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PROCESS MODELS OF READING: SOME DATA ON THE INITIATION OF PROCESSES

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Data are presented to demonstrate that resource reallocation during reading can occur in response to task demands. These reallocations can compensate for experimentally induced lower level deficits. Further, these reallocations appear to operate both top-down and bottom-up. The data are clearly inconsistent with serial and parallel noninteractive models of reading. The necessity of including resource allocation and compensatory resource reallocation provisions in interactive models of reading is emphasized.

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Abstract

Data are presented to demonstrate that resource reallocation during reading can occur in response to task demands. These reallocations can compensate for experimentally induced lower level deficits. Further, these reallocations appear to operate both top-down and bottom-up. The data are clearly inconsistent with serial and parallel noninteractive models of reading. The necessity of including resource allocation and compensatory resource reallocation provisions in interactive models of reading is emphasized.

Resource Allocation in Reading:
An Interactive Approach

We assume that reading is an interactive process where components interact in both a top-down and a bottom-up manner (cf. Rumelhart, 1977). Additionally, we hypothesize that reading is dependent upon both resource and data distribution among its subparts. Both data and resources are necessary to execute the type of processing required to understand text. Furthermore, we hypothesize that resources are transferrable from one component to another regardless of their position in the interactive hierarchy.

Extending the formalization of interactive models to encompass the exchange of resources between components may assist in distinguishing between interactive and non-interactive models of reading. The contentions of traditional interactive models are far from well established. For example, subprocess interactions expected on the basis of Rumelhart's (1977) early model (Levy, 1981, for a critical review) have not been observed. In addition, "non-interactive" models (Forster, 1979) have grown in complexity making it difficult to derive testable hypotheses without the aid of simulation.

The logic of our experiments focuses on what we consider to be the fundamental difference in types of models: The nature of resource exchange between interdependent component operations. It appears to us that both interactive and non-interactive models presuppose interdependence of components at some level. This interdependence amounts minimally to the exchange of data from one to another component operation involved in reading. Output(s) from one process serve(s) as input(s) to another. The data-flow from one process to another may be continuous in units of time or discrete. The nature of the data-flow, by itself, however, does not permit one to discriminate between classes of reading models. In contrast, if the exchange of resources between components (which are limited from moment-to-moment) also occurs, then such an exchange implies that more than one component process occurs within that unit of time. And, to the extent that one or all such exchanges of data and capacity modify the processing of the receiving component and to the extent that modifications can be shown to occur both from bottom-up to top-down and from top-down to bottom-up processes, this would serve to demonstrate that the processing is interactive (in the original sense of Rumelhart's (1977) model).

Our approach to interactive processing can be contrasted with Just and Carpenter's (1980). They explain top-down influences on bottom-up processing through indirect self sequencing of productions in working memory. The results of higher level productions, triggered by prior input are input into working memory. The effect of having higher level information in working memory is presumed to enable additional lower level productions to fire subsequently, inserting additional results in working memory. For example, sentence context may speed word recognition in the following way. Once input enables syntactic context productions to fire, syntactic hypotheses are input in working memory. This input in turn triggers the feature detectors to look for a specific syntactic form such as a noun. If a noun is found, the lexical possiblities of the word are limited and consequently word identification should be speeded. While this explanation can account for top-down influences on lower level processes and expands the processing explanation of interactive models, testable hypotheses designed to distinguish between models of reading are not easily derivable.

The concepts of data-limits and resource-limits developed by Norman and Bobrow (1975) are critical to the experimental logic we followed. The ideas to be examined were that there exist re-allocations of resources between components from the momentary limited pool in response to changes in task demands and that such re-allocations result in detectable changes in reading performance. In contrast, a serial non-interactive model suggests that components exchange data but not momentarily available resources, because competing components in most models do not occur simultaneously. In such a model, data-limits on one process should propagate to all processes depending on its output. Thus, no compensatory process could occur where a deficit in one knowledge source results in heavier reliance on another source. Moreover, evidence of resource reallocation would be inconsistent with serial non-interactive models.

We can conceptualize, however, a non-interactive model that is entirely parallel or serial for subsets of processes (e.g., where word recognition processes would and must precede parsing processes) whose respective components were parallel. In the parallel non-interactive model, a data limit could not be corrected for, because there is no interaction with other components. Hence the limit would propagate through to comprehension, producing deficits or errors in comprehension of various sorts (depending on the location of the data limit). In the stagewise parallel comprehension model, reallocations and modifications of processing could occur only within the particular set of components at a stage. Later higher processes could not affect early ones (i.e., higher-level processing could not affect lower level processing in a compensatory or modifying way).

