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Visual Search and Reading of Rapid Serial Presentations of Letter Strings, Words, and Text

James F. Juola, Nicklas J. Ward, and Timothy McNamara
University of Kansas

SUMMARY

Text is usually read by executing a series of eye movements resulting in a sequence of visual inputs to the reader that contain useful information about the word or small group of words fixated. This process can be simulated by a computer program that samples and displays successive segments of text for brief time intervals to a single visual locus. In this case the text can be read without necessitating any eye movements on the part of the reader. The present studies test perceptibility and readability of letter strings, words, and running text presented as sequences of rapid serial visual presentations (RSVPs) via a computer display.

Experiments 1 and 2 showed that college-student subjects could rapidly and accurately detect the presence or absence of a target letter in single letter strings and in RSVPs of five successive strings presented at rates of 100, 200, or 300 msec per string. Both experiments, which used computer displays, replicated results that have been found in studies using high-quality printed displays presented in tachistoscopes. Experiment 3 demonstrated that subjects could search for exemplars of a semantic category more accurately than they could search for single target letters given RSVPs of nine successive words. Further, accuracy was greater in both cases when the sequences formed normal sentences than when they were scrambled versions of those sentences. The advantage for grammatical word sequences persisted even at presentation rates of 50 msec per word (equivalent to 1,200 words per min.).

Experiment 4 compared comprehension performance for material read in a normal paragraph format versus RSVP sequences. Over a range of reading difficulties and presentation rates, comprehension was generally equivalent in the two modes of presentation. The results indicated that text can be read at rapid rates and with good comprehension when it is presented as a sequence of brief presentations of single words or small groups of words. The RSVP method of text presentation is a promising technique both for the study of reading processes and for the search for ways to speed understanding of textual information.

A person reading a text executes a series of eye fixations spaced between voluntary eye movements called saccades. Studies of eye movements and fixation durations in reading have shown them to be highly variable, but averages for skilled readers are about 200 to 250 msec per fixation and about 20 to 50 msec per saccade (Haber, 1976; Huey, 1908/1968; Levy-Schoen & O'Regan, 1979; Shebilske, 1975). The saccades traverse about 10 letter spaces on the average, so that about every one to two words in a text are centrally fixated. Adding in the fact that some 10%–20% of fixations are regressive (i.e., they return to an earlier part of the text), we can account for the typical adult reading speed of about 300 words per minute (WPM) for nonchallenging texts such as newspaper and magazine stories.

Psychologists studying information processing have seized on these facts about eye fixations and saccades and, with increasingly sophisticated monitoring equipment, have developed theories of the reading process linking external eye movement patterns to internal processes of comprehension (e.g., Just & Carpenter, 1980; Rayner & McConkie, 1977). It is generally agreed that reading is a dynamic, constructive process in which the reader's linguistic and world knowledge greatly complement the static text in helping the reader to arrive at some understanding of the author's intended meaning. Comprehension processes thus involve both encoding the fixated word or small group of words around the central point of regard and integrating their meaning into a developing coherent structure. Some of these processes are undoubtedly executed "on-line" in the sense that unusual words or words not highly predictable from context require additional processing time, and this time is reflected to some extent in the fixation duration. Other comprehension processes are more global, however, and the length of fixation might not reflect the processing of current input so much as time for tying the current or previous phrase's meaning into a coherent relationship with the topic or text macrostructure.

One might ask how important systematic variations in fixation durations are for normal comprehension processes. That is, is reading for comprehension disrupted when control over viewing times is taken away from the subject and determined by some display device? The research reported here asks this and other questions by substituting a dynamically changing text display and a static visual process for the normal operations in reading. Forster (1970) studied the readability of sentences presented one word at a time in a rapid sequence to a single visual location. This was done by photographing single words in successive frames of a motion picture film and then projecting it at normal speed. He found that undergraduate students could correctly report about four out of six words in a sentence when they were presented at a rate of 62.5 msec per word (equivalent to 960 WPM). Other studies using similar procedures have indicated that adults can read text presented one word or several words at a time at rates approximating those obtained when reading text normally (Aaronson & Scarborough, 1977; Bouma & de Voogd, 1974; Potter, Kroll, & Harris, 1980).

One goal of the present investigation is to extend Forster's rapid serial visual presentation (RSVP) technique to the study of reading for comprehension. Studies of reading using RSVP methods have usually employed mechanical devices such as filmstrips (Potter et al., 1980) or advancing rolls of paper visible through a narrow slit (Bouma & de Voogd, 1974). Those making use of computer displays have typically shown text one word at a time, sometimes under control of the subject (e.g., Aaronson & Scarborough, 1977). The computer-controlled display offers a great deal of flexibility in text presentation and thus a new means of studying reading from the input point of view. As a starting point, it is possible to simulate the visual process of reading; that is, a text can be broken up into short units of about 10 characters and spaces that are clearly identifiable during a brief presentation to foveal vision. Successive segments of text can then be continuously presented to a common visual locus at about 250-msec intervals. This sequence of displays mimics the visual input of normal reading, although without the typical variation due to the placement and duration of a reader's eye fixations. Further, parametric manipulations of the amount of text visible at any one time as well as the length of time that each segment is presented can be used to explore presentation conditions that enhance or reduce text readability.

The study of text readability when it is presented as a sequence of words and phrases to a single locus is important for at least three reasons. First, a growing percentage of texts that people read will be presented on television screens or on other electroni-

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Timothy McNamara is now at Yale University.

Requests for reprints should be sent to James F. Juola, Department of Psychology, Fraser Hall, University of Kansas, Lawrence, Kansas 66045.

cally controlled display devices in schools, homes, and various employment environments. It is important to discover ways of making computer-displayed text easily readable and understandable. It is of additional interest to optimize the presentation mode to enable maximal transfer between the data bank or other source of information and the reader viewing the system.

Second, it is not obvious that the best way to read for comprehension is to sit before a static text and initiate a series of eye movements and fixations. Although fixations tend to be correlated in a reasonable way with information value in text—that is, long, infrequent, and important words tend to be fixated with a higher probability and for a longer time than function words and highly redundant words (Just & Carpenter, 1980)—it is not certain that one's eye-fixation patterns are the most efficient way of sampling textual information. Inefficiencies could exist due to an imperfect correspondence between comprehension and perceptual processes, to errors in guidance of eye movements (especially in regressions or in moving to the beginning of a new line of type), or even to the existence of saccadic suppression that is known to reduce visual sensitivity before, during, and after each saccadic movement (Volkmann, 1976). It is therefore at least theoretically possible that a computer program could be designed to select and present text segments in a way that maximizes the informativeness of the visual input and actually improves reading speed and comprehension relative to normal reading based on conventional eye movements.

Finally, the method allows for new ways to test text readability and theories of comprehension due to the unique control that is possible over the way text is presented to the reader.

The present set of experiments begins with an investigation of the perceptual properties of letter strings presented on a cathode ray tube (CRT) display. Our initial concern was to ensure that display format and quality were sufficient to reproduce perceptual phenomena such as word-superiority effects that we have obtained using high-contrast black lowercase letters on a white background in tachistoscopic experiments (e.g., Juola, Leavitt, & Choe, 1974). A second study was designed to investigate similar phenomena using a letter-search task for single targets in a rapid sequence of several letter strings. Experiment 3 also used the RSVP task and included comparisons of performance obtained when viewing strings of unrelated words versus normal English sentences. Finally, Experiment 4 reports an investigation of reading texts for comprehension that are presented either as intact paragraphs or as series of briefly presented single words or small groups of words for the same total reading time.

Experiment 1

The first experiment made use of a letter-search task and single visual displays of common words, orthographically regular and pronounceable psuedowords, or irregular and unpronounceable nonwords. Since Reicher's (1969) demonstration of word-superiority effects in visual perception, many investigators have shown that words and regular pseudowords are more perceptible than irregular nonwords. The tasks reliably showing this phenomenon include same-different comparisons for pairs of strings (e.g., Bruder, 1978; Taylor, Miller, & Juola, 1977), letter search through single letter strings (e.g., Massaro, Venezky, & Taylor, 1979; McNamara, Ward, & Juola, 1978), letter search through lists of letter strings (e.g., Krueger, 1970; Krueger & Shapiro, 1979), as well as Reicher's probe recognition technique (e.g., Baron & Thurston, 1973).

