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Reading geometrically transformed text: A developmental approach

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An experiment is described in which third and fifth graders and adults read or searched through paragraphs that had word and sentence orientation (left to right and right to left) factorially varied. The principal factor that determined reading and search speeds was the orientation of the word irrespective of the orientation of the sentence. A developmental progression in reading proficiency was noted and all subjects performed at similarly slow rates when word orientation was reversed.

Extraction of meaning from text is the primary purpose in reading, but in order for that to be accomplished the physical or typographical features of text must be confronted. Over and above the orthographic features of the words themselves, word shape and boundary information provide important cues to word identification. Dramatic speed reductions occur when letter case and size are alternated within words in sentences (Smith, 1969; Smith, Lott, & Cronnell, 1969), when spaces between words are eliminated (Hochberg, 1970), and when both of these text characteristics are mutilated (Fisher, 1975; Fisher & Lefton, 1976; Fisher & Montanary, 1977; Lefton & Fisher, 1976; Spragins, Lefton, & Fisher, 1976).

These data have been interpreted as indicating that fluent readers possess the ability to modulate their reading strategies when task or text demands require a more in-depth analysis (Fisher, 1976; Fisher & Lefton, 1976; Fisher & Montanary, 1977; Spragins et al., 1976). The purpose of the present experiment is to examine this aspect of development as it relates to the rectification of geometrically transformed text. A methodology and set of stimuli will be used that are similar to those used by Kolers and his associates in the past to support more global notions of perceptual processing. Kolers (1968) set the groundwork for a series of experiments in which text is geometrically transformed so as to analyze the role of pattern analyzing functions in perception (Kolers, 1975; Kolers & Perkins, 1969a, 1969b). Kolers presented textual materials that were manipulated in a variety of ways, including rotating, reversing, and inverting both words and sentences.

Of concern in the present experiment is the developmental progression of the way in which readers realign or rectify sentences and words that go left to right and right to left. Normally, readers of English move their eyes from left to right across the page as a means of picking up textual information. Conditions in the present experiment were such that a sentence was presented so that it must be read right to left, while the words within the sentence were oriented so that they could be presented either from left to right or from right to left.

Subjects were third graders, fifth graders, and adults, in order that we might examine developmental progressions. Four geometric transformations of the text were employed: factorial combinations of both words and sentences presented left to right and right to left. An attempt was made to control for contextual load effects by comparing performance in both reading and high-speed search for words.

METHOD

Subjects

The subjects for this study were 112 children from Grades 3 and 5 (selected from several schools in and around Columbia, South Carolina) who were reading at or above their grade level and 112 students enrolled in course at the University of South Carolina, Columbia, South Carolina. Mean chronological ages were: 8 years and 6 months (8 years to 9 years and 6 months), 10 years and 5 months (10 years and 1 month to 12 years), and 20 years and 9 months (18 years and 3 months to 39 years and 4 months), for third and fifth graders and adults, respectively. Each child had written permission from his/her parents allowing participation in the study. Adult subjects' participation in the study partially fulfilled course requirements.

Stimuli

The stimuli were typed paragraphs published by the Educa-

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tional Developmental Laboratory, Huntington, New York (No. 367002). Six paragraphs were standardized for each grade level in terms of difficulty and, consequently, varied between grade level in length. The third-grade paragraphs had approximately 62 words, while the fifth-grade and adult paragraphs had approximately 118 words. The same paragraphs were used for the reading and search tasks.

Stimulus paragraphs were typed in two variations of orientation of the individual words and sentences. In the "normal-word" orientation, individual words were typed in the normal left-to-right manner. In the "reverse-word" orientation, individual words were typed in a reverse right-to-left manner so that "house," for example, would appear as "esuoh." Sentence orientation referred to the direction in which the individual sentences were to be read. "Normal-sentence" orientation indicated that the sentences were to be read in a left-to-right manner. "Reverse-sentence" orientation indicated that the sentences were to be read right-to-left. Examples of these variations are shown in Figure 1. Word and sentence orientations were combined factorially, yielding four possible experimental conditions.

