of a column of four-letter strings. The childrens' columns were 24 strings long and the adults' columns were 50 strings long. Each column was typed on a separate sheet (21 x 28 cm) in IBM Courier 72, 10 point, for the children and IBM Prestige Elite 72, 12 point, for the adults. The children's four-letter strings were .95 cm wide and the adults' four-letter strings were .78 cm wide. Since subjects sat approximately 35 cm from the stimulus sheets, the horizontal visual angle of the strings was 1.55 deg for the children and 1.28 deg for the adults.

The 24 words used in the word conditions for the children were chosen from high-frequency four-letter words, based on the Kučera and Francis (1967) count. Each word contained either the letter "a" or "r," but not both. The nonwords were formed by making unpronounceable anagrams of the words (e.g., "turn" was transformed into "rntu"). Another constraint on the construction of the anagrams was that the distributions of positions (first through fourth letter position) of the critical letters (a and r) were equated across word and nonword stimuli. The adults saw lists that contained these 24 items mixed with an additional 26 items that were chosen in the same manner.

In the upper- and lowercase conditions, all four letters were printed in a consistent case. In the mixed-case conditions, the case of the component letters alternated (e.g., TuRn). One-half of the items in the mixed-case conditions had an uppercase letter in the first position, and one-half of the items had a lowercase letter in the first position. The critical letters were always in lowercase form in the mixed-case conditions, thus allowing a direct comparison with the lowercase conditions. A different random ordering of the items was used in each of the six conditions. A hand-held stopwatch was used to measure the search duration. Latencies were measured to the nearest .1 sec.

Procedure

Subjects were individually tested in a session that lasted approximately 10 min. They were told that they would be seeing strings of letters that contained either an "a" or an "r" and that they were to go down the column and say as fast as possible which of the two critical letters was in each row. Timing began with the first response and ended with the last.

Subjects first completed a practice sheet that contained 10 items of all six types. Subjects then searched through four lists consisting of the factorial combination of lowercase vs. mixed case and words vs. nonwords. The order of both of these factors was counterbalanced across subjects. Thus, due to the counterbalancing and to the fact that lowercase target stimuli were used in both lower- and mixed-case conditions, a direct comparison of the word superiority effect in the two conditions was possible. Finally, the subjects completed the two lists (words and nonwords) of uppercase stimuli. Order of stimulus type was counterbalanced across subjects.

RESULTS

Since there were no sex differences on any of the performance measures, data from males and females were pooled in the analyses that follow. Also, for each age group two separate analyses were performed, one on the uppercase condition and another in which lower vs. mixed case (a "field" factor) was combined with wordness in a 2 by 2 factorial. The latter analysis is appropriate since the same-case targets were used in the lower- and mixed-case conditions in conjunction with a counterbalancing that makes the two conditions directly comparable. Order of conditions was included as a factor in all of the analyses in order to decrease the error terms. The main effects and interactions involving this variable only occasionally reached statistical significance, and it is not discussed further.

The mean search times for each age group and each condition are presented in Table 1. Turning first to the search times of the adults, an analysis of variance on the search times in the uppercase condition indicated a significant effect of wordness [$F(1,20) = 14.88$, $p < .001$]. An analysis of variance on the search times in the lower- and mixed-case conditions indicated that the effect of field type was significant at the .001 level [$F(1,20) = 19.49$] and that the effect of wordness

Table 1
Mean Search Times in Seconds

	Lowercase		Mixed Case		Uppercase	
Group	W	NW	W	NW	W	NW
Kindergarten	45.7	48.1	46.2	46.8	49.1	48.7
First Grade	36.2	37.3	35.0	36.3	41.1	42.6
Third Grade	24.1	25.9	24.9	25.3	25.8	30.2
Adults	33.5	34.8	32.2	31.6	33.3	34.8

was not significant [$F(1,20) = 1.29$]. However, there was a significant interaction of Wordness by Field Type [$F(1,20) = 4.41$, $p < .05$]. An analysis of simple main effects indicated that search was faster through words than through nonwords in the lowercase fields ($p < .05$) but not in the mixed-case fields.