Thus, if reallocation can be shown to occur between a subordinate and superordinate component in non-interactive models (or between antecedent and subsequent processes), then the serial non-interactive models could not be correct. Further, if compensatory or modified processing occurred at all, the parallel non-interactive model could not be correct. In other words, the apparent re-allocation and compensatory processing in response to the experimental manipulations can only be accounted for by interactive models of reading.

Since we seek to demonstrate that compensatory processing and reallocation occur in reading, we attempt to produce conditions experimentally which would make these processes more probable. The amount of text presented in a unit (unit size) was manipulated because there is ample evidence (e.g., Aaronson & Scarborough, 1977; Jarvella, 1971) that sentence and phrase boundaries determine the chunking of the text in short-term memory, and that chunking is a resource demanding activity. According to Kintsch and vanDijk (1978), when a chunk of propositions is processed, some of them are selected and stored in the buffer. However, the buffer's capacity is believed to depend on the individual's perception of the text's difficulty. Presumably also, the size of the buffer depends, within limits as yet unspecified, on the resources that must be devoted to other aspects of processing.

If chunking, inference making and long-term memory searches require less than the total available resources, some resources are free to be allocated to increase the size of the buffer. More units of text can be held and recycled for longer periods of time as the size of the buffer increases. Kintsch and vanDijk (1978) show that the time an item resides in the buffer is a good predictor of memory for that item. Additionally, the longer an item resides in a buffer the less likely is the necessity for long term memory searches connecting new items to that item. Furthermore, macroprocessing should be enhanced because more of the relevant items should be in the buffer at any one point in time. In other words, reallocation of resources to increase buffer size should be reflected in better and more complete textual recall. Thus, we expect that if processing is interactive, any resources freed by presenting chunk sized units of information will be reflected in our performance measures of higher level processing, namely the number of inferences, elaborations and macropropositions produced in the recall protocols of our subjects.

The rate at which texts are presented for viewing (rate of presentation) should also affect processing in an interactive system. Resources are presumably limited at each moment in time (Norman & Bobrow, 1975). This assumption implies that as the total amount of time available for processing decreases, the number of moments decreases and fewer cumulative amount of resources are available for processing. In an interactive system, if the total amount of resources available to a component process is less than that required by that process for execution, its output can deteriorate in a number of ways. First, the process can be slowed so that completion comes too late for output to be useful. Second, the process can fail to reach completion. In each case, the processing outcome will result in output that is degraded, placing data limits on other processes that use the data as input.

We expect that increasing rate of presentation will result in generally poor recall of textual information. However, reallocation and compensatory processing should also be initiated in experimental conditions where data degradation is caused by very fast rates of presentation. Should the subject initiate compensatory processing in an attempt to create coherence, it should be reflected in an increased proportion of inferences and macropropositions relative to normal rates of presentation.

Furthermore, we expect rate and unit size manipulations to interact. Chunk sized units of text should result in more thorough recall and a higher percentage of inferences, elaborations and macropropositions relative to non-chunk sized units at normal rates of presentation. Additionally, more evidence of compensatory processing should be evidenced at fast rates as unit size decreases. According to any sensible model of reading, information is more likely to be encoded at fast rates when unit size is small; as unit size increases, less information is likely to be perceived at very fast rates of presentation.

Our third experimental variable was reading ability. It is hypothesized that performance indicators of compensatory processing should be most observable in poor readers at medium and slow rates of presentation. Here, reading ability refers to both the speed and accuracy of the reading processes. In addition to the performance indicators of inference making, elaborations and macroprocessing, it is possible that slowing rate of presentation will particularly assist the poor reader. Thus, the relative improvement in overall recall at slow rates may be proportionally greatest for poor readers as slowing the comprehension processes may also be a compensatory action.

Experiment 1

In the first study, three groups of readers differing in reading ability read stories in an RSVP mode. Two variables were manipulated within subjects, rate of presentation and amount of text presented per unit of time.

Method

Subjects. The subjects were 18 Wayne State University undergraduates who participated in order to fulfill a course requirement. Subjects were grouped by their reading speed and comprehension accuracy by the following procedure. Subjects read a complete story and recalled the text. The number of correctly recalled ideas corresponding to the idea presented in each clause was divided by reading speed to measure reading efficiency. Subjects were then grouped according to this measure. Good readers scored one or more standard deviations above the mean and poor readers scored one or more standard deviations below the mean of reading efficiency scores.

Design. The three groups of subjects (good readers, average readers, and poor readers) were crossed with the three amount of text conditions (word by word, clause by clause, and sentence by sentence) and the three presentation rates (fast , medium, and very slow, as defined below). Additionally, subjects read one story in its complete form at their preferred reading rate. A 10 x 10 Greco Latin square was utilized to counterbalance the passages across rates and stimulus conditions within each group of subjects.

