

A Developmental Review of Response Time Data that Support a Cognitive Components Model of Reading

Barbara A. Greene^{1,3} and James M. Royer²

The present article provides a review of numerous studies that measured response times for cognitive tasks related to six components of the reading process. The component processes were single-letter recognition, multi-letter unit identification, word and pseudoword identification, semantic access/concept activation, phrase and sentence comprehension, and text comprehension. The response time data are presented in tables and summarized in the text. The data provide support for a componential view of reading.

KEY WORDS: reading; cognitive processing; response time.

INTRODUCTION

Many reading researchers agree that reading is best understood by examining component processes (e.g., Carr, 1982; Curtis, 1980; Frederiksen, Warren, and Rosebery, 1985; Graesser, Hoffman, and Clark, 1980; LaBerge and Samuels, 1974; Perfetti and Curtis, 1986). In fact, Perfetti and Curtis (1986) found a consensus among theorists for a single cognitive components model of reading. The model's cognitive components either interact or function as part of a serially ordered chain of processing units. Each unit has a specialized function such as recognizing letters, identifying words, or activating a semantic representation for a word.

¹University of Oklahoma.

²University of Massachusetts.

³Correspondence should be directed to Barbara A. Greene, Department of Educational Psychology, 820 Van Vleet Oval, University of Oklahoma, Norman, Oklahoma 73019.

Research on component processing theory has focused either on identifying the specific components that support skilled reading (e.g., Carr and Levy, 1990), or on characterizing the developmental parameters of component skills (e.g., Curtis, 1980; Sinatra and Royer, 1993). The latter literature is the focus of this review article.

Many component-processing theories of reading either explicitly or implicitly emphasize a partial or total bottom-up perspective on the development of reading skills. That is, the theorists argue that developing readers must first rapidly differentiate between letters and identify words with minimal cognitive effort before comprehension-level processes can mature to maximum efficiency. These theorists build on the empirical evidence that data-driven processing at the letter and word levels (i.e., processing that occurs without conscious attention) characterizes skilled comprehenders (e.g., Hunt, Lunneborg, and Lewis, 1975; Hunt, 1980; and see Perfetti, 1985, for a review of this evidence). Whereas the early component-processing theorists tended to argue for a totally bottom-up view of reading development (e.g., Gough, 1972), later theorists, such as Perfetti (1988), take a partial bottom-up position. The partial bottom-up position addresses the evidence that the knowledge of a young reader affects the development of his/her lower-level processes before those process become data-driven. Our view is consistent with Perfetti's verbal efficiency theory (e.g., 1988, 1992).

PERFETTI'S THEORY OF READING DEVELOPMENT

Perfetti suggested (1992) that children begin to acquire word identification abilities may initially using a kind of problem solving approach to word identification. In this early stage of reading acquisition, they utilize context, word-forms, and conscious strategies to identify printed words. As experience with frequently encountered words grows, identifying those words increasingly becomes a data-driven process. Perfetti (1992) suggested that identifying frequently encountered words becomes a "modularized" process (cf. Stanovich, 1990). A process that was previously a highly context-sensitive and strategic activity has been transformed into an activity that is "cognitively impenetrable." A cognitively impenetrable process is entirely data-driven and cannot be influenced by contextual or strategic events.

Whereas Perfetti believed skilled readers have modularized lexical identification activities (exceptions are unusual words or stimulus degraded text), he suggested they use a different process in deriving the meaning of multi-word text units. He referred to activities associated with deriving the

meaning of text units as "text modeling" activities. Text-modeling activities are unlike word identification activities because they are subject to contextual influence and because conscious reading goals and strategies drive them. In short, Perfetti divided reading activities into word processing activities that are data-driven and not subject to conscious control, and text-modeling activities that are context sensitive and under conscious control.

THE PURPOSE OF THE PRESENT REVIEW

We had two purposes in mind. First, based on Perfetti's work, we expected to find that component skills develop such that simpler word processing skills (e.g., letter identification) become data-driven before more complex processes (e.g., semantic access). Furthermore, word-level skills (through semantic access) should become data-driven before the text-modeling skills become highly efficient. Therefore, the data should support the idea that the development of skilled reading involves components that mature in a particular order. Evidence consistent with this expectation would be present if component-processing skills matured at different developmental points with lower-level skills maturing before higher-level skills. Thus, we review research evaluating the validity of this prediction from component processing theories.

