SESSION IV INNOVATIVE USE OF COMPUTERS IN READING RESEARCH

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Computer methods and ecological validity in reading research

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Computer-based procedures for obtaining word-by-word reading times are evaluated in terms of criteria for basic research and for ecologically valid research. Ecological validity can sometimes compromise experimental designs that should control extraneous variables or separate confounded factors. Two reading paradigms that were developed for basic research on linguistic coding mechanisms are also shown to meet many of the criteria for ecological validity.

During the past several years, research on reading has increased markedly, in part because computers have expanded the variety of research procedures in this area and have increased the efficiency of doing research. Thus, it is appropriate that we devote a symposium to the formal discussion and comparison of those computer advances. In this context, a fair amount of recent discussion (e.g., Just, Carpenter, & Woolley, 1982; Kieras & Just, in press) has favored experimental procedures with high "ecological validity." Questioning this trend, Mook's (1983) recent article suggested that, throughout psychology, phrases such as "ecological validity" have become "warm fuzzy purr words," and have relegated some of our traditional scientific buzz words to the status of "cold creepies."

The criteria for ecological validity may sometimes be inconsistent with high-quality scientific research. Or, at the very least, high-quality research need not be ecologically valid. For starters, some physics research is done in vacuum chambers that could not exist in nature, and some microbiology is done on dead tissue. To study an issue as ecologically important as mother love,

Harlow's (1958) monkeys were given a choice of sucking a rubber nipple on a wire-mesh form or hugging a terry-cloth cylinder warmed by a light bulb.

Table 1 provides a characterization of research paradigms in terms of three pairs of criteria for either ecological validity (on the left) or basic research (on the right). A comparison of points on the two sides of the table suggests that these two sets of criteria may be incompatible in many instances. The first criterion on the left states that an ecologically valid research environment should resemble the associated natural environment as closely as possible. However, in accord with the right side of the table, all of the research procedures to be discussed in this symposium were purposely designed to be artificial in many respects in order to control or separate variables that are confounded naturally (Dixon, 1984; Post, 1984; Young, 1984). The next two pairs of criteria in Table 1 state that ecologically valid studies should make predictions about, and generalize to, real-world behavior. In contrast, the studies in this symposium generally were planned to test, rather than to make, predictions. And their theory, as opposed to their results, should generalize to yet other laboratory situations. The extent to which a researcher favors one or the other side of Table 1 should depend on the precise reasons for which the research is being done.

Several years ago, it became clear to me that the differences between my own work and that of my sister Jean were well described by Table 1. She stated that my research had little to do with "real" reading, and that I should visit her classroom for evidence. In accord with

The work reported here was supported in part by PHS Grant MH 16,496 to NYU and by an NYU Research Challenge grant. I thank Steven Ferres and Hollis Scarborough for help in running the experiments reported here. I appreciate comments on an earlier draft from Gay Snodgrass and Hollis Scarborough, and ideas about ecologically valid and invalid issues from Douglas Mook. My mailing address is: Psychology Department, 6 Washington Place, Room 858, New York University, New York, NY 10003.

Table 1
Two Characterizations of Research Paradigms

	Paradigms for Ecological Validity	Paradigms for Basic Research
Criterion 1—Methods	The research environment should resemble natural settings in as many ways as possible.	The research environment may create an artificial situation in order to control extraneous variables or to separate factors that are confounded in nature.
Criterion 2—Results	The results should make predictions about everyday performance tasks.	The results should test predictions about and increase our understanding of underlying processing mechanisms.
Criterion 3—Generalizations	The empirical findings should generalize to real-world behavior.	The theory should generalize to other appropriately defined situations.

Note—The ideas in this table are based in part on Mook (1983).

Criterion 1 in the right-hand portion of Table 1, I paid college students \$3.00 to sit in a dark room and press a button to get individual words displayed on a CRT. In accord with Criterion 2 on the right, my research tested predictions about unobservable syntactic and semantic coding stages in reading. In accord with Criterion 3 on the right, the equations that accounted for overall mean reading times using easy sentences subsequently accounted for lexical category reading times in analogous conditions using difficult sentences.