The dependent variable was passage comprehension as assessed by qualitative recall analysis. Subjects received a score for each idea they produced which was represented in an independent or dependent clause in the original text. Subjects were also scored for the number of inferences, elaborations and macropropositions (cf. Kintsch & vanDijk, 1978) produced. These scores were based on the number of correct units minus the number of incorrect units in each category. A cumulative score was also devised which additively combined all of these measures.

A signal detection paradigm was used to determine the fastest rate at which a subject could detect single words. Fifty words and 50 orthographically and phonetically similar non-words were used as signal and noise, respectively. Word recognition time was used subsequently as the fast rate of text presentation to force subjects to perform in resource limited conditions. The average fast rate was 50 msec/word. The optimal or medium rate was determined by assessing the subject's normal reading speed by timing reading speed on a text of the Nelson-Denny Text and dividing it by the number of words. The slow rate added 1500 msec on to the optimal reading rate per word. The average presentation rate at each level of speed was 1200 words per minute, 250 words per minute, and 34 words per minute.

Materials. The materials for the signal detection task consisted of 100 slides containing one word or non-word each. The words, all nouns, were approximately equal in difficulty and frequency to those nouns in the experimental texts.

The reading materials consisted of ten nonfiction stories chosen for their probable unfamiliarity to subjects. Examples of topics include the history of ice cream, requiem sharks, and nazca lines. All stories were equated for number of clauses and averaged 350 words in length. According to the FOG index, the stories were eighth grade level in difficulty.

Apparatus. A three-channel tachistoscope was used in the signal detection task to determine the fastest rate at which each subject could recognize single words. Stimuli were projected in a series of trials that ended when a threshold d-prime was reached or the subject accurately recognized words at 25 msec exposure durations. (This exposure duration limited the speed of accurate presentation on the computer system used for the RSVP task.) Each trial was initiated with a button pressed by the experimenter, followed by a fixation point displayed in the center of the subject's visual field. An interstimulus interval of 500 msec followed the fixation point and preceded the onset of the stimulus word or non-word.The stimulus was followed in turn after a 10 msec delay of darkness by a complex noise mask. A millisecond clock also began timing at the onset of the stimulus word display. When the subject responded to the stimulus with a "yes" or "no" indicating whether or not it was a word, a microphone attached to the clock through a voice relay stopped the clock. The experimenter recorded the reaction time and the subject's response. After a series of 20 such trials, a d-prime was computed for word recognition and a new series of 20 trials was initiated, or the procedure was terminated if a d-prime of 75% accuracy had been achieved.

For the RSVP task, Wayne State's laboratory computing network was used. The network consisted of a Data General host computer interfaced with a Micronova mini-computer. Units of text were displayed on the CRT with the left-most character position stationary and centered vertically. A message to the subject indicated when the story presentation was to begin. The subjects read the story as it was presented on the CRT, making no response other than reading it, and the procedure was repeated for each of the other stories.

Procedure. Subjects participated individually and were first administered the comprehension portion of the Nelson-Denny reading test to determine their average reading rate. Then subjects were administered the signal detection task. Following this, each subject read 10 stories, one in each of the 10 conditions (i.e., 9 stories in the RSVP conditions and one story in the complete story condition), in counterbalanced order. Subjects recalled each passage immediately following its presentation. The recall instructions were: "Now we would like you to retell the story in its entirety, as if you were telling it to a friend. You may use your own words in your account of the story, but be sure to include as much information as you can remember, in its proper order of occurrence in the story."

Results and Discussion.

Rate of presentation had a significant effect on overall recall, $F(2,30) = 95.44$, $p < .01$, as the amount of time per word increased, recall improved. We assume that as the amount of time per word increased, more processing resources were available for use. As the amount of free resources increased, text recall became more thorough and comprehensive. This was further reflected by significant rate of presentation effects on the numbers of macropropositions, $F(2,30) = 10.19$, $p < .01$, and elaborations and inferences, $F(2,30) = 30.7$, $p < .01$, produced in the recall protocol. Recall in the medium speed RSVP condition was slightly better than recall in the normal self paced reading of the complete passage. Thus, on the whole, the RSVP paradigm did not artifactually cause decrements in comprehension. In fact, it slightly improved comprehension as measured by recall in this experiment.

Unit size was marginally significant when total recall was analyzed, $F(2,30) = 2.57$, $p < .08$. Fewer items were recalled when individual words were presented than when chunks or sentences were the units of presentation. Furthermore, this effect was significant when only recall of idea units (one idea unit per clause of text) were analyzed, $F(2,30) = 3.74$, $p < .05$.