For the present study, we chose to use the letter-search task through single displays of horizontal letter strings, since this task has been most recently used in our laboratory to demonstrate word-superiority effects in visual perception (Gilford & Juola, 1976; Juola, Schadler, Chabot, & McCaughey, 1978; McCaughey, Juola, Schadler, & Ward, 1980). Thus, we would be in a good position to judge whether or not results using typed words appearing in a tachistoscope generalize to the light-against-dark, dot-matrix characters formed on the CRT screen.

A second issue investigated in Experiment 1 is whether there is evidence for a perceptual difference between regularly spelled pseudowords and common words. This issue is important for contrasting theories of word perception. Some theorists assert that word perception is based on letter perception plus use of the redundancies of English orthography to facilitate recognition processes in similar ways for words and other orthographically regular strings (e.g, Massaro, 1975; Massaro et al., 1979). This view predicts equivalent perceptual effects for words and regular pseudowords. Others assert that highly familiar words are special in the sense that they can be processed as higher order units or as "wholes" in a way that makes them uniquely different from regular psuedowords (e.g., Henderson, 1980; Juola et al., 1974; Taylor et al., 1977). For Experiment 1 we constructed a set of pseudowords that obey the structural definitions of English orthography, and performance on these items was compared with that for common words and for irregular nonwords.

Method

Subjects. Twelve native English-speaking undergraduates participated for research credit in an introductory psychology class at the University of Kansas. They reported normal or corrected-to-normal vision and were naive with respect to viewing tachistoscopic displays. Four additional subjects, including the three authors of the present article, also participated; they were experienced with tachistoscopic viewing and had participated in other, similar studies.

Stimuli. The stimuli were 120 common words (mean frequency of about 260 occurrences per million words, Kucera & Francis, 1967), 30 each of lengths 3, 4, 5, and 6 letters. None of the words had any repeated letters. Each word was permuted into an orthographically regular and pronounceable pseudoword and into an irregular, unpronounceable nonword; 16% of the psuedowords and nonwords had been changed by a single letter from their parent words in order to make acceptable anagrams. The acceptability of the pseudowords was determined by subjective judgments of each item's pronounceability and by determining that each included only permissible letter clusters, including the special constraints on those at the beginnings and ends of strings. Finally, each digraph in each successive serial position was compared with tables of digraph frequencies provided by Mayzner and Tresselt (1965) and by Massaro, Taylor, Venezky, Jastrzembski, and Lucas (1980). These data confirmed that the pseudowords chosen were actually slightly more regular in terms of summed spatial digraph frequencies than the words, and that both types of regular items differed by an order of magnitude from the nonwords in orthographic regularity. The complete list of 360 stimuli is provided in Table 1, and the details of the orthographic structure analysis are presented in Table 2.

The stimuli were divided into two balanced blocks of 180 items each, and a third block was made up of 90 items from each of the first two blocks. Within each block, the items were randomly ordered and then randomly selected to be used on positive and negative trials. Those selected for positive trials had a target letter chosen randomly from one of the positions in the string. For negative items, a target letter was selected from a set of letters balanced in frequency with those occurring in all strings, with the constraint that the target letter not occur in the display. This entire process was done five times to yield five different three-block sequences that were used in separate experimental sessions.

Apparatus. All experiments were run using a PDP 11/03 minicomputer with a real-time clock. The stimuli were presented on a Teleray CRT terminal interfaced with the computer. The targets and display strings were composed of illuminated white dots against a dark background with a potential 5 × 9 dot matrix available for each letter space. Actual letters used a maximum 5 × 7 matrix for ascenders and descenders and a 5 × 5 space for "small" letters such as *a* or *n*. A nonilluminated 2 × 9 column of dots separated adjacent letters within a string, and the dots were illuminated with a fast-decay P31 phosphor. The words measured 1.2–1.7 cm in length, and from a line-of-sight viewing distance of about .7 m, a six-letter word subtended a horizontal visual angle of 1.5°.

Procedure. The 12 unpracticed subjects were run individually in single 1-hr. sessions. After instructions, they were given 12 practice trials using materials similar to the experimental stimuli. These were followed by three blocks of 180 trials each, separated by short rest periods. The four practiced subjects were run through all 15 trial blocks distributed over several days. The sequence of events on both practice and experimental trials was the same. A trial began with the presentation of a single lowercase target letter centered on the display screen for 1.0 sec. The target letter was followed by a masking field of eight overlapped uppercase Xs and Os for 500 msec. The mask extended one character space to the left and one character space to the right of the largest display used. The mask was replaced by the stimulus display, presented in the center of the screen for 250 msec, after which the mask reappeared.

All subjects were asked to indicate whether or not the display contained the target letter and to respond as rapidly and as accurately as possible. Responses were made by depressing one of two paddle switches with either hand. The assignment of positive (target present) and negative (target absent) responses to right and left hand switches was counterbalanced across subjects. Response latencies were measured to the nearest millisecond from stimulus display onset to the initial depression of the switch. No feedback was provided for correct responses; the mask remained on for 1.75 msec after the response until the next target letter was presented. Immediately after each incorrect response the word ERROR appeared in the center of the screen and remained on for 2.0 sec, followed by the mask for 1.75 sec, and then the next target letter.

Results

Mean response times (RTs) for correct responses were computed for each cell of the design for each subject. Outlying RTs were defined as those exceeding twice their cell means and were eliminated from the data (approximately .5% of the data were so eliminated).

The mean RT data were analyzed using an ANOVA (analysis of variance) with the between-subjects variable of subject group (practiced vs. unpracticed) and the three within-subjects variables of display type

Table 1
Stimuli Used in Experiments 1 and 2

Three letters		Four letters		Five letters		Six letters	
			Words				
air	act	born	best	break	board	almost	action
big	ask	come	both	claim	chief	behind	around
boy	bit	game	fear	earth	clear	course	change
cut	car	gone	girl	field	faith	enough	during
few	far	hour	head	great	forms	formed	figure
gun	gas	king	just	horse	heard	ground	friend
hot	hit	left	lead	large	house	island	growth
job	how	near	line	night	month	modern	itself
led	key	rate	pain	quite	plant	number	months
men	low	rise	rest	shown	short	reason	public
old	nor	role	road	sound	sight	second	result
red	put	sort	shot	speak	south	spring	showed
sat	run	take	step	think	stage	strong	square
son	sea	true	town	those	third	turned	toward
top	sun	west	turn	young	trade	worked	walked
			Pseudowords				
ain	cay	hest	mest	breat	bourd	stalom	tacion
hig	bas	thob	bron	maich	chiet	hinbed	unroad
yob	tid	fean	moce	thare	crale	scoure	haceng
cet	cer	glar	mage	feald	thaif	honuge	ruding
faw	fer	hode	goen	trage	froms	morfed	furige
nog	gos	bour	loer	harse	heark	droung	refind
toh	hib	gink	pust	grake	bouse	dalins	worgth
jok	hom	telf	lade	ginth	nomth	morned	fiselt
lod	koy	rane	lein	quate	glant	nomths	bernum
nem	lor	reat	naip	sught	trosh	sonare	plubic
ald	nar	sier	ster	nouth	douns	condes	sulter
rud	tep	soth	doar	geast	pakes	prings	whosed
tas	nur	stap	sart	dirth	thonk	storng	quares
sou	ase	toun	tade	drate	hotes	treund	wotard
wot	nos	nurt	ture	whons	yourg	rowked	klawed
			Nonwords				
rwa	tca	obnr	tbes	krbea	rbdoa	edbnih	ndruao
ibg	ksa	rfae	btoh	lcmia	cfeih	rcueos	gcneha
ymb	ibt	rlig	mcoe	htrae	lraec	uhngoe	uigdrn
etu	rco	hdea	gmea	tfiah	ngyou	emrdof	ieugrf
wfe	rfa	ohru	ngeo	sfmor	dleif	dgnruo	efdnri
ugn	sga	ngki	htea	rdhea	rtaeg	adlnsi	rtgohn
hto	hti	fiel	jtus	hseou	hrsoe	dnemro	etflsi
bjo	ohw	nrea	dlea	tnomh	rgael	rbuenm	honstm
lde	eks	rtea	lnei	tpaln	tgihn	nrsoea	lpiucb
emn	wlo	rsie	aipn	rsoht	qteiu	ocnsde	rtlseu
ldo	nro	htos	rtes	htigs	nwohs	pngris	odwhse
rde	ptu	tpes	rdoa	gsaet	dsuon	tsogrn	aueqsr
tsa	nru	nwot	otsr	hdtir	ksaep	eurdtn	otdrwa
nso	csa	ntru	tkea	aedtr	tknih	ekdwla	edrwko
pto	nsu	wtes	uetr	htsuo	htsoe	oaitcn	mtsaol