In contrast, Jean paid attention and compliments to real hyperactive children to induce them to utter words in response to grade-school textbooks in a miniclassroom, satisfying Criterion 1 of the ecological-validity (left-hand) portion of Table 1. The reading level for her children should predict their performance in other school subjects, in accord with Criterion 2 on the left. Finally, her behavior-modification procedures were designed to generalize to hyperactive readers of other ages and to other problem readers, satisfying Criterion 3 on the left in Table 1.

Indeed, the above comparison is an extreme one. The different research goals dictated rather different abstract criteria for designing research methods. That many high-quality laboratory procedures can also have ecological validity may sometimes be true. But one must always entertain two questions: First, what particular dimensions of ecological validity are directly relevant to the research questions being asked? Second, does instituting a procedure with various types of ecological validity compromise other research goals?

METHOD

At this point, I would like to describe some of my research, considering its relationship to both sides of Table 1. Let us start with the research method, as illustrated in Figure 1. Subjects view sentences displayed on a computer screen one word at a time in a self-paced silent reading task. Each time they want to read another word, subjects press a response key. This signals the computer to extinguish the previous word, record its reading time, and display the next word in the center of the screen. Subjects are divided equally into two postsentence task groups: recall and comprehension. Immediately after viewing the last word in each sentence, recall subjects are signaled by the displayed

Figure 1. Top: The time course of events on a trial for the word-by-word reading paradigm. Bottom: Sample stimuli and information about the experimental design.

word "recall" to repeat the sentence verbatim into a tape-recorder microphone. Comprehension subjects see a 3-7-word true-false statement about the sentence content, and press one of two keys labeled "T" and "F." All subjects have the same 6 practice and 80 test sentences in a 1-h session.

The bottom of Figure 1 has a sample pair of stimulus sentences and information about the experimental design. Two age groups, fifth-graders and college students, participated in each of the reading tasks. We further divided subjects into slow and fast readers on the basis of median splits of the overall reading times for each group. Finally, we analyzed the data separately for two half-sessions of practice. Thus, the word-by-word reading time procedure and the experimental design were developed as research tools to study three determinants of reading strategies: the linguistic structure of the text, the cognitive demands of the reading task, and the individual readers' abilities.

Table 2 contains an evaluation of the word-by-word reading time procedure in terms of Criterion 1 in Table 1. Contrary to ecological validity, the procedure requires keypresses, rather than more natural saccades, in order to view new words. But the more natural saccades may create problems of data analysis and interpretation. For example, researchers using eye movements standardly eliminate about 10%-20% of the total time from their data attributed to saccades, blinks between words, regressions and rereadings, even with special instructions to subjects to suppress these visual activities (Hogaboam & McConkie, 1981; Just & Carpenter, 1980). For research purposes, our preference is to use a procedure that includes the total viewing time in the data analyses, because subjects may be cognitively processing words during the various time intervals omitted from eye-movement analyses. Our subjects fixate the center of

Table 2
An Evaluation of the Word-by-Word Paradigm in Terms of
Ecological Validity and Basic Research

Artificial	Natural
1. Keypress responses.	1. Subject paced silent reading.
2. No saccades.	2. RTs not limited by motor times.
3. No regression.	3. Natural reading rates.
4. No preview.	4. RTs reflect cognitive processing.
5. No multi-word viewing.	5. RTs reflect linguistic information.
6. All words viewed.	6. Display size = natural fixation size.

the screen, where all words are presented. Thus, the procedure itself eliminates many of the visual events that are deleted from the data analyses with other methods.

Further, because our displays are restricted to single words in many experiments, there is no regression to previously read text, no preview of subsequent text, and no multiword viewing. Eye-movement studies permitting such natural activities may have difficulty mapping visual events into cognitive processing time. For example, if the subject has preview of the next word while still viewing the preceding word, it is difficult to allocate viewing time to particular linguistic units or attributes of the text. Untestable assumptions must be made in eye-movement studies to decide what portion of the total fixation time should be allocated to the central word versus the peripherally visible words, when three or four words can often be seen simultaneously (Hochberg, 1976).