Insert Table 1 about here

The sentence and clause superiority effects are modified when one takes into account their interaction with rate. F(4,60) = 3.08, p < .05. In the fast condition where individual words were presented at rates equal to those obtained in the signal detection task, recall was best when the text was presented word by word. It is conceivable that the resources available for forming a coherent text base are exceeded at this rate. In fact, subjects can take in so little information when units larger than the word are presented that they must produce many inferences to construct a coherent internal representation of the text. Heavy reliance on inference making is a compensatory process designed to produce coherence in the absence of signal data. That at least better readers did engage in extensive inferencing in the fast conditions is supported by Tukey tests administered to the significant rate by groups interaction on inferences and elaborations variable, F(4,30) = 4.87, p < .005. Good readers produced a higher percentage of inferences in the fast conditions than in the medium or slow conditions. Also, good readers tended to produce significantly more inferences in the fast word by word condition than in any of the other fast conditions.

As predicted, the clause condition produced the best recall at normal rates of presentation as assessed by Tukey tests. This condition frees the subject from at least some of the processing that determines which items form coherent units, leaving more capacity for integrative activities.

Generally, the unit size conditions and each of the rate conditions associated with superior recall performances were also associated with a signficantly greater number of inferences and elaborations, F(4,60) = 1.75, p < .10. However, the significant amount of text by speed by reader group interaction, $F(6,60) = 2.14$, $p < .05$, indicates that the patterns of performance described above are characteristic of only the good and average readers. The poor readers' recall performance in the word by word conditions at the medium rate was as comprehensive as that of the good readers in the fast word by word conditions. Equivalent levels of performance are not necessarily indicative of similar processing, however. We know that poor readers have problems with lower order processes like word identification (Vipond, 1980). It is, therefore, possible that poor readers abstracted a sample of words and related them through inference making procedures in the word by word medium rate condition. Poor readers performed best in the medium sentence by sentence conditions. Specifically, they were able to recall approximately the same amount of information as the good and average readers did in the sentence and word conditions at medium rates. One reason for this marked improvement in comprehension lies in the possibility of a compensatory process based on context effects. Such an interpretation is suggested by Stanovich and West (1979), who found that poor readers tend to rely upon sentence context more heavily than do good readers. At slow rates, poor readers comprehended equally well across all amounts of text conditions while the good and average readers performed best in the clause and sentence conditions. Lengthy exposure duration may have served to facilitate word decoding for the poor readers. Under these conditions, it is not necessary to decipher meaning through context and inferences alone.

Summary. Experiment 1 provided preliminary support for the three hypotheses of interest. In general, recall improved with increased unit size. Our argument is that chunking requires resources that could be devoted to other processes. Providing subjects with optimal or near optimal chunks reduces or eliminates one resource demand, permitting an allocation of those resources to other processes that contribute to recall.

As rate of presentation increased, recall deteriorated. The argument here is that time limits impose resource limits. The reader might be able to compensate for these limits by strategically allocating available resources to higher level processes, making up for less than adequate data. The higher levels of inferencing exhibited by better readers is consistent with this possibility.

Additionally, rate of presentation and unit size interacted to determine recall. The chunk effect on recall is maximal at medium rates of presentation. We interpret this outcome to imply that resources freed by experimental chunking are best deployed in favor of recall when textual material is presented at a normal rate where neither resource limits imposed by fast rates or memory limits imposed by slow rates are operative.

Finally, compensatory reallocation as just described, differed across groups of readers in a significant three way interaction. The reallocation patterns described above held only for average and good readers. Poor readers showed all together different responses to the experimental manipulations.

Experiment 2

The powerful effect of unit size observed in Experiment 1 might be attributable to parsing the stories into meaningful chunks that could be easily encoded and buffered, thereby freeing capacity that otherwise would have been devoted to the identification of meaningful units. Another possibility is that the advantage accruing to recall after reading a story in the RSVP task comes from breaking the text into small units, and not necessarily chunks. To determine whether assisting the subject in chunking was responsible for the unit size effect we used a new unit size, three words selected successively and independently of clausal boundaries in Experiment 2. If, as we hypothesize, chunking is a resource demanding activity which is generally performed in accordance with surface structure clauses, resources will be freed only when clauses are used as unit size. In contrast, if it is not parsing into clauses per se that frees resources for the subject, but merely the breaking of text into units that are conveniently sized for input to the information processing system, the new amount of text condition in which units are comprised of three words independent of clausal boundaries should improve recall as much as breaking the text into clauses.

Units of text were presented one at a time with the left most position stationary in Experiment 1. Thus, many of the eye movements that would be required in normal reading were eliminated. Imprecision in movement or information pick-up by the eyes was removed because the eyes remained fixated at the same location on the screen throughout every passage. Inefficient sampling strategies, inefficient eye movements and possible confusion from accidentally fixated material was also eliminated in Experiment 1. To determine the role that eye movements play in the unit size effects of Experiment 1, an additional display condition was included among the manipulations of Experiment 2 in which text units were selectively unblanked in sequence on the CRT. Each word was displayed for 200 msec as in the stationary RSVP condition. However, it appeared in the position that it would normally appear if the whole text was shown on the screen. By selectively unblanking only one text unit at a time, this condition gave rise to the sensation of moving text that had to be followed with the eyes to be read.