Table 2
Mean Summed Spatial Digraph Frequencies of the Stimuli Listed in Table 1, Based on Statistics Provided by Mayzner and Tresselt (1965) and Massaro, Taylor, and Venezky (1980)

	Three letters		Four letters		Five letters		Six letters	
Display type	MT	M	MT	M	MT	M	MT	M
Words	55	1525	68	1865	67	2022	46	1470
Pseudowords	66	1883	73	2034	64	1982	43	1433
Nonwords	0	1	5	162	6	229	3	114

Note. MT = Mayzer and Tresselt; M = Massaro et al.

(word, pseudoword, or nonword), display length (3, 4, 5, or 6 letters), and response type (positive vs. negative). All four factors had significant effects. Practiced subjects responded more rapidly than unpracticed subjects, $F(1, 14) = 16.5, p < .001$; positive responses were faster than negative responses, $F(1, 14) = 24.3, p < .001$; response times increased with number of display letters, $F(3, 42) = 43.9, p < .001$; and response times differed for words, pseudowords, and nonwords, $F(2, 28) = 13.5, p < .001$. The only significant interaction was that between subject group and display length, $F(1, 42) = 3.5, p < .05$. When the data for practiced and unpracticed subjects were examined separately, it was found that besides being faster overall, RT increased more slowly with number of display letters for practiced subjects than for unpracticed subjects. Least-squares linear fits to the RT by display length functions resulted in slopes of 18 msec/letter for the practiced group and 31 msec/letter for the unpracticed group. These data, along with display-type and display-length effects are shown in Figure 1.

The data for the first experiment are summarized in Table 3, which combines the results for the four practiced and 12 unpracticed subjects. The mean RT averaged across

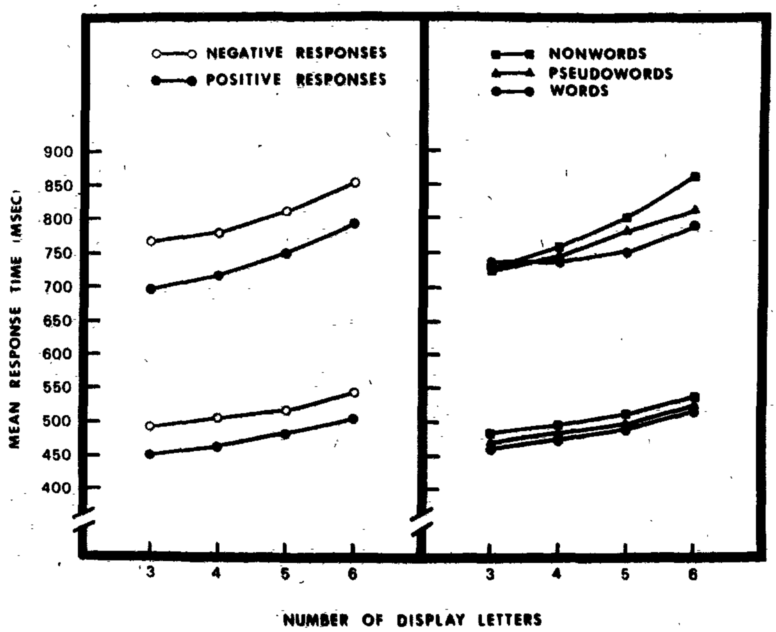

Figure 1. Mean response times in Experiment 1, plotted against number of display letters. (In both panels, the data in the lower half of the figure are for the four practiced subjects, and the data in the upper half are for the 12 unpracticed subjects.)

Table 3
Response Times and Proportions of Errors (in Parentheses) for Each Cell of the Design in Experiment 1

	Three letters			Four letters			Five letters			Six letters		
Display type	P	N	*M*	P	N	*M*	P	N	*M*	P	N	*M*
Words	633 (.019)	706 (.019)	669 (.019)	641 (.025)	706 (.028)	674 (.027)	655 (.016)	722 (.019)	689 (.018)	699 (.030)	752 (.028)	726 (.029)
Pseudowords	626 (.016)	703 (.025)	665 (.021)	647 (.032)	719 (.013)	683 (.023)	708 (.034)	724 (.021)	716 (.027)	713 (.045)	771 (.036)	742 (.041)
Nonwords	645 (.024)	690 (.015)	667 (.020)	672 (.028)	708 (.016)	690 (.022)	685 (.049)	772 (.016)	729 (.032)	753 (.080)	815 (.071)	784 (.075)

Note. Data are for practiced and unpracticed subjects combined. Response times are given in milliseconds. P = positive trial; N = negative trial.

all string lengths was 689 msec for words, which was significantly less than the 701 msec mean RT for pseudowords, $t(381) = 3.0, p < .01$. The pseudowords were in turn responded to more rapidly than the nonwords (mean RT = 718 msec), $t(381) = 4.25, p < .01$.

Separate analyses were performed on the RT data from positive trials only, with the serial position of the target letter added as a variable to the previous ANOVA design. Significant or marginally significant serial-position effects were found for four-, five-, and six-letter items: $F(3, 42) = 5.3, p < .01$; $F(4, 56) = 2.8, p < .08$; $F(5, 70) = 5.2, p < .001$, respectively. Significant main effects were found for the same variables as in the overall analysis, and there were no significant interactions involving serial position and any other factors. The serial position data are presented in Table 4.

A final analysis was made of the error data. The percentage of errors for each subject and each cell of the design were calculated and converted to arc sines before the ANOVA. Error rates increased with display length, $F(3, 42) = 10.0, p < .01$, and were smallest for words and largest for nonwords, $F(2, 28) = 4.6, p < .02$. Multiple comparisons revealed that the 2.3% error rate for words did not differ significantly from the 2.8% rate for pseudowords, $t(381) = .75$. However, the 3.7% error rate for nonwords was significantly greater than that for pseudowords, $t(381) = 2.74, p < .01$. No other main effects or interactions were significant.

Discussion

The results demonstrated that subjects could rapidly and accurately detect the presence or absence of a target letter in a string and that word-superiority effects were found in both the RT and error data. Thus, we replicated earlier findings that had resulted from similar procedures and high-quality, typed stimuli exposed in a tachistoscope (e.g., Juola et al., 1978; McCaughey et al., 1980). We had anticipated these results but considered it necessary to demonstrate them before proceeding to a study of text readability using the dot-matrix character font of the CRT; it has been shown that even such apparently innocuous distortions as enlargements of printed words to slightly greater than normal reading size can affect perceptual processes (e.g., Purcell, Stanovich, & Spector, 1978).

The differences in performance that we observed for words and pseudowords were consistently small but reliable across several studies, being 12 msec in the RT data and .5% in the error data for the present experiment. In turn, pseudowords produced a 17-msec RT advantage and a .9% accuracy advantage over the nonwords. Since both the RT and error data demonstrated the same trends, the word advantage cannot be attributed to speed–accuracy trade-offs. We conclude that the general advantage in perceptual processing for words over pseudowords is due to some property of words that is not captured by the orthographic regularity of the pseudowords. Common words have been experienced as wholistic visual objects thousands of times by college students and appear to have the capacity to be processed differently from pseudowords. The nature of this processing difference is not revealed by our data, but a consistent explanation would be that word perception can proceed directly from detection of letter features, and perhaps features of the overall shape of the item, to identification of the entire word. Pseudowords, and possibly words on some occasions, are processed by an indirect method—perhaps from letter and shape features to identification of individual letters or letter clusters. Knowledge of orthography and spelling patterns in English presumably facilitates this recognition process and results in an advantage for regular pseudowords over irregular nonwords.