An analysis of variance on the search times of the third-graders in the uppercase condition indicated that the wordness effect was significant at the .001 level [$F(1,16) = 28.83$]. An analysis of variance on the search times in the lower- and mixed-case conditions indicated that the effect of field type was not significant [$F(1,16) = .06$], that the wordness effect was significant at the .025 level [$F(1,16) = 7.80$], and that there was no interaction of Field Type by Wordness [$F(1,16) = 1.19$]. An analysis of simple main effects indicated that search was faster through words than through nonwords in lowercase fields ($p < .01$) but not in mixed-case fields.

The uppercase search times of the first-graders were lower in the word condition than in the nonword condition, but an analysis of variance indicated that this effect did not reach significance [$F(1,16) = 2.54$, $p < .15$]. An analysis of variance on the search times in the lower- and mixed-case conditions indicated that the effect of field type was not significant [$F(1,16) = 2.86$] and that the effect of wordness approached statistical significance [$F(1,16) = 3.38$, $p < .10$]. There was no interaction of Field Type by Wordness [$F(1,16) = .02$]. An analysis of simple main effects indicated that the wordness effect approached significance in the lowercase fields ($p < .10$) but not in the mixed-case fields. This pattern emerges, despite the fact that the difference between word and nonword search times in the two field conditions was approximately the same, because the error variance in the mixed-case condition was considerably larger.

An analysis of variance on the search times of the kindergarten children in the uppercase condition indicated that the wordness effect was not significant [$F(1,16) = .06$]. An analysis of variance on the search times in the lower- and mixed-case conditions indicated that there was no significant field effect [$F(1,16) = .10$], wordness effect [$F(1,16) = 1.25$], or Field by Wordness interaction [$F(1,16) = .73$]. An analysis of simple main effects indicated that there was no wordness effect in either of the field conditions.

DISCUSSION

The results from the adult subjects are rather easily described. There was a word superiority effect when searching through lower- and uppercase stimuli, but not when searching through mixed-case stimuli. The lack of a word superiority effect in the mixed-case condition seems to imply that the effect observed in the other two conditions was due to a unitization process (i.e., use of supraletter features) rather than to an inference process operating on letter-size units. The reason for the lack of support for the inference model might be the fact that the experimental paradigm involved continuously exposed stimuli and reaction time as a dependent measure. Such tasks, as opposed to tachistoscopic paradigms, have tended to produce evidence supporting unitization models rather than single-letter inference models (compare Thompson & Massaro, 1973, with Taylor, Miller, & Juola, 1977).

The results of the third-grade subjects mirrored those of the adults. A significant word superiority effect was observed in the lower- and uppercase conditions but not in the mixed-case condition. The results from the first-graders approximated those of the older subjects. The effect of wordness in the mixed-case condition did not approach significance. In the upper- and lowercase conditions, search was faster through words than through nonwords; however, the effects did not quite reach accepted levels of statistical significance ($p < .15$ and $p < .10$, respectively). The kindergarten subjects displayed no word superiority effect in any of the three field conditions.

The fact that no age group showed a word superiority effect in the mixed-case condition supports the notion that the development of an inference process making use of sequential redundancy and operating on letter-size units was not the cause of the increase with age in wordness effects in the lower- and uppercase conditions. To insure that the lack of a word superiority effect in the mixed-case condition was not due to the subjects attending to only lowercase letters, 26 additional adult subjects completed a similar search task where the target letters could appear in either case. The mean search times were 35.6 for the word list and 36.2 for the nonword list, a difference not approaching significance [$t(25) = .16$]. Thus, the word superiority effects displayed by the adults and third-graders when searching through the upper- and lowercase fields appear to be due, at least in part, to their ability to extract features of larger than letter size. Supraletter features are probably automatically extracted by these subjects when the orthographic structure of the string is familiar and the horizontal visual angle is fairly small (see Purcell et al., 1978). The first-grade subjects, on the other hand, seem only to have begun to display the ability to extract supraletter features. The performance of the kindergarten subjects indicated that no unitization process was operating to facilitate their search through word stimuli. This is to be expected, since the three field types were probably equally unfamiliar to them.

In summary, the present study has extended the large adult literature on the word superiority effect to show that the effect first emerges in Grade 1 and appears to be fully developed by Grade 3. The present research goes beyond previous studies in showing that a specific process, unitization, accounts for the increasing speed with which words are recognized as the child progresses from kindergarten through the third grade.

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