Materials and Apparatus

Booklets containing six paragraphs were prepared for each grade level. The first paragraph was always a normal-word/normal-sentence paragraph, and thus served as practice for all subjects. The remaining five paragraphs were five different stories, all typed in the same word/sentence orientation condition. The first of these was also practice and was excluded from the data analysis. The same five paragraphs were used in all conditions, with the order of presentation counterbalanced across subjects. During *reading*, 10 "yes-no" questions concerning the content of each paragraph were presented on a separate page immediately following each paragraph. During *search*, instead of "yes-no" questions, subjects searched for a single target word (a noun) that appeared only once in the paragraph, but in neither the first nor last sentence of the paragraph. Of five possible targets, each subject saw one word, typed in "normal orientation," that appeared on a separate page immediately preceeding its corresponding paragraph. Target words and paragraph orders were counterbalanced across subjects. Reading and search times were measured by means of an Electronic Research Manufacturing Digital Clock Counter (Model 262) to the nearest .10 sec.

Procedure

Subjects were randomly assigned to either the reading or search portion of the experiment, so that there were 56 from each grade level in each task, and to one of the four orientation conditions, yielding 14 subjects per grade in each orientation condition. Subjects were tested individually and instructed to press the response button upon completing reading or upon locating the target word. The readers then answered the questions and the searchers circled the target and turned to the next target word. If the target was not found on the first pass through the paragraph, an "X" was drawn over the paragraph. All subjects were thoroughly familiarized with the task before they began.

Orientation		
Word	Sentence	Example
Normal	Normal	John Holland invented a successful submarine in 1898. This Irishman hoped to free Ireland from England.
Normal	Reversed	exceptionally an was Darrow Clarence a as career his began He .lawyer able .lawyer corporation
Reversed	Normal	iniduoH saw eno fo eht s'dlrow tseb epacse stsitra. nroB hcirhE ssieW ni 4781, eh koot sih lanoisseforp eman
Reversed	Reversed	rehcaet hcnerF a saw elliarB siuoL saw thgis nwo s'elliarB .dnilb eht fo .tnedicca na ni deyortsed

Figure 1. Examples of typographical transformations.

RESULTS AND DISCUSSION

Times taken to read and search were converted into speed scores of words per minute, to accommodate differing paragraph lengths and locations. The reading and search rates were averaged over the four test paragraphs and the mean number of words per minute read or searched were entered into separate analyses of variance with grade (third, fifth, and adult) and typographic treatment as between effects. Analyses of the combined task (reading vs. search), comprehension, and search errors are described.

Reading

Speed. An analysis of the reading speed data found all main effects and the interaction of Grade by Treatment to be significant at the .001 level or beyond. Reading speed increased with grade level [$F(2,156) = 13.24$, $MSe = 599.06$]. Reading speed was reduced for all grades when the word/sentence orientation was distorted from normal, as indicated by the significant main effect of treatment [$F(3,156) = 354.76$, $MSe = 599.06$]. Reversing word orientation within the sentence proved significantly detrimental to reading speed performance for all groups, but especially for adults, as indicated by the Grade by Treatment interaction [$F(6,156) = 11.35$, $MSe = 599.06$]. These data are shown in Table 1.

A series of post hoc comparisons was conducted using Tukey's honestly significant difference (HSD) procedure (Winer, 1971) to assess simple effect. Of all possible comparisons, the following failed to reach the critical value at the .05 level of significance or beyond. For comparison of treatment means, no difference was found between the reversed-word/normal-sentence and reversed-word/reversed-sentence conditions. No difference was found between the third- and fifth-grade performance while reading in the normal-word/reversed-sentence (NR) condition; however, both performed significantly slower than the adults, while none of the groups differed in the reverse-word/reversed-sentence (RR) condition. As anticipated, the developmental trend was evidenced in the normal-word/normal-sentence (NN) condition. Of particular interest is the fact that reversing the direction of the sentences in the NR condition eliminated difference between third- and fifth-grade readers. Similarly, adult readers were reduced to the same level of reading as the third and fifth graders in the two word-reversal conditions (RN and RR). Finding such great reductions in adult readers is not new (Fisher & Lefton, 1976; Spragins et al., 1976) and are taken once again to indicate the high degree of plasticity