Just, Carpenter and Woolley (1982) maintain that gaze variablity directly reflects comprehension processes. Thus, eye movements should be limited by resource availability. On the other hand, Ward and Juola (1982) maintain that eye movements are relatively independent of reading comprehension processes, being primarily influenced by inefficiencies in planning and execution of the eye movement control system. The process of computing where the eyes move to fixate each unit of text may be either resource or data limited. The literature regarding eye movements does not provide a strong indication of the kind of limits to which the process is susceptible. However, in Experiment 2, the effect of computing eye movements on the reading process as a whole should be most apparent in the single word conditions where eye movements are completely eliminated (in the stationary RSVP condition) or are required frequently by the nature of the visual display (in the moving condition). Thus, an examination of type of presentation should provide a more complete picture of resource and data distribution among lower order processes.

Finally, the results of Experiment 1 indicated that poor readers compensate for poor comprehension processes by slowing all processing down. That is, they may have persisted in using resources in the same way as other readers, but may have required more resources for accurate comprehension. It is possible that the poor readers responded differently in Experiment 1 to the manipulations of resource requirements because they spontaneously use a strategy of slowing processing to heighten accuracy. This strategy would not have been detected by our indices of compensatory processing. Thus, we chose to test indirectly whether poor readers require more resources to overcome faulty comprehension processes by preventing them from slowing down. In contrast to Experiment 1 where the rate of presentation was individualized, rate in Experiment 2 was constant at 200 msec per word across individuals. We expect that if poor readers do normally use a strategy of trading speed for accuracy, preventing them from slowing down should force them to initiate alternative compensatory strategies which should be detected by our indices of compensatory processing.

Method

Subjects. Eighty-four undergraduate students at the University of Colorado served as subjects for this investigation. Subjects read a whole story at 200 msec per word and recalled it. They were then grouped on the basis of their recall performance. The distribution of recall scores was normal and poor readers scored at least one standard deviation below the overall mean while good readers scored at least one standard deviation above the mean. This grouping criterion resulted in 12 poor readers, 60 average readers and 12 good readers.

Design. A 3 x 2 x 3 design was employed in the study using the variables of reader group, display location and unit size. Subjects read two stories in each of the three textual unit size conditions (word-by-word, clause-by-clause, and three words at a time). One of the stories in each condition was presented via RSVP in a stationary position on the computer screen and the other was viewed by unblanking the selected amounts of text in normal position on a printed page. Hereafter, these are referred to as the stationary and moving conditions, respectively. Thus, two within subjects variables (*Unit Size and Location of Presentation*) and one between subject variable (*Reader Group*) were employed. Exposure duration was controlled across all conditions at 200 msec per word, a duration slightly shorter than the average eye fixation. Thus, subjects were unlikely to move their eyes during presentation of a text unit. Note that pauses between the display of text units were negligible as in Experiment 1. Subjects read one story in a natural condition where the entire text was displayed on the CRT screen in addition to reading stories in the experimental conditions. Here again the text was displayed for 200 msec per word times the number of words in the story. Passage comprehension was assessed through qualitative recall analysis as described in the first experiment.

Materials. The reading material for the study consisted of seven of the ten texts used in Experiment 1, one for each of the six experimental conditions and one for the whole story condition. A 7 x 7 Greco Latin square was utilized to counterbalance the passages and stimulus conditions.

Apparatus and procedure. A PDP-11 computer was used to present the different stories in the different stimulus conditions. There were four experimental stations, each equipped with a CRT and keyboard. This allowed four subjects to be run independently at the same time. The apparatus permitted the experimenter to enter the subject's identification and the condition and the story with which the reader was to start. The remainder of the experiment was under computer control. Once the experimenter entered the above information, the computer program asked for a button press from the subject when he/she was ready to begin reading the first story. When reading of the story was complete, recall directions were displayed on the screen instructing the subject to write a recall of the story in a booklet. Recall instructions remained on the screen until the subject pushed the button indicating he/she was ready to begin reading the next story. This procedure was repeated on the apparatus until all seven stories had been read.

Results and Discussion.

Conditions that were designed to alter resource allocation were effective in both qualitatively and quantitatively improving text recall relative to the normal reading condition. The superiority of recall in the RSVP tasks over the normal task observed in Experiment 1 was replicated, $F(6,480) = 2.87$, $p < .01$. The main effect of location of presentation, $F(1,80) = 3.28$, $p < .03$, revealed that significantly more text was recalled in the stationary conditions than the moving conditions. These results are consistent with the hypothesis that eliminating the necessity for eye movements improves performance. The stationary condition increases the probability that subjects view every word and reduces the probability of confusing memory by looking too far or not far enough for the next fixation.