Our second purpose is concerned with a practical implication of component processing theory. Several researchers have noted that information about component-processing performance has diagnostic potential (e.g., Levy and Hinchley, 1990; Royer and Sinatra, 1994; Sinatra and Royer, 1993). Specifically, assessments of component functioning could identify underdeveloped components that could then be remediated through educational interventions. However, in order for reading diagnosticians to make use of information about component processing proficiency, they will need normative data for students at different ages and levels of development. So, our second purpose is to summarize research on reader's performance on component processing tasks at different grade levels.

DESCRIPTIVE OF REVIEW

The review began with an exhaustive search through the PsychAbstracts and ERIC databases for all articles, published from 1972 through the present, that included response time measures of cognitive processing. After reviewing the abstracts, approximately 175 articles that included data from language tasks were read. Initially, 90 studies were considered relevant

for the review. There were three criteria for inclusion: (a) the subjects were classified by grade-level; (b) the response time data were presented by tasks, grade level and/or ability level; and (c) the tasks were clearly related to reading. After further analysis of the 90 studies, 38 were found to be inappropriate either because the tasks were not clearly related to reading or because the subjects were college students and the findings did not add to the review. Therefore the data presented here were culled from 52 articles.

We review studies that examined readers' speed and accuracy on selected reading activities that have been suggested as indices of component-reading skills. We focus on the amount of time it takes subjects to perform reading activities. Response time is highlighted because it provides an index of reading skill maturation. We assumed that a skill is mature when advancing age and continuing practice no longer improve response time.

Because we focus on the development of component-processing skills, the bulk of studies we review utilize children as subjects. Of particular interest are variances in response-time (RT) performance on component-processing tasks as a function of grade level. The components that we examined involve the following processes: single-letter perception, multi-letter unit identification, word and pseudoword identification, semantic access/concept activation; phrase and sentence comprehension, and text comprehension. We chose these components because they sample reading performance over a range of task complexity from very simple to reasonably complex reading activities.

The data for each of the components are summarized in two ways. First the data are organized in tables by task and grade level. We then describe the trends suggested by the tables. We decided to exclude college-level data from the tables because of length considerations; however, we will describe some of the college data in the text.

CAVEATS

There are two major problems with compiling and summarizing reaction-time data across studies. First, researchers have utilized different tasks to measure a given component, and it is often not obvious how to compare different tasks. We decided to examine the data in the two different ways described in the previous section. By first summarizing the data in terms of trends found with specific tasks and then looking at the data by collapsing over tasks, it should be apparent where trends are robust.

A second problem concerns the possibility that tasks that are essentially the same vary in terms of measurement precision. The clearest example of this is found when comparing studies that measure naming time

and oral reading. In both cases the amount of time to say a stimulus is measured, but naming times for letter and words are consistently shorter than are oral reading tasks involving the same types of words. Notably, naming and oral reading tasks are contrasted with tasks that measure vocalization latency because the latter measures the amount of time before the onset of vocalization. Vocalization latencies should be shorter than measures that are based on time to produce the name of a stimulus.

The best explanation for the difference between the naming and oral reading times is that these tasks are measured somewhat differently. For the purposes of the present review, it seemed reasonable to differentiate between oral reading and naming time because the differences in average RT were so apparent and because they were conveniently labeled differently. Other situations where similar tasks vary in terms of measurement precision are not apparent, but it seems likely that they exist and that they may cloud the appearance of trends.

THE RESPONSE TIME DATA

Single-Letter Processing

Letter-Matching Tasks. We first describe the data showing reaction-times for single-letter processing tasks that are presented in Table I. Doe-hring (1976) found that matching a visually presented letter to one that was just heard takes over 2 second until the first grade. A 400 millisecond (msec) drop in time required to perform the task was observed during the first grade and a somewhat smaller reduction in response time from year to year as students got older.

The next task involved matching two visually presented letters. Doe-hring (1976) found that children in kindergarten took over 3 seconds to make these judgments. By the first grade, the average RT dropped by 800 msec, and it dropped by 600 msec during the first grade. Considerably smaller (100 to 200 msec) drops were observed consistently until the sixth grade where, except for minor variation, performance appeared to level off.