Table 1
Mean Number of Words Read or Searched Per Minute

	Reading									Search								
	NN		NR		RN		RR			NN		NR		RN		RR		
Grade	M	SD	M	SD	M	SD	M	SD	M	M	SD	M	SD	M	SD	M	SD	M
3	135	40.9	99	34.0	38	17.2	38	11.0	78	303	95.2	287	142.9	118	30.7	155	118.8	216
5	200	41.3	97	20.6	31	5.1	30	6.8	89	351	108.4	407	176.3	131	48.0	129	48.8	255
Adult	215	36.4	123	16.7	32	7.9	36	8.9	101	666	184.3	614	167.2	248	53.6	251	82.3	445
M	183		106		34		34		89	440		436		165		179		305

Note–NN = word normal/sentence normal, NR = word normal/sentence reversed, RN = word reversed/sentence normal, RR = word reversed/sentence reversed.

or "falling-back" ability in adult readers' processing repetoires.

Comprehension. Requiring subjects to answer 10 "yes-no" questions after each paragraph was expected to keep them on the reading task. Mean number of correct answers was then entered into an analysis of variance with grade and treatment as between effects. Analysis of these scores showed a significant main effect of grade [$F(2,156) = 7.54$, $MSe = 1.48$, $p < .001$], with means of 7.7, 7.6, and 8.4 for the third-graders, fifth-graders and adults, respectively. No other main effects or interactions proved significant. The grade effect may be attributable to differences in difficulty between grade level paragraphs. However, although significant decreases in reading speed occurred with word/sentence manipulations, comprehension was not so affected.

Search

Speed. Time taken to find the target in each paragraph was transformed into a search speed measure in words per minute, and an overall mean determined by averaging across paragraphs searched. This mean for each subject was entered into an analysis of variance with between effects of grade and paragraph treatment. All main effects and interactions proved significant at the .001 level or beyond. Search speed was found to improve with grade level [$F(2,156) = 61.55$, $MSe = 13,635.17$]. Search speed also decreased when specific word/sentence orientations deviated from the normal orientation, as indicated by the significant main effect of treatment [$F(3,156) = 72.65$, $MSe = 13,635.17$]. The interaction of Grade by Treatment [$F(6,156) = 5.28$, $MSe = 13,635.17$] indicated that, although all three grades exhibited a reduction in search speed as a function of the distortion of the specific word/sentence orientation, this reduction proved greater for adults than for third graders. The data for these main effects and interactions are also shown in Table 1.

Once again simple effect comparisons were made post hoc using Tukey's HSD for critical values exceeding the .05 level of significance. Only nonsignificant differences will be described. No differences were found between the RN and RR treatments or the NR and NN treatments, and this trend remained consistent for comparisons with the third-, fifth-, and adult grade levels. No differences were found between the third- and fifth-grade search speeds. Third and fifth graders searched equally rapidly through NN, RN, and RR sentences with the only difference being in the NR sentences, where for some yet unexplained reason fifth graders searched slightly faster than they did in the NN sentences.

In short, the critical determination causing decreases in search speed occurred when word orientation was reversed, regardless of sentence direction.

Error rate. When a subject searched through a paragraph but failed to find the target word, an error was noted. The total number of errors made by each subject was determined and these data were entered into an analysis of variance with grade and paragraph treatment as between effects. The overall error rate was 5.9%. A significant main effect of paragraph treatment [$F(3,156) = 20.89$, $MSe = .42$, $p < .001$] indicated that the largest percentage of errors occurred under the RN and RR conditions (11.2% and 8.3%, respectively). These data are taken to indicate simply that as word orientation is transformed there is a consonant debilitation on rectifying words for detection.

Task Comparison

Comparing the reading and search data allows for the assessment between tasks in which the comprehension component was maximal (reading) and minimal (search). Task, grade, and treatment were between-subjects effects. All main effects and interactions in this analysis were significant at the .01 level or beyond ($MSe = 7,117.12$). As expected, search speed was significantly faster than reading speed, as shown by the significant main effect of task [$F(1,312) = 54.83$], with the greatest increase of speed from reading to search occurring for adults, as indicated by the significant Task by Grade interaction [$F(2,312) = 48.74$]. Although there was 178% and 185% increase in speed from reading to search for the third and fifth graders, respectively, the adult speed increased 338%.