Accuracy of recall (which was assessed by computing the number of incorrect inferences and idea units) was much higher in the stationary conditions than in the moving conditions, $F(1,80) = 5.2$, $p < .01$. Far fewer incorrect idea units, elaborations, and inferences were produced in the stationary conditions. The notion that eye movements create data limits may account for this significant main effect.

Insert Table 2 about here

These recall results are similar to those of Just, Carpenter and Woolley (1982), who compared moving and stationary RSVP conditions with normal text format. Their recall data from the moving conditions very closely resembled the data obtained from normal text. We interpret our results (and theirs) to indicate that experimental restrictions of eye movements in the stationary condition reduced data limits caused by inefficient sampling techniques. The memorial representation of the text is thus enhanced by improving the quality of the data input to the system.

Unit size (one word vs. three words vs. chunks) was only mariginally significant in total recall scores. The mean total recall score was highest in the chunk conditions although the difference among sizes was not significant when collapsed across the stationary and moving conditions. The largest effect of amount of text emerged from an analysis of macropropositions, $F(2,160) = 3.04$, $p < .05$. Significantly more macropropositions were produced in the clause condition than elsewhere. These differences were preserved when the relative percentage of macropropositions to idea units, (defined as the idea represented in a clausal unit) was computed. Assisting subjects in parsing into clauses appeared to free resources which were then channeled into other resource demanding tasks such as producing macropropositions. Furthermore, the effect of unit size on macropropositions was not moderated by any interactions.

Insert Table 3 & 4 about here

Of most interest was the significant interaction of amount of text by location of presentation, $F(2,142) = 4.57$, $p < 01$ (see table 4). Post hoc tests were done to contrast conditions that were especially telling for our hypotheses. First, Tukey tests show that the stationary chunks condition was associated with significantly more thorough recall than the three word stationary condition, $p < .05$. Thus, recall is facilitated by parsing text into meaningful units over and above merely segmenting arbitrary units of comparable size.

Significantly more was recalled in the chunks stationary condition than in the chunks moving condition, $p < .05$, showing the benefit that is uniquely due to chunking. When only macropropositions were analyzed, the amount of text by location interaction was not significant. There was, however, a significant amount of text effect on the number of macropropositions in recall (see table 3). Taken together, these effects argue that that higher level processing was affected by chunking alone.

In general, subjects performed worst in the word moving condition, which was significantly different from the word stationary condition, $p < .01$. Subjects recalled the least text yet produced the greatest number of false statements in the words moving condition, compared to all others (see table 2). These contrasts indicate that improving the quality of the data by restricting eye movements and removing the need to allocate resources to the chunking component resulted in better performance than just removing the chunking demands. They support the hypothesis that performance is dependent on both data from other components and the amount of available resources. Limits at one point in the system may influence subsequent processing through the compensatory reallocation of resources.

Still more evidence for the compensatory hypothesis comes from marginal group differences $F(2,80) = 2.18$, $p < .11$, and groups by amount of text interaction on the macropropositions variable, $F(4,142) = 1.9$, $p < .10$.

Furthermore, poor readers produced more macropropositions than good or average readers. Poor readers produced the most macropropositions in the three words and chunk conditions, the conditions in which they recalled the fewest idea units.

Insert Table 5 about here

In contrast, for the good and average readers, macropropositions were positively correlated with the number of idea units recalled. The number of additions (elaborations and inferences) in recall was positively correlated with the number of idea units recalled for all groups of readers. We interpret these findings to indicate that certain compensatory processes such as abstracting the main idea of a text, can be initiated when a reader perceives that other processes are failing. Thus, the reader may shift comprehension strategies and choose to allocate more resources to the compensatory processes and less to other processes normally used in comprehending text especially if they are prohibited from using speed/accuracy tradeoffs. When the component processes are adequately functioning, no compensatory actions are initiated and resource utilization results in a more complete protocol. Abstracting main ideas, producing inferences and drawing on world knowledge sources are thought to be among the most resource demanding activities in reading. However, they may also be the most susceptible to data limits. Since activation of the appropriate world knowledge source depends on receiving correct data from the text it is not surprising that the number of inferences, elaborations and macropropositions increased as the number of idea units recalled increased when there were no data limits and plenty of resources. However, when poor quality or little data are input into the system from the text, using world knowledge to augment the data in the form of inferences, elaborations, and macropropositions will result in inaccuracies like those found to be so prevalent in the poor readers protocols.