Mackworth and Mackworth (1974), who also compared good and poor readers on the matching task, found similar trends. Mackworth and Mackworth found one second decreases for both good and poor readers from the first to second grade, and then smaller decreases until the fifth grade. They additionally found that differences between good and poor readers were around 300 msec in grades 1 and 2, around 200 msec in grades 3 and 4, and approximately 400 msec in grades 5 and 6. However, the poor readers in the sixth grade were faster than the good readers.

Table I. Single Letter Processing Times as Function of Task, Grade and Ability Level, and Time

Task	Grade	Ability	Time	MSEC	Reference
aud-vis match	0	avg		2400	Doehring, 1976
aud-vis match	0.5	avg		2300	"
aud-vis match	1.0	avg		2100	"
aud-vis match	1.5	avg		1700	"
aud-vis match	2.0	avg		1700	"
aud-vis match	2.5	avg		1700	"
aud-vis match	3	avg		1600	"
aud-vis match	4	avg		1600	"
aud-vis match	5	avg		1600	"
aud-vis match	6	avg		1400	"
aud-vis match	8	avg		1400	"
aud-vis match	9	avg		1200	"
aud-vis match	10	avg		1100	"
aud-vis match	11	avg		1500	"
match	0	avg		3400	"
match	0.5	avg		3500	"
match	1.0	avg		2800	"
match	1.5	avg		2200	"
match	1.5	avg		1900	"
match	2.0	avg		2200	"
match	2.5	avg		1900	"
match	3	avg		2000	"
match	4	avg		1800	"
match	5	avg		1700	"
match	6	avg		1500	"
match	7	avg		1400	"
match	8	avg		1500	"
match	9	avg		1300	"
match	10	avg		1300	"
match	11	avg		1600	"
match	1	good		3910	Mackworth and Mackworth, 1974
match	1	poor		4210	"
match	2	good		2930	"
match	2	poor		3280	"
match	3	good		2710	"
match	3	poor		2920	"
match	4	good		2360	"
match	4	poor		2530	"
match	5	good		1790	"
match	5	poor		2210	"
match	6	good		1780	"
match	6	poor		1320	"
match	2	avg	1	1106	Sinatra and Royer
match	2	avg	2	1052	"
match	3	avg	1	1049	"
match	3	avg	2	909	"
match	4	avg	1	867	"

Table I. Continued

Task	Grade	Ability	Time	MSEC	Reference
match	4	avg	2	869	"
naming	1	good		775	Stanovich, 1981
naming	1	poor		774	"
naming	3	good		576	Stanovich <i>et al.</i> , 1986
naming	3	poor		581	"
naming	5	good		497	"
naming	5	poor		518	"
oral read	2	avg		720	Biemiller, 1977-1978
oral read	3	avg		640	"
oral read	4	avg		580	"
oral read	5	avg		530	"
oral read	6	avg		490	"
oral read	0.5	avg		1700	Doehring, 1976
oral read	0.5	avg		2200	"
oral read	1.0	avg		1500	"
oral read	1.0	avg		1800	"
oral read	1.5	avg		900	"
oral read	1.5	avg		1000	"
oral read	2.0	avg		900	"
oral read	2.0	avg		1000	"
oral read	2.5	avg		700	"
oral read	2.5	avg		800	"
oral read	3	avg		700	"
oral read	3	avg		800	"
oral read	4	avg		600	"
oral read	4	avg		700	"
oral read	5	avg		500	"
oral read	5	avg		600	"
oral read	6	avg		400	"
oral read	6	avg		500	"
oral read	7	avg		500	"
oral read	7	avg		600	"
oral read	8	avg		400	"
oral read	8	avg		500	"
oral read	9	avg		400	"
oral read	9	avg		400	"
oral read	10	avg		300	"
oral read	10	avg		300	"
oral read	11	avg		300	"
oral read	11	avg		400	"

Sinatra and Royer (1993) also provided data that show a developmental trend for increasing letter matching speed with increasing grade level. They found decreases in RTs from second to third and from third to fourth grades. Sinatra and Royer (1993) also tested their subjects on

two occasions, approximately one year apart. Students in grades 2 and 3 showed decreases in response times on the second testing occasion, whereas students in grade 4 remained nearly the same.

Several researchers looked at letter matching Rt for college students (Sloboda, 1976; Sloboda, 1977; Jackson and McClelland, 1979; Mason, 1982). These researchers typically examined whether variations in some aspects of the letter stimuli resulted in variations in RT. The RTs observed in these studies were typically much shorter (easily by 500 msec) than those observed with children, even at the high school level. Although there may be differences due to measurement and task factors, it seems fair to say that college level students are typically able to match letters within 50 msec.