Display length and display type did not interact significantly. This result is consistent with localizing word and pseudoword advantages over nonwords at an early, encoding stage of processing rather than at a later, comparison stage involving the target and display letters. If display type influenced comparison processes in visual search, we would expect an interaction between display length and display type (Sternberg, 1966, 1969; see also Gilford & Juola, 1976).

Experiment 2

The first study demonstrated that the visual quality of the characters presented on the Teleray CRT was sufficient to generate accurate rapid letter-search performance through a single brief exposure of a letter string. In all important ways the results were comparable to those obtained using high-quality stimuli exposed in a tachistoscope. We could thus proceed with reasonable confidence to studies of reading computer-presented text under the assumption that there were no serious perceptual problems with the CRT display and the character font used. A second experiment was designed to further test perceptual properties of the display in a task approaching the RSVP method of text presentation. The same task and materials were used as in Experiment 1, but the displays consisted of series of five words, pseudowords, or nonwords successively presented to a common visual locus. The aim was to test the limits of search performance, and therefore the perceptibility of the displays, in RSVP conditions.

Method

Subjects. Sixteen native English-speaking undergraduates participated for research credit in an introductory psychology class at the University of Kansas. The four practiced subjects from Experiment 1 also participated.

Stimuli and apparatus. The words, pseudowords, nonwords, target letters, and masking field were the same as those used in Experiment 1. The display items were arranged into 15 blocks of 72 sets each. Each set contained five items that were to be displayed successively. The five items in each set were all words, pseudowords, or nonwords, and all had the same number of letters. Thus there were 12 different kinds of sets cor-

Table 4
Mean Response Times and Mean Proportions of Errors (in Parentheses) for All Serial Positions at Each Display Length in Experiment 1

Display length	Serial position 1	2	3	4	5	6
3	626 (.021)	641 (.014)	638 (.018)			
4	618 (.031)	639 (.015)	666 (.030)	689 (.052)		
5	651 (.029)	699 (.029)	664 (.018)	711 (.013)	717 (.062)	
6	663 (.035)	700 (.054)	717 (.055)	737 (.042)	773 (.056)	785 (.093)

Note. Data are combined for all three display types. Response times are given in milliseconds.

Table 5
Mean Response Times and Proportions of Errors (in Parentheses) for Words, Psuedowords, and Nonwords at the Three Exposure Durations in Experiment 2

Exposure duration per item	Positive trials			Negative trials		
	Words	Pseudowords	Nonwords	Words	Pseudowords	Nonwords
100	719 (.19)	731 (.22)	752 (.29)	730 (.18)	668 (.18)	674 (.19)
200	711 (.10)	707 (.09)	741 (.12)	752 (.08)	729 (.12)	709 (.12)
300	753 (.07)	751 (.06)	761 (.09)	805 (.03)	796 (.06)	798 (.07)
M	728 (.12)	730 (.12)	751 (.17)	762 (.10)	731 (.12)	727 (.13)

Note. Response times and exposure durations are given in milliseconds.

responding to the combination of three display types and four display sizes. In forming the sets, care was taken to ensure that no two consecutive items had the same letter in any corresponding serial position.

Within each 72-set block, half of the sets in each condition were randomly selected for positive trials and half were selected for negative trials. For positive trials, target letters were randomly chosen from one of the positions in the second, third, or fourth item, with the constraint that the target occur exactly once in the set. The target did not occur anywhere in the set on negative trials. Negative target letters were selected to approximate the overall relative frequency of occurrence of the letters in the stimulus set.

The apparatus and display conditions were the same as those used in Experiment 1.

Procedure. The 16 unpracticed subjects were run in single 1-hr. sessions using different combinations of six of the fifteen 72-set blocks, plus 12 practice trials. The four practiced subjects were run through all 15 trial blocks, distributed over several days. On each trial, the target letter was presented in the center of the display for 1.0 sec and was followed by a masking field of overlapped Xs and Os for .5 sec. The mask was followed by the sequential presentation of the five items in the set, all appearing in the center of the window, followed by the reappearance of the mask. Three presentation rates were used, and these were crossed in a random order with all other factors in the design. The five items in a set were presented for either 100, 200, or 300 msec each.

All subjects were instructed to indicate whether the target occurred anywhere in the stimulus set (positive response) or nowhere in the set (negative response) and to make their responses as rapidly and accurately as possible. As in Experiment 1, responses were made by pressing one of two paddle switches, and RTs were measured from the onset of the last item in the set on negative trials and from the onset of the string containing the target on positive trials. Following each correct response, the mask remained on for 1.25 sec before the next target letter appeared. If an incorrect response was made, the word ERROR appeared for 1.5 sec followed by the mask for 1.25 sec and then the next target letter.

Results

The mean RTs for correct responses for each subject and cell of the design were obtained in the same manner as in Experiment 1. An overall ANOVA included the factors of subject group (practiced vs. unpracticed), display type (words, pseudowords, or nonwords), display length (3, 4, 5, or 6 letters), exposure duration (100, 200, or 300 msec per letter string), and response type (positive vs. negative). The group effect was highly significant; mean RT for practiced subjects was 575 msec, and the mean for unpracticed subjects was 799 msec, $F(1, 18) = 10.1, p < .01$. The subject-group factor did not enter into any significant interactions.

The ANOVA found no significant main effects for response type or display type, but the two factors interacted significantly, $F(2, 36) = 7.2$, $p < .01$. This interaction is observable in Table 5. In general, response times were shortest for words and longest for nonwords on positive trials, and the reverse was true for negative trials. The negative response data are unusual, since in Experiment 1 they showed the same trends as the positive data, and the positive RT data are similar in the two experiments. Perhaps the more demanding search task in Experiment 2 resulted in a response compatibility problem, such that it was relatively more difficult to execute a negative response to a set of familiar words than to a set of unfamiliar pseudowords and nonwords.

Table 6
Mean Response Times and Proportions of Errors (in Parentheses) for Each Display Length Condition in Experiment 2

Trial	Number of display letters: 3	4	5	6
Positive	712 (.12)	718 (.13)	756 (.16)	760 (.14)
Negative	696 (.08)	715 (.10)	748 (.12)	801 (.17)

Note. Response times are given in milliseconds.

Further significant effects in the RT ANOVA indicated that, somewhat paradoxically, RT increased with exposure duration, $F(2, 36) = 7.0$, $p < .01$, and this increase was greater for negative responses than for positive responses, $F(2, 36) = 6.0$, $p < .01$ (see Table 5). Response times were found to increase significantly with display length, $F(3, 54) = 15.4$, $p < .001$, and this increase was also greater for negative responses than for positive responses, $F(3, 54) = 3.8$, $p < .05$. The RT data for positive and negative responses for the various display lengths are given in Table 6. These data are also somewhat unusual, since in Experiment 1 positive and negative response times increased at the same rate with increasing string length, indicating an exhaustive search process. It is possible that in the longer and more difficult search task Experiment 2, there was a greater tendency to terminate the search with location of the target letter.

Because of the greater difficulty of the search task in Experiment 2 than in the first study, and the resultant higher error rate, the RT data in the second study are relatively less informative and the error data are of greater interest. These are shown in Tables 5 and 6, but for purposes of clarity in discussing the effects of display type, display length, and exposure duration we decided to convert the error data to d's before further analysis. This was done by considering correct responses on positive trials as hits and incorrect responses on negative trials as false alarms. Figure 2 presents mean d's for the various display-length and exposure-duration conditions. An analysis of these data, with subject group as an additional factor, found d's to increase significantly with duration, $F(2, 36) = 90.2$, $p < .001$. In addition, the Display Length × Duration interaction was marginally significant, $F(6, 108) = 2.2$, $p < .05$, indicating that sensitivity of detecting the presence or absence of the target letter was independent of display length for the 100-msec exposures (one-way $F < 1$), but sensitivity decreased with display length for the longer durations, $F(3, 54) = 10.0$ and 9.0 for 200- and 300-msec exposures, respectively, both $ps < .001$. Finally, although the practiced subjects had significantly larger mean d's than the unpracticed subjects—about 3.2 and 2.4, respectively, $F(1, 18) = 18.4$, $p < .001$—the subject-group factor did not enter into any significant interactions.