Finally, there were quantitative and qualitative differences among the reader groups which were formed using the efficiency ratio. This ratio reflects the speed-accuracy tradeoffs of a subject and was based on their total recall scores in the normal condition where an entire text was read in one viewing. Three factors determined the numerator of the ratio used for group placement: number of false statements, total amount of data recalled, and number of inferences and elaborations. Of these, the relative percentage of false to true statements accounted for most of the variance. Poor readers recalled significantly fewer items than either the good or average readers. Moreover, the recall of the poor readers contained as many incorrect statements as correct which is not the case for average and good readers.

There were significant group differences in total recall, $F(2,80) = p < .01$, and in accuracy of recall, $F(2,80) = 4.69$, $p < .01$. The number of falses is lower and the number of trues is higher for good and average readers relative to poor readers.

The significant groups by amount of text interaction $F(4,142) = 2.45$, $p < .01$, indicated that the performance of poor readers was best in the one word condition. While one might venture to say that this is because they normally read this way, the evidence contradicts such an interpretation. Poor readers performed significantly better in all three amount of text conditions relative to the normal condition as assessed by Tukey comparisons. The groups by location of presentation interaction, $F(2,80) = 3.28$, $p < .05$, shows that performance of inefficient readers was best in the moving conditions. For all other readers, the stationary conditions enhanced performance more than the moving conditions. Inefficient readers were also more accurate (fewer falses) in the moving conditions while the opposite pattern was observed for the good and average readers, F(2,80) = 3.16, p < .05. To complicate matters further, these interactions were modified by significant groups by amount of text by location of presentation interaction, F(4,142) = 3.34, p < .01. The performance of inefficient readers was best in the chunks and words moving conditions. Everyone else did worse in the words moving conditions and best in the chunks stationary and words stationary conditions.

The consistently better and more accurate performance manifested by the poor readers in the individual words and moving conditions needs to be addressed. Slow readers are slow verbal coders (Hunt, Frost & Lunnenborg, 1975; Hunt, Lunnenborg & Lewis, 1973; Perfetti & Lesgold, 1976). When only one word is presented at a time, yet every word is presented, the poor reader is more likely to encode information from all parts of the text. This would improve performance over presenting more than one word at a time because all words have an equal probability of being fixated as opposed to only certain words in each group. In Experiment 1, good readers performance in the fast conditions linearly decreased as the amount of text increased; the same pattern seen in the poor readers in Experiment 2. We assume that the normally slow reading rate of poor readers can account for the similarity between these two findings. If a reader is pushed to perform at rates faster than preferred, it is possible that decreasing unit size assists their performance. The poor readers in Experiment 1 did not benefit from small unit sizes because readers read at their individual preferred rate. The good readers do not tradeoff speed for accuracy which is why they are called good readers in Experiment 1. The poor readers are inefficient and by definition tradeoff speed for accuracy. However, in Experiment 2 poor readers were prohibited from doing so and hence look like good readers in the fast conditions in Experiment 1.

What does flashing words in different locations do for the poor reader? The moving conditions might have facilitated encoding for two reasons. First, the flashing of a word in the peripheral vision of the poor reader might have attracted his or her attention. It has been suggested by Badcock & Lovegrove (1981) that poor readers have shorter iconic memories when viewing items the size of normal text. If the poor reader makes a second fixation to finish encoding but a new word has appeared in the same place, confusion should result, producing signal data limits in the stationary conditions. Rayner (1975) investigated such confusions and found that when a critical word previously viewed was substituted for a different word during a saccadic movement, fixation duration radically increased. Given this, the better performance of poor readers in the moving as opposed to the stationary condition might be attributable to the elimination in the moving condition of this source of confusion.

General Discussion

These experiments were conducted to distinguish empirically between interactive and non-interactive models of reading. To the traditional conceptualization of interactive models we added the notion of resource exchange between component processes. Although the issue of resource allocation was not formally addressed in Rumelhart's model (1977), we hypothesized that resources could be exchanged in both a top-down and bottom-up manner. This is consistent with Rumelhart's theory of how component processes interact. What we did was to provide an additional way in which subprocesses could influence one another.

Our initial rationale for adding a resource exchange principle was to derive testable hypotheses. If we could demonstrate that component operations exchanged resources it would imply that the operations occur in parallel. Further, if the exchange of resources modified processing, it would demonstrate that processing is interactive.

The unit size manipulations in Experiments 1 and 2 demonstrated that assisting subjects in chunking and thereby freeing resources used to chunk resulted in both improving text memory and increasing the number of macropropositions produced. Processing was not merely made easier as a serial model would predict. Rather, resources were rechannelled to improve memory both quantitatively and qualitatively. Additionally, when data were experimentally degraded and severe resource limits were placed on lower level operations (eye movements or rate of information input) in the fast conditions in Experiment 1, resources were <u>reallocated</u> to higher-level operations (e.g., in fast word-by-word conditions to inference-making). Such reallocation is contrary to expectations from serial non-interactive models that assume the limits are propagated throughout the system.