It is important to note that Jackson and McClelland (1979) found significant differences in letter-processing time between fast and average college students. They compared the two groups of college readers on a visual-matching task and on a name-matching task. They found a relatively small difference on the physical-identity task and a 100 msec difference on the name-matching task. They argued that differences in speed of access to information stored in long-term memory were what differentiated skilled and less-skilled college readers.

Naming and Oral Reading Tasks. Several researchers looked at the time required to read aloud a single letter. Stanovich, Nathan, and Vala-Rossi (1986) collected naming times for good and poor readers in the first, third, and fifth grades. They found that from the first grade to the third the RTs decreased for both good and poor readers by nearly 200 msec, but from the third to fifth the decrease was less than 100 msec for both groups. The differences between the good and poor readers were not significant at any of the ages.

Biemiller (1977-1978) looked at oral reading time for grades 2-6 and found consistent decreases in average RT. However, each difference between grade level was less than 100 msec, and each subsequent difference was less than the previous difference.

Doehring's data also supported this trend because he found consistent decreases in RT with increasing grade levels, with the decreases remaining at around 100 msec after grade 2. Doehring found the largest decrease in oral reading time during the first grade (i.e., from the beginning of first grade to the second half of the year).

Doehring also looked at the differences in reading times for upper- and lower-case letters. He found a 500 msec difference in kindergarten and a 300 msec difference at the beginning of the first grade. In both cases children were faster reading upper-case letters. By the second half of the first grade the difference was reduced to 100 msec and remained at 100 msec until it disappeared in the tenth grade.

Summary of Single-Letter Processing Data. Several conclusions can be drawn from the single-letter processing data. First, it seems that the largest increases in speed for letter processing occur in the first grade. Because formal reading instruction usually begins in the first grade, this finding makes sense as a possible consequence of increased exposure to reading-related tasks. A second conclusion is that decreases in letter-processing speed typically taper off by grade 5 or 6, but appear again when college students are compared. It seems likely that the asymptote for single-letter processing occurs at around grade 5 or 6. A possible explanation for the decreases typically seen at the college level has to do with the selective nature of the college population. Whereas the data from school-age children are potentially from the whole population of school-age child, the data from college students is from a selection of above-average readers.

Processing Multi-Letter Units

We reviewed several studies that examined reaction time performance on tasks that involved multi-letter, nonword units. These data are shown in Table II. Doehring (1976) examined reaction times on six tasks involving syllables. On a visual matching task, mean latencies decreased with increasing age through the seventh grade. The largest decreases occurred in the second grade from the first to second half, and then from the second to third grade. In both cases the RTs decreased by 400 msec. After the fifth grade, the RTs remained at approximately 1500 msec through to the eleventh grade.

Doehring (1976) used four tasks involving matching auditorily presented syllables to visually presented syllables. The data for all four tasks followed similar trends, and those trends were consistent with the trends found with the visual-matching tasks. Consistent decreases were seen through grade seven, but the largest decreases in latency (around 450 msec) were found from the first half of grade 2 to the second half.

Doehring (1976) also looked at oral reading times for pronounceable syllables. Again, the largest decrease occurred during the second grade. The mean latency decreased 1 second by the second half of the second grade to 1500 msec. Consistent decreases were observed through the sixth grade.

Frederiksen, Warren, and Rosebery (1985) utilized a search task. They trained five high school students, who were problem readers, to search rapidly through words for targeted orthographic units (some of the units were not syllables). They found a 100 msec decrease in mean search time following training.

Table II. Multi-Letter Processing Times as Function of Task, Grade, Ability Level, and Time

Task	Grade	Ability	Time	MSEC	Reference
match	1.5	avg		3300	Doehring, 1976
match	2	avg		3200	"
match	2.5	avg		2800	"
match	3	avg		2400	"
match	4	avg		2100	"
match	5	avg		1800	"
match	6	avg		1600	"
match	7	avg		1500	"
match	8	avg		1600	"
match	9	avg		1400	"
match	10	avg		1300	"
match	11	avg		1600	"
oral read	1.5	avg		2900	"
oral read	2.0	avg		2500	"
oral read	2.5	avg		1500	"
oral read	3	avg		1500	"
oral read	4	avg		1400	"
oral read	5	avg		1100	"
oral read	6	avg		800	"
oral read	7	avg		1200	"
oral read	8	avg		900	"
oral read	9	avg		700	"
oral read	10	avg		200	"
oral read	11	avg		700	"
search-word	12	poor	1	335	Frederiksen <i>et al.</i> , 1985a
search-word	12	poor	2	236	"