If we focus on the right side of Table 2, the word-by-word procedure is indeed natural in important respects. The reading times are paced by the subject rather than by the experimenter, and they are not limited by motor response times for the following reasons. The reading time data for many word strings included reading rates of 300-600 words per minute (wpm) as fast as moderately rapid natural reading rates,¹ but slower than motor response times about 75 msec/word for control subjects who pressed the key to advance the displays but did not read the words. However, the experimental subjects responded much more slowly than 300 wpm at linguistically important points, such as key content words and phrase boundaries. Thus, their cognitive processing of linguistic information limits their reading time. Natural reading averages about 1.1 words/fixation (Hogaboam & McConkie, 1981; Just & Carpenter, 1980; Taylor, 1965), close to our single-word display size ($SD = .67$ words/fixation, computed from data in Carpenter & Just, 1983). Further, the foveal area generally spans about seven characters, approximately one word (Haber, 1976). Thus, although some aspects of the reading time procedure were designed to be "artificial," in order to provide a research tool for studying the roles of linguistic and task variables in reading, those aspects important to selected generalizations and predictions to real-world behavior were designed to be as natural as possible.

RESULTS

In terms of research goals, the word-by-word reading times should increase our understanding of cognitive and linguistic processing during reading. The data in Figure 2 provide a step in that direction. Earlier research on cognitive task demands (Aaronson & Scarborough, 1976) predicted that different linguistic coding strategies would be used when reading for comprehension than for memory. When reading for memory, the surface phrase structure provides natural "chunking" units that can facilitate perception (Miller, 1962), retention (Glan-

zer & Razel, 1974), and retrieval (Tulving, 1968). But, reading for comprehension of gist should not require such syntactically based coding. Instead, the reading time patterns for comprehension subjects should primarily reflect the semantic content of the sentence. Figure 2 shows the word-by-word reading time profiles for two stimulus sentences that support these strategy predictions. For recall subjects, prolonged pauses occur at (subjectively rated) phrase boundaries, marked by vertical lines. Comprehension subjects do not show any evidence for such syntactic coding. Instead, they show evidence for "semantic facilitation." Reading time decreases, marked as SF in Figure 2, occur at words such as "suit" and "years," shown in a separate experiment to be highly predictable from prior context. But, recall subjects do not show the semantic facilitation effect. When reading times are averaged over all sentences, the interactions between reading task demands and linguistic attributes of the sentence are highly reliable. (For further details, see Aaronson & Ferres, 1984).

Figure 3 provides a second test of the prediction that recall subjects have a syntactic or structure-oriented coding strategy, whereas comprehension subjects have a semantic or meaning-oriented strategy. On the left of Figure 3 are data from an independent study (Aaronson & Ferres, in press), in which words in 18 lexical categories were rated on a 5-point scale for their contribution to the structure and the meaning of their sentences. The verb set consisted of main verbs, auxiliary verbs, and the adverbs that modify verbs, and the noun set contained nouns, adjectives, and the adverbs that modify adjectives. The rating data on the left show that the verb set is rated higher on structure than the noun set, but the noun set exceeds the verb set on meaning. On the right

Figure 2. Word-by-word reading times for two sentences, averaged over all subjects in the adult recall and comprehension groups. Subjectively marked phrase boundaries are indicated with vertical lines. SF denotes reading time for target nouns selected on the basis of the semantic facilitation scoring.

Figure 3. Left: Subjective ratings of meaning and structure for two categories of content words. Right: Reading time difference scores between reading times for particular lexical categories and the mean word-by-word reading times for their sentences, for two sets of content words.

of the figure, the word-by-word reading time data for these lexical categories, for the same stimulus sentences, again support the prediction of task-linked linguistic coding strategies. The y-axis is the reading time difference between the given lexical categories and the mean reading times for all words in their sentences. Recall subjects spend more of their time on the "structure-oriented" verb set and less on the "meaning-oriented" noun set than do comprehension subjects. This effect holds separately for words at phrase breaks and at phrase-intermediate positions. (For further details, see Aaronson & Ferres, 1983). Thus, in accord with the criteria for basic research, the results test, and support, predictions about linguistic processing mechanisms during reading.