Furthermore, in Experiment 2, the effects of chunking interacted with the demand for eye movements. Chunking the text for subjects in the moving conditions resulted in superior memory for text and increased the number of macropropositions produced relative to the other unit sizes in the moving condition. Thus, process limits placed by the experimental task demands at a point later in processing were observed to affect processes presumed by stagewise parallel models to occur earlier in processing (e.g., parsing manipulations modified quality of input effects from fixed or moving text).

Our most powerful demonstration of the effects of resource allocation on the reading system was the compensatory processing observed in poor readers during Experiment 2. Poor readers produced the most macropropositions in the conditions where they recalled the least amount of information.

It should be noted that some of our results are explainable by Just and Carpenter's (1980) model. The unit size effect could be attributed to having the clausal unit input into working memory and thereby activating integrative processes. However, there is nothing in their model that relates to reader strategies, making it difficult at best to explain the compensatory processing observed in poor readers. By adding the notion of resource exchange to Just and

Carpenter's and Rumelhart's models we provide an additional mechanism to explain interactions which accounts for more empirical data than a data excange mechanism. Additionally, our formalization resulted in clearly testable hypotheses which are not evident in other interactive models of reading.

Thus, we conclude that our data are inconsistent with both serial and parallel non-interactive models of reading. Further, we maintain that resource allocation among component processes is an integral part of any interactive model. It appears that both resources and data are exchanged in both top-down and bottom-up manners during reading. Further, resource allocation may be dynamic and vary with task demands and reading abililty. Certain resource utilizing strategies appear to be initiated by the reader and under the reader's control, as demonstrated by the compensatory processing observed in the poor readers of Experiment 2.

Our method of presenting text extends both that of Juola, Ward and McNamara (1982) and Just, Carpenter and Woolley (1982). Juola et. al. presented texts using what we termed stationary RSVP, varying window size by letters. We manipulated window size by words, adding clause and sentence conditions to their approximate one, two and three word conditions. Just et. al. used both moving and stationary RSVP conditions but limited their display size to one word units. Moreover presentation was subject-controlled in contrast to experimenter-controlled in our experiments. Our measure of performance is more comprehensive than either of the preceding studies. Juola et. al. used comprehension questions to assess reading performance, tapping general text memory. Just et. al. employed recall protocols, but did not analyze the data obtained from the stationary RSVP condition and therefore did not contrast moving versus stationary RSVP conditions. In addition, they provide no measure of macropropositions, inferences and elaborations.

Within the limits of these methodological differences, our data are entirely consistent with those of Juola, et. al. and Just, et. al. We believe, however, that our technique allowed us to (1) examine more carefully the role of eye movements in the reading system. While we didn't actually monitor eye movements, according to Just et. al. the one word moving RSVP condition is analogous to eye movement monitoring. By contrasting moving with stationary RSVP conditions and analyzing the data for evidence of higher level processing, we were able to investigate what eye movements contribute to reading. Secondly, our technique enabled us to address at greater depth some of the issues raised by competing reading models.

In sum, it appears that any model of reading *must* include a means of exchanging both data and processing resources among components and *must* provide for the modification of a component process by all other ongoing processes. Few data in the literature indicate quite so clearly as these the fundamentally interactive nature of reading.

Table 1

Speed by Amount of Text Interaction

on Total Recall Scores, Experiment 1

	Rate of Presentation		
Amount of Text	Fast	Medium	Slow
Words	2.7	9.7	12.4
Clauses	1.4	12.5	15.6
Sentences	1.0	11.4	16.0

Table 2

True and False Idea Units,

Inferences and Elaborations, Experiment 2

Condition	Trues	Falses	Ratio of falses to trues
Total text normal	11.14	1.90	17
Words Stationary	14.95	1.55	10
Words Moving	12.08	2.49	21
Three Words Stationary	13.89	2.27	17
Three Words Moving	13.43	1.92	14
Chunks Stationary	14.80	2.06	13

Table 3

Mean Recall Scores for

Amount of Text Variable, Experiment 2

	Words	Three Words	Chunks
Total Recall	12.1	12.8	13.3
Macropropositions Only	.28	.36	.41

Table 4

Amount of Text by Location of

Presentation Interaction

in Total Recall Scores, Experiment 2

Location of Presentation	Amount of Text One Word	 Three Words	 Clauses
Moving	10.2	12.8	13.2
Stationary	13.7	12.8	13.8

Table 5

Number of Macropropositions and Idea Units Produced By Each Reader Group For Amount of Text Variable, Experiment 2

	Good		Average		Poor	
	Macros	Ideas	Macros	Ideas	Macros	Ideas
One Word	.30	10.96	.30	8.75	.20	7.80
Three Words	.36	11.88	.30	9.53	.75	6.20
Chunks	.40	11.45	.40	10.32	.50	6.55

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