Word Level Processes

Matching and Searching Tasks. Many of the studies reviewed examined reaction time performance on tasks that involved processing words. All word-level data are shown in Table III. Doehring (1976) required subjects to match a word that they heard to one that they read (an auditory to visual match). Students in the first grade took over 2.5 seconds to match the words, but by the first half of the second grade the average reaction times decreased by approximately 300 msec. During the second grade a decrease of nearly 500 msec was observed. Not much change occurred until a 200 msec decrease was observed in the sixth grade. Another 200 msec difference was observed between grades 6 and 7 with the seventh grade students showing an average reaction time of 200 msec less than the sixth grade students. Very little change was observed after the seventh grade.

Table III. World Level Processing Times as Function of Task, Grade, Ability Level, and Time

Task	Grade	Ability	Time	MSEC	Reference
aud-vis match	1.5	avg		2600	Dochring, 1976
aud-vis match	1.5	avg		2700	"
aud-vis match	2.0	avg		2400	"
aud-vis match	2.0	avg		2200	"
aud-vis match	2.5	avg		1800	"
aud-vis match	2.5	avg		1900	"
aud-vis match	3	avg		1800	"
aud-vis match	3	avg		1700	"
aud-vis match	4	avg		1800	"
aud-vis match	4	avg		1800	"
aud-vis match	5	avg		1800	"
aud-vis match	5	avg		1700	"
aud-vis match	6	avg		1600	"
aud-vis match	6	avg		1500	"
aud-vis match	7	avg		1300	"
aud-vis match	7	avg		1400	"
aud-vis match	8	avg		1400	"
aud-vis match	8	avg		1400	"
aud-vis match	9	avg		1300	"
aud-vis match	9	avg		1300	"
aud-vis match	10	avg		1200	"
aud-vis match	10	avg		1300	"
aud-vis match	11	avg		1500	"
aud-vis match	11	avg		1500	"
match	2	avg		1873	Chabot, Petros, and McCord, 1983
match	4	avg		1338	"
match	6	avg		1083	"
match-name	2	avg		2156	"
match-name	4	avg		1482	"
match-name	6	avg		1231	"
match	1	good		3720	Mackworth and Mackworth, 1974
match	1	poor		7850	"
match	2	good		4140	"
match	2	poor		4870	"
match	3	good		3110	"
match	3	poor		4060	"
match	4	good		2300	"
match	4	poor		2750	"
match	5	good		1680	"
match	5	poor		2600	"
match	6	good		1300	"
match	6	poor		1610	"
match	1	good		7050	"
match-d	1	poor		10140	Mackworth and Mackworth, 1974
match-d	2	good		5130	"
match-d	2	poor		6230	"
match-d	3	good		4000	"
match-d	3	poor		5400	"

Table III. Continued

Task	Grade	Ability	Time	MSEC	Reference
match-d	4	good		2740	"
match-d	4	poor		3440	"
match-d	5	good		2030	"
match-d	5	poor		3460	"
match-d	6	good		1540	"
match-d	6	poor		1600	"
match-homoph	1	good		7930	Mackworth and Mackworth, 1974
match-homoph	1	poor		11350	
match-homoph	2	good		4830	"
match-homoph	2	poor		6200	"
match-homoph	3	good		4350	"
match-homoph	3	poor		5560	"
match-homoph	4	good		2680	"
match-homoph	4	poor		3040	"
match-homoph	5	good		1950	"
match-homoph	5	poor		3620	"
match-homoph	6	good		1630	"
match-homoph	6	poor		1570	"
search sent	2	avg		4000	Friedrich, <i>et al.</i> , 1979
search sent	4	avg		2950	"
naming	1	good		1008	Stanovich, 1981
naming	1	poor		1351	"
naming-rel	3	good		608	Stanovich <i>et al.</i> , 1986
naming-rel	3	poor		672	
naming-rel	5	good		463	"
naming-rel	5	poor		494	"
naming-neut	3	good		642	"
naming-neut	3	poor		763	"
naming-neut	5	good		549	"
naming-neut	5	poor		624	"
naming-pword	3	good		956	"
naming-pword	3	poor		984	"
naming-pword	5	good		696	"
naming-pword	5	poor		870	"
naming-rhyme	3	good		1050	"
naming-rhyme	3	poor		1117	"
naming-rhyme	5	good		937	"
naming-rhyme	5	poor		953	"
naming-pic	8	avg		650	Wiegel-Crump and Dennis, 1986
naming-pic	4	avg		1030	
naming-pic	6	avg		970	"
naming-rhyming	4	avg		3400	Wiegel-Crump and Dennis, 1986
naming-rhyming	6	avg		3340	
naming-rhyming	8	avg		2460	"
naming-semant	4	avg		1350	"
naming-semant	6	avg		1090	"
naming-semant	8	avg		820	"
oral read	1.5	avg		1800	Deohring, 1976
oral read	2.0	avg		1500	"