A second analysis was made of the Display Type × Exposure Duration data presented in Figure 3. Again, the significant effect of subject group is not shown, since it did not interact with either factor. Both duration, $F(2, 36) = 86.6$, $p < .001$, and display type, $F(2, 36) = 7.4$, $p < .01$, main effects were significant, and they did not interact, $F(4,$

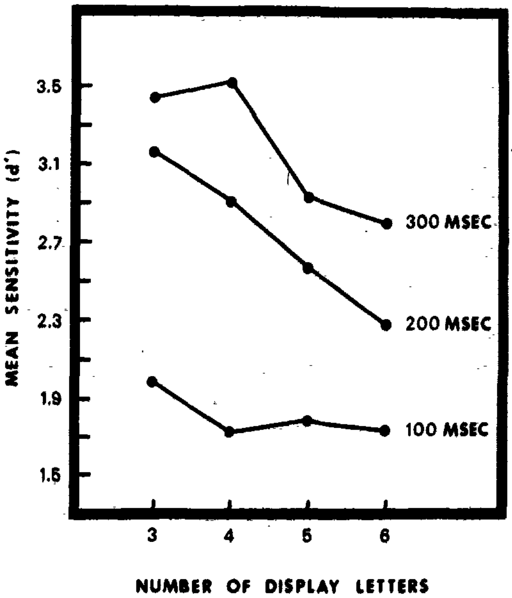

Figure 2. Mean target letter-detection sensitivity (expressed as d') as a function of the number of letters in each item of the five-item set in Experiment 2. (The data are combined for words, pseudowords, and nonwords.)

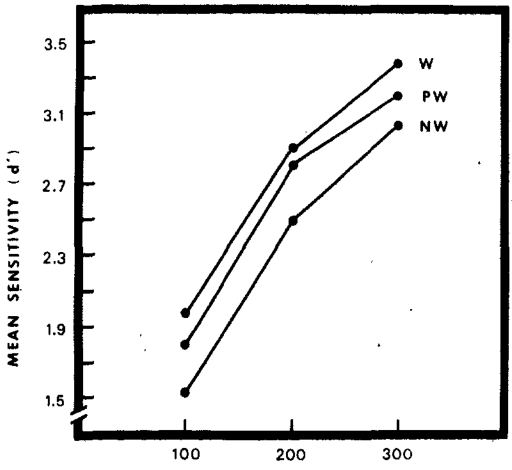

Figure 3. Mean target letter detection sensitivity (expressed as d') as a function of exposure duration per item in the five-item set in Experiment 2. (The data are combined across number of letters per display item and are presented separately for words [W], pseudowords [PW], and nonwords [NW].)

72) = 1.5, $p > .05$. Thus, the differences in detection sensitivities among words, pseudowords, and nonwords were maintained across all three duration conditions.

Discussion

The results of Experiment 2 generally replicated those of Experiment 1, despite some anomalies in the RT data in the second study. Specifically, unlike the majority of data from visual search tasks involving single-string displays (including Experiment 1), the RSVPs of five strings in Experiment 2 resulted in word-superiority effects in the positive data only; negative responses were actually slowest for words. Also, mean RTs increased faster with display length for negative responses than for positive responses, a result not typically found in visual search (but see McNamara et al., 1978). The average error rate of about 12% necessitates some qualification of the RT data, since RTs can be unreliable in difficult tasks that result in guesses on many trials. The error data and d' analysis in Experiment 2 provide greater justification for generalizing the results from single-item search tasks to the RSVP task. The results replicated those of Experiment 1 in showing perceptual differences among words, regular pseudowords, and irregular nonwords. The word-superiority effect was maintained in the letter-search task using RSVPs equivalent to rates of from 200 to 600 WPM. The present data also replicate a recent finding reported by Krueger and Shapiro (1979). They used uppercase six-letter words and irregular nonwords in a similar visual search task, presenting nine successive displays per trial. As in our Experiment 2, they found a 4% difference between accuracy levels for words and nonwords over a similar range of exposure durations.

Since normal perceptual processes are apparently only limited, and not disrupted, by RSVPs, these results encourage further exploration of the RSVP technique both as a tool to gain understanding of the reading process and as a technique to present text rapidly to a reader using a computer.

Experiment 3

In normal reading, textual information is integrated over several fixations into a general, coherent representation. Successive eye fixations tend to follow the linear order of the text, and it is expected that RSVP text should not only be read and understood better, but actually perceived more accurately if it is presented in the correct serial order rather than in some rearranged order. The third experiment tested this general hypothesis and made use of presentation conditions that more closely approximated the visual experience of reading than did those of Experiments 1 and 2. Instead of manipulating redundancy *within* items, between-item redundancy was manipulated by presenting series of words that were either simple sentences or scrambled versions of those sentences. Forster (1970) has shown that subjects can recall words more accurately if intact rather than scrambled sentences are presented at higher rates. His RSVP conditions were equivalent to a presentation rate of 960 WPM, although an average of only about half the words in a six-word sequence could be reported. Sentence recall, of course, involves memory and reconstruction of the original words in order; either process could be facilitated by having to deal with meaningful, structured text rather than unrelated words. However, there are many reasons to believe that the meaningfulness and structure of text also aid in initial encoding and assimilation of meaning from the perceived words.

The effects of meaningful context on the recognition of individual words presented under impoverished or noisy stimulus conditions have been demonstrated in both speech perception (e.g., Miller, Heise, & Lichten, 1951) and visual recognition (e.g., Tulving & Gold, 1963). It has also been shown that children and adults can search meaningful texts more rapidly for specific words and for exemplars of semantic categories than for meaningless subunits of words such as letters or syllables (Friedrich, Schadler, & Juola, 1979; Juola, McDermott, & Miller, Note 1). In addition, search rates for targets of all types are slowed by about 10% when scrambled versions of paragraphs are substituted for normal text (Juola et al., Note 1; see also Ball, Wood, & Smith, 1975).

In Experiment 3 we again used a search task involving single targets, with normal sentences or scrambled versions of those sentences presented in RSVP conditions. The targets were either single letters or any one of many possible exemplars of a given semantic category. The present study provides additional comparisons of results we have obtained using intact and scrambled text viewed normally versus similar materials presented under RSVP conditions on a CRT display.

Method

Subjects. Eight native English-speaking undergraduates participated for research credit in an introductory psychology class at the University of Kansas. The four practiced subjects from the first two studies also participated.

Stimuli and apparatus. The stimuli included 120 different simple nine-word sentences and scrambled rearrangements of these sentences. The sentences had been used in an earlier study by Friedrich et al. (1979) and were at about the second-grade level in readability. Each sentence was paired with four targets: (a) a letter that occurred once in the sentence, (b) a letter that did not occur in the sentence, (c) a category name, such as FOOD or CLOTHING, that had one exemplar (but not the category name itself) in the sentence, and (d) a category name with no exemplar in the sentence. These targets were used for positive and negative trials, and care was taken to ensure that the position of the target item on positive trials was not changed when the sentences were scrambled. (Scrambling was done by reversing word order in the sentence except for the target item and then rearranging any additional words to eliminate relevant or spurious meaningful interpretations). The locations of targets across sentences were balanced in that one third of them occurred in each three-word segment of the sentences. Thus, there was a total of 960 different word-string–target-item combinations. These were divided into eight balanced blocks of 120 trials.

The apparatus was the same as that used in Experiments 1 and 2. The masking field was enlarged to 13 characters to extend one space to the left and one space to the right of the longest word used.

Procedure. All subjects were run for a 1-hr. session on each of two days. Each session began with instructions and 16 practice trials using materials similar to the experimental stimuli. Four of the trial blocks were then presented in the first session, with the remaining four presented in the second session. Order of presentation of the four blocks was counterbalanced across subjects.