In the context of ecological validity, one should ask about predictions from these results to everyday performance. In daily life, most reading tasks do not entail such extreme processing demands as those in our labora-

tory procedure. People do not usually read purely for memory or for gist, but rather for some mixture of these purposes. Thus, not only the display procedure, but also the reading goals in this research have less than perfect ecological validity. However, one reason to use such extreme and nonnatural tasks is, strangely, to be in a better position to make predictions about mixture strategies that do occur in everyday reading. Natural reading tasks vary along a continuum from high memory and low comprehension to low memory and high comprehension (Aaronson, 1976). An example of the former is when students read textbooks in preparation for an exam, and all too often demonstrate rote memory with little comprehension. An example of the latter is when subway commuters read newspapers in preparation for an evening cocktail party, and all too often forget, distort, or permute the order of the original content. Our research suggests that people have command of a wide range of linguistic coding strategies, appropriate to the particular reading task at hand. If we had used ecologically more natural tasks in the middle of the continuum, we might never have discovered the existence of different strategies or the possibility of a range of mixtures.

The children in our research illustrate the possibility of natural mixtures even better than the adults. Because fifth-graders haven't had experience with enough reading tasks to gain reliable control over their strategies, they show mixtures in both of our task conditions. Figure 4 illustrates two types of mixtures shown by a number of our young subjects. On the top, Cindy mixes the two strategies within a sentence. Many of her trials show the phrase-based scallops characteristic of the recall strategy for half of the sentence, and the smoother, more rapid comprehension profile for the other half-sentence. On the bottom, Ian shows an alternation of strategies from one sentence to the next. Likewise, some of the adults in our experiments mix strategy components. Some slow comprehension adults show components of the recall strategy, and some fast recall subjects show components of the comprehension strategy. Thus, the use of somewhat artificial laboratory tasks indeed permits us to make predictions about a range of natural reading strategies.

GENERALIZATIONS

Finally, let us turn to the third pair of items in the criteria for laboratory research and ecological validity (Table 1): those dealing with research generalizability. According to the criteria for basic research, the theoretical ideas from one study should generalize to other appropriately defined experimental situations. Thus, we might ask whether the hypothesized task-linked coding strategies are revealed in different paradigms and with different postsentence tasks.

As a check on this, we ran subjects in the perceptual monitoring procedure illustrated at the top of Figure 5

Figure 4. Word-by-word reading times that illustrate the mixing of strategies within a trial (top), and from one trial to the next (bottom).

Figure 5. Top: The time course of events on a trial for the perceptual monitoring paradigm. Bottom: Information about the experimental design.

and previously used in our laboratory with spoken stimuli (Aaronson, 1968; Aaronson, Markowitz, & Shapiro, 1971). At the start of each trial, subjects saw one to three target words, one of which might occur in the following word string with a probability of $\frac{3}{4}$. A few seconds later, three sets of dashes and nine words were shown, one at a time, on a computer screen at 300 msec/display, about the average rate reported in "natural" reading experiments. The subjects were instructed to press a "YES" key as soon as they detected a target word in the display, or to press a "NO" key after the last word was displayed if no target word occurred. As indicated on the bottom left of the figure, half the subjects simply monitored for the target as just described. The other half had a subsequent recognition memory task in addition. For those subjects, on "Same" recognition trials the original words were displayed together, 4 sec after the word string ended. On "Different" recognition trials, the word string had a single word changed. Further, for the monitor-only and the monitor + memory tasks, we had two subgroups of subjects. Half the subjects received displays of English sentences, whereas the other half had lists with words drawn randomly from the total sentence pool, but with the same monitoring target words in the same serial positions as the sentences. Finally, half of the sentences for each subject were one-clause sentences, and the other half were two-clause, with the second clause beginning at Word 5. The one- and two-clause stimuli had words matched for length, word frequency, and lexical category.