Table III. Continued

Task	Grade	Ability	Time	MSEC	Reference
oral read	2.5	avg		700	"
oral read	3	avg		800	"
oral read	4	avg		700	"
oral read	5	avg		500	"
oral read	6	avg		500	"
oral read	7	avg		500	"
oral read	8	avg		500	"
oral read	9	avg		400	"
oral read	10	avg		300	"
oral read	11	avg		400	"
oral read	2	avg		820	Biemiller, 1977-1978
oral read	3	avg		850	"
oral read	4	avg		630	"
oral read	5	avg		570	"
oral read	6	avg		460	"
oral read	3	avg		798	Schwantes, 1981
oral read	6	avg		653	"
oral read	4	good		900	Bowey, 1985
oral read	4	poor		1010	"
oral read	5	good		750	"
oral read	5	poor		870	"
read/con	1.5	avg		1300	"
read/con	2.0	avg		1000	"
read/con	2.5	avg		400	"
read/con	3	avg		400	"
read/con	4	avg		400	"
read/con	5	avg		300	"
read/con	6	avg		200	"
read/con	7	avg		300	"
read/con	8	avg		200	"
read/con	9	avg		200	"
read/con	10	avg		200	"
read/con	11	avg		200	"
read/con	2	avg		530	Biemiller, 1977-1978
read/con	3	avg		520	"
read/con	4	avg		370	"
read/con	5	avg		320	"
read/con	6	avg		240	"
read/con	3	avg		717	Schwantes, 1981
read/con	6	avg		643	"
read/con	2	avg		530	Biemiller, 1977-1978
read/con	3	avg		520	"
read/con	4	avg		370	"
read/con	5	avg		320	"
read/con	6	avg		240	"
read/con	3	avg		717	Schwantes, 1981
read/con	6	avg		643	"
read/con	4	good		490	Bowey, 1985
read/con	4	poor		680	"

Table III. Continued

Task	Grade	Ability	Time	MSEC	Reference
read/con	5	good		350	"
read/con	5	poor		530	"
voc latency	4	good		768	Hess, 1982
voc latency	4	poor		860	"
voc latency	6	good		693	"
voc latency	6	poor		825	"
voc latency	3	good		916	Perfetti and Hogaboam, 1975
voc latency	3	poor		1180	"
voc latency	5	good		949	"
voc latency	5	poor		1298	"
voc lat 1 syl	3	good		1020	Hogaboam and Perfetti, 1978
voc lat 1 syl	3	poor		1140	"
voc lat 1 syl	4	good		980	"
voc lat 1 syl	4	poor		1140	"
voc lat 1 syl	3	good		1130	"
voc lat 2 syl	3	poor		2000	"
voc lat 2 syl	4	good		1090	"
voc lat 2 syl	4	poor		1730	"
voc latency	2	avg	1	1005	Sinatra and Royer, 1993
voc latency	2	avg	1	912	"
voc latency	3	avg	1	649	"
voc latency	3	avg	2	615	"
voc latency	4	avg	1	618	"
voc latency	4	avg	2	622	"
voc latency	12	poor	1	736	Frederiksen <i>et al.</i> , 1985a
voc latency	12	poor	2	589	"
voc latency	12	poor	1	403	"
voc latency	12	poor	2	306	"
voc lat 1 syl	12	poor	1	630	Frederiksen <i>et al.</i> , 1985b
voc lat 1 syl	12	poor	2	510	"
voc lat 2syl	12	poor	1	800	"
voc lat 2 syl	12	poor	2	550	"

We reviewed several studies that examined reaction times on visual matching tasks. Chabot, Petros, and McCord, 1983 looked at the word matching reaction times for students in grades 2, 4, and 6. They found that in the second grade students on average took approximately 1.9 second. A 535 msec decrease was found by the fourth grade and another 255 msec decrease was observed in the sixth grade.