On each trial the target letter or category name was shown centered on the display for 1.0 sec followed by the mask presented for .5 sec in the same place. The intact or scrambled sentence was then presented one word at a time, with the leftmost letter of each word indented one space from the left edge of the mask. Presentation rates of 50 and 100 msec per word were used, the latter being equivalent to the fastest RSVP condition in Experiment 2. Immediately after the last word, the mask reappeared and remained on for 1.25 sec after the response until the next target appeared. If an error was made, the word ERROR was presented for 1.5 sec followed by the mask for 1.25 sec before the next target. As before, the assignment of positive and negative target detection responses to the left- and right-hand switches was counterbalanced across subjects.

Results

The overall percentage of correct responses for the unpracticed group was 88%, and for the practiced group it was 89%. In all other ways, the data for the two groups were very similar. This level of performance was slightly higher than that obtained in Experiment 2, although the presentation rates were equivalent to 1,200 and 600 WPM in Experiment 3 versus between 600 and 200 WPM in Experiment 2. Obviously some of the differences in Experiment 3 contributed to this relatively high level of performance, including the search for semantic information as well as single letters and the use of sentences as well as lists of unrelated words. However, performance was about

Table 7
Mean Proportions of Errors in Letter- and Category-Search Conditions at Presentation Rates of 50 and 100 Msec per Word in Experiment 3

Sentence type	Letter search 50	Letter search 100	Category search 50	Category search 100
	False alarms			
Intact	.22	.09	.13	.05
Scrambled	.24	.12	.15	.06
	Misses			
Intact	.14	.09	.08	.04
Scrambled	.17	.10	.11	.04

67% more accurate in Experiment 3 for both practiced and unpracticed subjects for comparable conditions—that is, in letter search for 100-msec displays of scrambled sentences on Day 1 of Experiment 3 versus letter search for 100-msec displays of unrelated words in Experiment 2. The mean word length in Experiment 3 was about 4 letters per word, as opposed to 4.5 in Experiment 2, and the short function words in the scrambled sentences never contained the target letter or matched the target category. These facts could have been used by the subjects to improve performance in Experiment 3 over that obtained for the uniform-length word displays of Experiment 2.

As in Experiment 2, the error data were converted to d's prior to analysis (Table 7 presents the error data on which the d's were based). A four-way ANOVA of the d' data, involving the factors of target type (letter vs. category), sentence type (intact vs. scrambled), presentation rate (50 msec per word vs. 100 msec per word), and subject group (practiced vs. unpracticed) found all factors to produce significant main effects except for subject group. The data were thus collapsed across groups and are presented in Figure 4.

Detection of the presence or absence of categorical information was more accurate than detection of the presence or absence of letter targets, $F(1, 10) = 19.1$, $p < .001$. Intact sentences resulted in better performance than scrambled sentences, $F(1, 10) = 10.0$, $p < .01$, and the slower presentation rate resulted in better performance than the faster rate, $F(1, 10) = 58.2$, $p < .001$. None of the interactions approached significance.

Discussion

There are several unusual aspects of the data that deserve comment. First is the high level of performance, averaging about 84% correct at a presentation rate of 1,200 WPM and about 92% at 600 WPM. These presentation rates are about four times and two times as fast, respectively, as typical college-student reading rates. Second, category-search performance averaged about 8% better than letter-search performance, despite the fact that subjects knew exactly what to look for in the letter-search condition, but any of several words could appear in the category-search condition (in fact, 12 different target words were used for each of the 10 category names). Finally, despite the small differences in favor of the practiced subjects in Experiment 3, the group performance differences were not significant as in the first two studies.

The first result is encouraging, since high levels of performance in the RSVP search task indicate that the technique should be

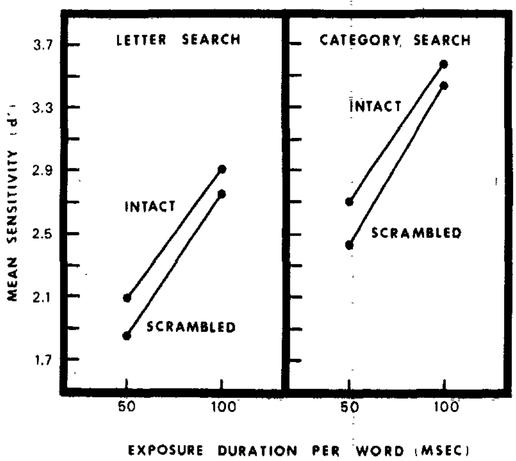

Figure 4. Mean target letter detection sensitivity (expressed as d') for letter targets (left panel) and for category targets (right panel) as a function of exposure duration per word in the nine-word sequences in Experiment 3.

a useful way to present text rapidly in a study of reading for comprehension. The result that category information is detected more easily than letter information has been reported before (Friedrich et al., 1979). Although reading has sometimes been characterized as "a search for meaning" (Haber & Hershenson, 1973, p. 205), the advantage of category search over letter search might not be due to a priority to conscious processes of meaning over perceptual information. In the letter-search condition there was only a single item containing the evidence necessary for a positive decision. In the category-search task, however, often several words in both the intact- and scrambled-sentence conditions contained information relevant to the target category. For example, consider the target category FOOD and the sentence, "All the honey in the jar has been eaten." Although honey is defined as the matching word, other words relate to the target category in a way that could facilitate semantic detection. Of course it is just this sort of linguistic redundancy that enables efficient reading for comprehension. The importance of syntax is also underscored in the results by the advantage that normal, intact sentences show over scrambled sentences in both letter and category search.

Experiment 4

The first three studies demonstrated that the perceptual characteristics of letters and words displayed on the CRT screen were conducive to highly accurate and rapid recognition responses. This was true both for single displays and for sequences of up to nine words presented at rates equivalent to a maximum of 1,200 WPM. Further, both within-string orthographic redundancy and between-string linguistic redundancy facilitated visual search performance in the RSVP task. Efficient reading for comprehension presumably depends on similar use of orthographic and linguistic redundancy in obtaining meaning from print (e.g., Gibson & Levin, 1975; Smith, 1978). Thus, we expect subjects to make use of redundant sources of information in reading RSVP text much as they do in normal reading. The final experiment reported here tested the readability of text presented in the RSVP format. All subjects read a series of short paragraphs, some displayed in their entirety on the CRT screen (page condition) and some presented via the RSVP mode (window condition). Each paragraph was followed immediately by a set of comprehension questions. We used a variety of RSVP conditions in order to test several different combinations of window size and window duration. These conditions spanned a wide range of reading rates; reading comprehension scores were compared over these rates for window and page conditions in which total reading time had been equated.

Method

Subjects. Forty-eight native English-speaking undergraduates participated for research credit in an introductory psychology class at the University of Kansas. The practiced subjects from the previous experiments were not used, primarily because of their familiarity with the paragraphs and comprehension questions selected and used in the study.

Stimuli. Twelve short paragraphs (mean length = 199 words) from the Nelson-Denny Reading Test Forms C and D (Nelson & Denny, 1976) and 12 additional paragraphs (mean length = 168 words) selected from the McCall-Crabbs Standard Test Lessons in Reading (McCall & Crabbs, 1961) were used as experimental stimuli. Each of the Nelson–Denny paragraphs had four 5-alternative multiple-choice questions, and each of the McCall-Crabbs paragraphs had more than four 4-alternative, multiple-choice questions provided in the test manuals. For consistency in the present study, each paragraph was followed by four 4-alternative multiple-choice questions selected from the materials provided. In three of these questions the answers were altered slightly so that the correct response alternative could not be easily identified without first reading the paragraph. A subsequent analysis of the 96 comprehension questions showed that 56 of them tested memory for specific details in the paragraphs, and the rest tested memory for more general information and logical inferences.

The choice of stimulus materials was motivated by a desire to span a range of reading difficulty. Thus, the McCall–Crabbs paragraphs were chosen to represent a relatively easy level and the Nelson–Denny paragraphs represented a more difficult level of text. An application of the Dale-Chall Readability Formula (Dale & Chall, 1948) to each paragraph resulted in an assignment of the 7th–8th grade level to eight of the McCall–Crabbs paragraphs, with three slightly below and one slightly above this level. Similarly, six of the Nelson–Denny paragraphs were rated at the 9th–10th grade level, with two slightly below and four slightly above this level. The McCall–Crabbs paragraphs will therefore be referred to as the *intermediate set* and the Nelson–Denny paragraphs as the *secondary set* for the remainder of this article.