Figure 6 shows the monitoring response times for the "YES" and "NO" responses. Again, we see evidence for task-lined coding strategies. Subjects who read English sentences for memory show a large response time peak at the clause boundary, suggesting a phrase-based coding strategy similar to that illustrated with the word-by-word reading time procedure. In contrast, subjects in the monitor-only conditions do not show such exaggerated

response time peaks. A closer examination of the monitoring + memory data suggests that the response time peak obtained with two-clause sentences represents a linguistic strategy, and not simply a grouping or chunking strategy, because no peak occurs for one-clause sentences or for the control group having random word lists with matched targets. Finally, the data suggest that subjects simply monitoring the sentences without memory are also doing some kind of linguistic coding for two reasons. First, their "YES" response times (on target trials) indicate about 50 msec more processing than those for the word-list control group. Second, their "NO" response times (on catch trials) are about 100 msec longer than those of the control group, suggesting a sentence-integration process after the last word is displayed.

Because the study of mental events is necessarily indirect, it is useful to have two rather different procedures to provide converging evidence in support of underlying coding processes. The word-by-word reading time paradigm and the perceptual monitoring paradigm complement each other in this way. They also satisfy the third criterion for basic research, that the coding theory should generalize to new research situations.

On the other hand, the third criterion for ecological validity specifies that the empirical findings should generalize to real-world behavior. Table 3 suggests possible directions for everyday applications of the word-by-word procedure. First, Durkin (1978-79) and others in the field of education have stated that reading "strategies" are generally not explicitly taught in the schools. The subject-paced paradigm could provide an operant procedure to teach task-linked reading strategies. Our practice data show that within 1 h fifth-graders become

Figure 6. Monitoring response times for four groups of 24 subjects for two types of stimuli. "1 clause" and "2 clause" word lists were chosen randomly from the associated pool of sentence words, except that the target words and positions were matched. C = catch trials with no targets in the displays.

Table 3
Applications of the Word-by-Word Procedure

1. Education—to teach reading "strategies."
2. Reading Deficiencies—to aid selection and integration of coding skills, using CAI.
3. Human Factors—to provide explicit human control over the rate, amount, and size of displayed text.

faster and smoother. The voluntary buttonpressing response may be an important component in making people aware of their reading behavior and thus enabling them to improve.

Second, recent reviews of linguistic and cognitive factors in reading deficiencies show that most researchers are oriented toward single-factor theories (Carr, 1981; Vellutino, 1978). But there is little or no agreement on what the "critical" factor is, with studies implicating everything from visual code formation to contextual integration (Benton & Pearl, 1978). Our comparison of fast and slow readers suggests that some reading deficiencies occur because the reader does not select and integrate multiple cognitive and linguistic skills in an optimal way for a given reading task. Perhaps the present methods, within a CAI environment, could provide appropriate remedial training. Providing active control over the display of text may help some distractible children focus their attention more effectively on the reading task.

Finally, human factors are being considered in developing a computer facility for the visually impaired at NYU. It appears to be useful for many impaired students to display small amounts of text at a time to facilitate focusing on one place and to prevent losing one's place. I am currently negotiating to purchase a microcomputer from Visualtek, Inc., which permits the visually impaired reader to magnify the text by a variable amount and to display self-selected amounts in a "visual window." The relevance of our self-paced reading procedure to the human factors requirements for such special-purpose computer equipment is strong.

CONCLUSION

In conclusion, I suggest that the criteria for ecological validity are not necessary for many types of basic research. In fact, incorporating such features can sometimes compromise good experimental designs that should control extraneous variables or separate confounded factors. However, when ecologically valid procedures can be incorporated without jeopardizing basic research goals, they will facilitate subsequent applications of the research to everyday life.

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NOTE

1. The adult word-by-word reading times can be compared with reading times obtained with whole-sentence displays in experiments that use similar computer monitors and subject button-pressing responses. Our adult "comprehension" reading

times averaged 413 msec/word, in comparison with reading times in comprehension tasks for coherent stories (344 msec/word) and for stories with coherence links deleted (506 msec/word) (Cirilo, 1981). The adult "recall" reading times were 617 msec/word, in comparison with reading times in recall tasks for sentences in stories (338 msec/word) and in unrelated lists (809 msec/word) (Haberlandt, Berian, & Sandson, 1980). According to Buswell's data, our reading times are within the distribution of "natural" reading times. His research shows that 25% of the readers are slower than 333 msec/word and 6% are slower than 500 msec/word (Kolars, 1976). Our fastest adult comprehension subjects averaged about 260 msec/word, which would place them in the fastest 25% of the population, according to Buswell's data.