Chabot *et al.* (1983) also had their subjects match words on the basis of whether or not they had the same name. These reaction times were consistently higher than when subjects could decide on the basis of visual information alone. Also the difference between the times observed for the second and fourth grade students was greater (674 msec), whereas the dif-

ference found between the fourth and sixth grade students remained very much the same (251). This suggests that the younger subjects had more difficulty using the phonological information than did the fourth or sixth grade subjects.

Mackworth and Mackworth (1974) measured RT for visual matching. They found consistently large differences between good and poor readers throughout the six grades. In the first grade, the difference was over 4 seconds. No other difference exceeded 1 second, but several came close to a 1 second difference.

There were also consistent differences between grade levels through grade six (Mackworth and Mackworth, 1974). With the exception of the good readers across grades 1 and 2, students in the higher grades were consistently faster than students in the lower grades. For the good readers, the decreases in RT from one grade to the next start at approximately 1 second, between the second and third grade, and steadily decline in magnitude until the difference between the fifth to sixth grade is 380 msec. For the poor readers the difference between the first and second grade was nearly 3 seconds. The other decreases in RT between grade levels for the poor readers varied from 150 msec to 1310 msec; but unlike the pattern found with the good readers, the magnitudes of the differences did not decrease steadily with increasing grade levels.

Mackworth and Mackworth (1974) also looked at performance on the matching task when the stimuli were different. Differences found between the performance of good and poor readers were consistently large, with the good reader showing the shorter RTs, until the sixth grade when there was only a 60 msec difference. The difference in the first grade exceeded 3 seconds.

The differences from one grade level to the next were found consistently through grade six for both the good and poor readers (Mackworth and Mackworth, 1974). The patterns observed were also the same for the good and poor readers. In both cases students in the higher grade level were always faster and the largest differences between grade levels were found in the earlier grades.

Finally, Mackworth and Mackworth (1974) looked at RT performance for good and poor readers that matched words on the basis of the word names. They found that RTs decreased steadily from the first to sixth grades and that the poor readers were considerably slower than the good readers until the sixth grade.

Jackson and McClelland (1975) also looked at RT to match a word on the basis of the name code. Interestingly, they found that average college students were slower matching on the basis of the name code than college students who were identified as being fast readers.

In one of the studies reviewed, the amount of time to search through a sentence for a target word was measured (Friedrich, Schadler, and Juola, 1979). There was a decrease observed in RT, of over one second, when second grade performance was compared to fourth grade performance. College students were over 1.5 seconds faster than the fourth grade students. These data suggest that the amount of time it takes to identify a target word in a sentence decreases with increasing reading experience.

Naming, Oral Reading, and Vocalization Latency Tasks. A number of researchers looked at the amount of time to name or read words aloud. For example, Stanovich (1981) found that good readers in the first grade took around one second to name words, whereas poor readers were about 350 msec slower. Stanovich *et al.* (1986) looked at naming time as a function of grade level, reading ability, and the relatedness of the preceding context (related versus neutral). The good readers were consistently faster than the poor readers, and the fifth grade students were faster than the third grade students. The differences between good and poor readers were smaller given a related context, and decreased in magnitude with increasing grade level.

Stanovich *et al.* (1986) also looked at pseudoword naming time and rhyme production time for that same group of subjects. The good readers in the third grade were only 28 msec faster in naming pseudowords than were poor readers, but by the fifth grade the good readers were 174 msec faster than the poor readers. For the rhyme production task, the largest difference between good and poor readers was found in the third grade. The subjects were slowest overall with the rhyme production task.

Wiegel-Crump and Dennis (1986) looked at word naming times when subjects were provided with different types of cues: pictures; rhyming information; and semantic information. Consistent with the findings of Stanovich *et al.* (1986), subjects in grades 4, 6, and 8 were consistently slower on the rhyme production task than on the other two tasks. Additionally, across the three tasks, the youngest subjects were slowest, and RTs decreased with increasing grade level.