Apparatus and display. The computer-driven CRT terminal was the same as that used in Experiments 1–3. Two different modes of text presentation were used for the paragraphs. In the page condition, each paragraph was presented in its entirety and appeared on the CRT screen in a normal format of no more than 65 characters per line and about 14–20 lines.[1] The page condition was used as a control to approximate conventional paragraph reading conditions, as opposed to RSVP reading in the window condition. In the window condition, text was serially presented as successive chunks, with each chunk containing one or more words. Since the average word length in the materials used was about 5 letters, the smallest window that could be used while consistently presenting at least one word at a time was 5 character spaces. In addition, two other window conditions were used in which an average of either 10 or 15 characters and spaces were presented at once. The final manipulation in the window condition was duration; successive windows were presented for either 200 msec or 300 msec each. The conditions were chosen specifically to include the range of visual information sampled during a typical eye fixation in reading.

The CRT-controller program presented successive chunks of text with window sizes averaging 5, 10, or 15 characters and spaces (i.e., about one, two, or three words at a time, on the average). It is important to emphasize that these are average window sizes, since it was decided not to truncate any words within a window. Thus the program in the 10-character window size condition, for example, scanned the upcoming text for 10-space segments and entered this segment into the display buffer only if the 11th character was a space. If the 10th character occurred in the middle of a word, the program scanned forward and backward through the text to find the nearest space, and then presented the segment of text up to that space on the CRT. Another modification of the program emphasized sentence boundaries within paragraphs by presenting a blank window between sentences. These modifications of the program resulted in different (generally slower) presentation rates than what might be expected if WPM rates were actually calculated (e.g., 15 characters and spaces every 200 msec = about 900 WPM). The actual presentation rates obtained are reported in the Results section. The paragraphs in the page condition were shown for three different total exposure times to span the same range of reading rates experienced in the window condition.

Procedure. The window condition included 12 different trial types (intermediate vs. secondary paragraphs; 5, 10, or 15 spaces per window; and window durations of either 200 msec or 300 msec each). There were six trial types in the page condition, corresponding to intermediate versus secondary paragraphs and three total presentation times roughly equivalent to the times necessary for slow normal reading, fast normal reading, and very fast reading. All 24 paragraphs were used twice in each window condition and four times in each page condition across the 48 subjects. For half of the subjects the page condition was presented first, and the window condition was presented first for the other half.

Each session began with three practice paragraphs presented in the mode appropriate to the initial presentation condition for that subject. The conditions were explained, and the practice paragraphs were shown in either the page or window condition. In the page condition, the instructions "Read Normally," "Read Rapidly," or "Read Very Rapidly" were shown in the upper left corner of the screen for .5 sec followed by a full page of overlapped Xs and Os for .5 sec. This mask was then followed by the onset of the entire paragraph for a varying amount of time corresponding to the reading-rate cues. The paragraph was followed immediately by the full-page mask for .5 sec, after which the first of the four comprehension questions appeared. The subjects were instructed to type one of the letters a, b, c, or d on the terminal keyboard to select one of the answers given for each comprehension question.

The block of window trials was also preceded by three practice paragraphs selected to represent the range of presentation conditions used. Unlike in the page condition, however, no preceding cues were used to indicate the window sizes or durations. Each trial began with a .5 sec presentation of a 25-character mask of overlapped Xs and Os presented in the center of the screen. This mask was then replaced with the first window, in which the initial letter was indented one space from the left-hand side of the mask. The last window was followed immediately by the mask for .5 sec and then the first comprehension question. The subjects were allowed unlimited time for answering each question and were given feedback after incorrect responses only by the presentation of the word ERROR. For each subject all 24 paragraphs and comprehension questions in both conditions were completed in a single 1-hr. session.

Results

Tables 8 and 9 present the mean reading rates and comprehension performance for the page and window conditions, respectively. The reading rates in the page condition were calculated from the number of words in each paragraph and the total time that the paragraph was displayed in each of the three duration conditions. The three durations were determined separately for each paragraph to keep the total amount of reading time per word within the same range for the page and window conditions.

[1] None of the displays presented on the Teleray terminal appeared instantaneously; rather they were serially written and displayed at a rate of about .83 msec per character. This serial writing process was not noticeable for the smaller displays, but it was for the paragraphs. The longest paragraphs used required almost a full second to display from the first character in the first sentence until the final character in the last word. However, this rate was so much faster than the maximum reading rate required that it was not thought to limit readability in any way.

Table 8
Mean Reading Rates and Proportions of Correct Choices on Comprehension Questions for the Page Condition in Experiment 4

Paragraph difficulty	Reading rate instruction		
	Normal	Rapid	Very rapid
Secondary			
Reading rate	214	328	705
% correct	.581	.526	.435
Intermediate			
Reading rate	216	330	705
% correct	.797	.721	.471

Note. Reading rates are given in words per minute.

The comprehension performance data were analyzed by linear regression methods to test for the effects of presentation rate, paragraph difficulty, and for any differences between performance in the page and window conditions. The regression analyses treated percentage of correct responses on the comprehension questions for each paragraph in all conditions as functions of the reading rate. Separate functions were found for the intermediate and secondary paragraphs in both the window and page conditions. The differences between the regression slopes and intercepts found in the two presentation conditions were evaluated using a jack-knife procedure (Mosteller & Tukey, 1977). For the secondary paragraphs, the slope differences between window and page conditions were found not to differ significantly from zero (mean slope difference for window–page conditions = .002 ± .024, the 95% confidence interval). Similarly, the mean difference between the window and page intercepts also did not differ significantly from zero (mean intercept difference = −.4 ± 11.8). For the intermediate paragraphs, no window–page differences were found for the slopes (mean slope difference = −.001 ± .022), and the intercept was not significantly greater in the page condition than in the window condition (mean intercept difference = −5.5 ± 8.0).

To further test for any possible performance differences in the page and window conditions, t tests were performed on the comprehension data for those reading rates that were equivalent in the two conditions. That is, performance in the normal-rate page condition was compared with that in the 300 msec 5-character (300/5) window condition, the rapid page condition was compared with the mean of the 300/10 and 200/5 window conditions, and the very rapid page condition was compared with the 200/15 window condition. The slight advantages for the window conditions in the first and third comparisons for intermediate paragraphs were not significant (both ts < 1.0), but the 5% comprehension advantage for the rapid page condition was significantly greater than that for the mean of the two corresponding window conditions, $t(47) = -2.14$, $p < .05$. Similar t tests for the secondary paragraphs found no significant differences in comprehension between page and window conditions.

A final analysis of the comprehension data was made for questions about specific details versus those asking for more general information. A three-way ANOVA using the factors of paragraph difficulty, presentation format, and question type found only the difficulty factor to be significant, $F(1, 84) = 22.9$, $p < .001$. The mean score of 59% correct for the specific questions did not significantly exceed the 55% correct score for the

Table 9
Mean Reading Rates and Proportions of Correct Choices on Comprehension Questions for the Window Condition in Experiment 4

Window duration	Window size (spaces)		
	5	10	15
Secondary paragraphs			
200			
Reading rate	321	524	705
% correct	.552	.474	.422
300			
Reading rate	214	350	470
% correct	.531	.547	.484
Intermediate paragraphs			
200			
Reading rate	323	511	705
% correct	.698	.510	.505
300			
Reading rate	215	341	470
% correct	.807	.647	.484

Note. Reading rates are given in words per minute; window durations are given in milliseconds.