The Task by Treatment [$F(3,312) = 26.4$] interaction indicates that although search and reading were sensitive to similar manipulations, the specific effects of the word/sentence orientations were different for the two tasks. This particular finding is important because the effect cannot be simply attributed to differences in decoding. More specifically, decreases in reading speed were brought about by reversal of sentence direction and by a reversal of word direction;

in search, however, only a reversal of word direction resulted in a reduction in search speed. This effect might be considered as a consequence of perceptual and cognitive competition for processing capacity during reading. Further, as a consequence of the most difficult paragraph treatments, search speed was reduced to a level equivalent to that of normal word/sentence orientation during reading.

The interaction of Task by Grade by Treatment [$F(6,312) = 3.71$] indicates that the three grade levels were affected differently by the word/sentence orientation changes in reading and search. This is particularly evident in examining the data for reading in the RN and RR conditions for the three grades, which indicate that regardless of grade level all readers were reduced to the same low-level reading speed, which was practically item by item. In search this was not the case, as there was a fairly great discrepancy between the adult searchers in these conditions and third- and fifth-grade searchers. This effect is interpreted as reflecting the greater facility of the adults to use peripheral cues, even in highly mutilated conditions.

GENERAL DISCUSSION

The present study explored the ability of subjects to read or search through texts that are geometrically transformed. Sentences and words were presented in normal left-to-right or reversed direction. Developmental trends were straightforward. Consistent with previous findings, search was faster than reading and adults read and serched faster than children. Predictably, any manipulation made of either sentence or word orientation reduced reading and search speed regardless of age. Adults were found to read at the level of the young children when words were oriented right to left, a result similar to that described previously when spacing and word shape were mutilated (Fisher & Lefton, 1976; Lefton & Fisher, 1976).

Reading in an unfamiliar direction can be somewhat tedious, especially if the words are also unfamiliarly oriented. However, Kolers' research has shown that reading speed increases with practice even in the most contrived geometric transformations. Examining the data from the reversed-sentence (NR) condition alone, it seems reasonable to conclude that subjects are still able to easily rectify the transformation. They do not proceed through the text word-by-word because reading and search speeds would have to be much slower. Here, familiar word patterns allowed recognition to proceed with only minimal impairment resulting from sentence orientation. By contrast, when the orientation of words was modulated and words were presented from right to left (e.g., stcejbus) all subjects read at the same rate. This possibly indicates that so much effort had to be devoted to decoding the transform that the effect of spacing cue was diminished. During search, performance does not appear to be nearly so encumbered. Presumably because of a minimal need for contextual awareness, decoding processing capacity increased so that global cues again proved facilitating. However, search speed was further reduced when sentence orientation was reversed, indicative of the complex and complementary relationship between context and typography (Fisher, in press).

Differences between reading and search are a critical aspect of the present investigation. Both reading and search have been shown to be sensitive to similar manipulations, but to different extents (Fisher & Lefton, 1976; Lefton & Fisher, 1976). When not required to extract meaning, adults can search 666 wpm, compared to reading only 215 wpm. Even in the most debilitating reverse-word/reverse-sentence conditions, subjects still search rapidly at 251 wpm, while their reading speed is reduced to 40 wpm. Visual search can be characterized as feature extraction guided by physical cues, with only minimal, though seemingly unavoidable, meaning information extracted (Fisher, 1975; Lefton & Fisher, 1976).

We feel that these data provide additional support for combining the models of Hochberg (1970) and the complementary model describing experiential, memorial, and attentional components proposed by LaBerge and Samuels (1974) as expanded upon by Fisher and Montanary (1977). These data support the notion that subjects are able to prescreen information in the periphery whenever word information is held intact, and that they use this information in both reading and search. When comprehension demands are minimal, as in search, subjects are able to proceed at a much faster rate and use peripheral information to a much greater extent. Inasmuch as experienced readers use the periphery to a greater extent than beginners, they do so with less effort so as to approach automaticity.

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