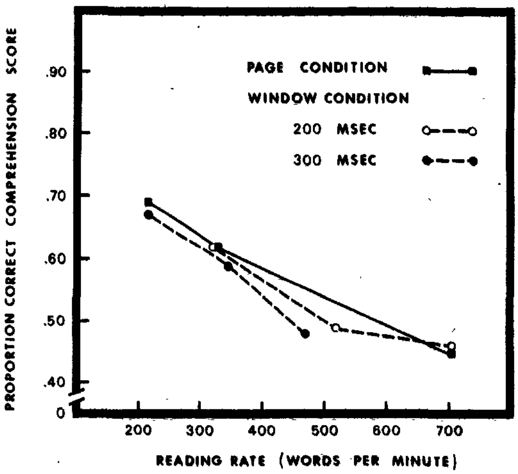

Figure 5. Mean proportion correct on the comprehension questions for paragraphs presented for various lengths of time (converted to words per minute) in Experiment 4. (The connected data points are, from left to right, for the normal, rapid, and very rapid reading-rate instructions in the page condition and for windows of 5, 10, and 15 character spaces in the window condition.)

more general questions, $F(1, 84) = 1.36, p > .05$, nor did performance differ for window and page conditions, $F(1, 84) = 1.14$. None of the interactions was significant. The general lack of significant differences in comprehension performance between the page and window conditions, as well as the effects of presentation rate, are further illustrated in Figure 5. In this figure, the data for the intermediate and secondary paragraphs presented in Tables 8 and 9 have been combined. The data show comprehension performance in the window condition to be at or only slightly below that obtained in the page condition across the range of reading rates used (200–700 WPM). Further, the differences in comprehension appear to be less for the more rapid sequence of windows (200 msec each) than in the slower, 300-msec window condition when overall rates of presentation are equated.

Discussion

The results demonstrated that reading short paragraphs for comprehension can be efficiently done via the RSVP mode on a CRT screen. With only one exception there were no significant differences in comprehension scores between the successive window conditions and the complete page condition over the range of materials and presentation rates used in Experiment 4. Thus, even though the subjects had had many years experience reading paragraphs presented as wholistic entities to be scanned with normal eye movements, their comprehension as measured by the test questions was no better than that obtained in the uniquely different RSVP mode of presentation. This was true for materials from the sixth-grade level to college levels and for slower than normal reading rates to rates of about twice the normal college-student reading rate.

These results support the conjectures of Bouma and de Voogd (1974) and Potter et al. (1980) that text can be presented one or more words at a time to a single visual locus without necessarily disrupting normal reading comprehension processes. (In fact, Potter et al. report some evidence for superior reading performance in the RSVP condition over that obtained for normal reading. This result was obtained mainly in conditions in which subjects were unable to read the entire paragraph as a whole in the allotted time.) Thus, there is apparently only a minor contribution to comprehension from the highly variable and somewhat erratic pattern of eye movements and fixation durations in normal reading. These data support the notion that most of reading comprehension depends instead on conceptually driven processes that operate normally over a wide range of variable input formats. The data also suggest that there is a limit to what can be inferred about reading comprehension processes from an analysis of eye-movement patterns alone (but see Just & Carpenter, 1980). Finally, the results of Experiment 4 encourage the extension of the RSVP technique not only to the study of normal reading for comprehension behavior but also to examination of reading speeds and comprehension abilities beyond any limits imposed by the mechanical movements of the eye.

General Discussion

Presenting text under computer control allows for testing reading comprehension over a wide range of possible input formats. The research reported here represents an initial stage in the study of text presentation methods that allow some degree of comprehension at rates equivalent to or faster than normal reading using standard page formats. Because of the relatively novel methods of text presentation employed, we felt it was necessary to test legibility and other perceptual factors involved in viewing single letter strings and RSVPs of string sequences before extending the method to studies of actual reading. Thus the issues successively investigated and discussed here include (a) the perceptibility of letters presented as light-against-dark dot patterns on a CRT screen, (b) the relative perceptibilities of words and unfamiliar strings made up of such characters, (c) the perceptual effects of orthographic and linguistic structure on the perception of RSVP letter strings, and (d) the relative readability of text presented in normal paragraph format as opposed to a variety of RSVP formats for the same total viewing time.

The results indicated that both perceptual processes and reading for comprehension are only minimally disrupted by presenting letter strings and text on the CRT screen and by eliminating the need for eye movements through successive presentation of displays to a single visual location. These results are important in that they demonstrate the viability of reading text presented in formats that are unusual yet ideally suited to the visual display capabilities of computer terminals. Further, the results suggest the possibility that, with practiced readers, text presentation methods can be found that will lead to improved reading speed and comprehension abilities over those obtainable when text is viewed in a normal page format. Also, RSVP techniques might be useful for manipulating text processing on-line, leading to new methods of studying reading behavior.

The first two experiments demonstrated that letters in words and other character strings can be detected reliably and accurately using the dot-matrix letters of a typical CRT computer terminal. The results were in all ways comparable to those obtained using similar materials presented as high-quality, typed displays of black letters on a white background (e.g., Juola et al., 1978). Experiment 2 further demonstrated that RSVP sequences of five letter strings also resulted in reliable letter-detection performance even when the rate of presentation was increased to the equivalent of 600 WPM. Both studies also found small but reliable advantages in letter-recognition performance for word displays over orthographically regular pseudowords and for pseudowords over irregular nonwords. These results indicate that orthographic regularity plays a role in the visual perception of letter strings, perhaps by facilitating inferential processes or eliminating some alternatives for letters before they are identified. The word-superiority effect itself undoubtedly owes a large part of its existence to the use of orthographic redundancy in the recognition process. However, the consistent advantage for common words over regular pseudowords observed in Experiments 1 and 2 and in many other studies points to some special property of words that is not captured in manipulations of orthographic regularity in nonword letter strings. Admittedly, word recognition might be based on single-letter recognition processes plus the use of redundant orthographic information, and the word advantage often reported might then be due to the fact that the orthographic regularity of words is not adequately represented in the pseudowords despite the best intentions of careful researchers. On the other hand, that words are composed of letters does not mean letter identification must precede word recognition any more than separate perception of leaves, branches, trunk, and bark must precede recognition of a tree. The main point is that the similarity of results from tachistoscopic studies and those obtained here using a CRT and RSVPs indicates that the perceptual processes involved in word recognition are not unduly affected by the use of these rather unusual computer displays.

Beyond word-recognition issues in the study of reading lie considerations of how readers use semantic and syntactic information and other relevant knowledge to construct meaningful interpretations of text built up across several successive eye fixations. Experiment 3 demonstrated that even in searches for a single letter or an example of a given semantic category, the structure of sentences is important, because performance was better for intact than scrambled sentences. Linguistic redundancy was useful even at RSVP rates equivalent to 1,200 WPM. It was also of interest to find that in all combinations of degree of structure and rate of presentation, search for meaning was superior to performance in the letter-search task.

The final study reported here demonstrated that short paragraphs can be read about as well for immediate comprehension tests in the RSVP mode as in a standard page format. This was true for a variety of RSVP conditions, including successive windows of 200 msec or 300 msec each, with window sizes spanning 5 to 15 characters and spaces. The materials ranged widely in difficulty, and the overall presentation times corresponded to reading rates ranging from about 200 to 700 WPM, yet the results were consistent: Comprehension performance as measured by the test questions was not reliably better with the standard page format than in the novel RSVP mode. The data also suggested that some RSVP conditions might be better than others at a given processing rate. That is, small windows presented at 200 msec each might be more easily read than larger windows at 300-msec durations, although definitive resolution of the question of how best to choose window parameters awaits additional research. It will also be desirable in future research to include rigorous tests of comprehension to insure that null results are not merely due to insensitivity of the comprehension measure. Our measure showed strong effects of paragraph difficulty and presentation rate, but possible reading differences among various RSVP conditions and between window and page conditions deserve closer consideration in future research.

The results of Experiment 4 are encouraging in that they suggest that the active eye-movement patterns of a skilled reader are not necessarily the optimal way to sample information from text. The present RSVP methods of text presentation made no concession to linguistic structure other than displaying entire words without truncations and inserting a blank window between sentences. It is possible that more sophisticated parsing programs that include text structure variables in the selection of window contents could result in improvement in the readability of RSVP text. Further, the present subjects had less than 30 minutes of experience in the RSVP reading task, as opposed to thousands of hours of experience with normal text formats. It is uncertain what levels of immediate comprehension and long-term retention might be obtainable using more sophisticated text presentation programs and experienced readers who, perhaps, could interact with the computer to select and modify text presentation parameters. New manipulations of text presentation modes using computer-controlled displays might well result in higher levels of information transmission between the data source and reader than are presently possible with static pages and dynamic eye movements determining the information flow.

Reference Note

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