Several studies showed similar developmental trends looking at oral reading of single words in isolation. For example, Doehring found (1976) that subjects in the first grade and first half of the second grade took well over a second to name single words, but by the middle of the second grade students were already at only 700 msec. The next reliable decrease was observed from the fourth to fifth grade, and then again from the eighth to ninth grade. Biemiller (1979-1978) found that second grade subjects were a little faster than third grade subjects, but decreases were found for subsequent grade levels through to grade 6 and then again from the sixth grade to college. The largest difference was found between grades 3 and

4. Schwantes (1981) compared grades 3 and 6 and found that the sixth grade students were faster by 145 msec. Finally, Bowey (1985) compared good and poor readers in grades 4 and 5. The poor readers in each grade were slower than the good readers, but the larger differences were those found between the two grade levels.

The five studies just described also examined reading times for words read in context. The same basic patterns hold, the major difference found being that students at all ages are faster at reading words in context. Doe-hring again found (1976) that the larger decrease in reading time occurred during the second grade, whereas Biemiller (1979-1978) found that the largest difference was between students in grades 3 and 4. Schwantes (1981) found a sizable difference between grades 3 and 6, but the magnitude of the difference was smaller by nearly half when subjects read words in context rather than in isolation. Finally, Bowey (1985) found that the poor readers in each grade were slower than the good readers, and that the fourth grade students were slower than the sixth grade students. With word reading in context, the larger differences were now found between the two groups of good and poor readers.

Vocalization Latency Tasks. Whereas the oral reading tasks measured *total time* to articulate a word, vocalization latency tasks measured the amount of time it takes a subject to *begin vocalizing* a word. Perfetti and Hogaboam (1975) used this task to study differences between good and poor readers in grades three and five. Large response time differences were found between good and poor readers at each grade level. The poor readers were considerably slower. There was a very small difference between the good readers across grade levels with the older subjects vocalizing faster. There was virtually no difference between the poor readers across the grade levels.

Hogaboam and Perfetti (1978) looked at good and poor readers in the third and fourth grades and also compared latencies for one and two syllable words. Although the good readers were consistently faster than the poor readers at both grade levels, the differences were considerably larger with two syllable words. The observed difference with one syllable words was 160 msec for both grades three and four. With two syllable words, the third grade poor readers were 870 msec slower than the good readers, and the fourth grade poor readers were 640 msec slower than the good readers.

Hess (1982) compared good and poor readers in grades 4 and 6. Consistent with the findings of Perfetti and Hogaboam's work (Perfetti and Hogaboam, 1975; Hogaboam and Perfetti, 1978), Hess found that the larger differences in latency were due to ability differences rather than to grade level differences.

Sinatra and Royer (1993) examined vocalization latency differences between students in grades 2, 3, and 4. They found a large grade level difference between students in grades 2 and 3 with students in grade 2 showing the longest response time. They also tested their subjects on two occasions that were about a year apart. They found that students in grades 2 and 3 decreased their response times a year later, whereas students in grade four remained about the same. They found this same pattern with single-letter identification.

Frederiksen and his colleagues (Frederiksen *et al.*, 1985) examined the gains poor high-school readers made as a function of instructional interventions that targeted speeded practice of component processes in reading. They consistently found decreases in latency when their subjects were tested following the intervention. These poor readers also start out with RTs similar to those found in several of the studies with grade school students but after the intervention the RTs are more similar to those of college students.

Most of the researchers who examined vocalization latencies for words also looked at vocalization latencies for pseudowords, because latency data for pseudowords has been found to be a good predictor of reading performance (Perfetti, 1985). It is important to note that these data consistently show longer RTs than do data for words. In addition, the differences between word and pseudoword latencies are considerably more dramatic for the poor readers, as demonstrated by the Perfetti and Hogaboam (Perfetti and Hogaboam, 1975; Hogaboam and Perfetti, 1978) data. For each grade level and task, the discrepancy in RT between word and pseudoword latencies is considerably greater for poor readers than it is for good readers. This finding is important, because pseudoword vocalizing addresses a reader's facility with using knowledge of print-to-sound correspondences, and the data indicate that this is a major stumbling block for the poor reader.

Sinatra's (1989) data provide the clearest evidence for developmental trends in processing pseudowords (because her subjects at the different grade levels saw the same stimuli). Decreases in RT were observed from both grade 2 to grade 3 and from grade 3 to grade 4, but the larger decrease was found from grade 3 to grade 4. It should be noted that with real word data the larger decrease found by Sinatra and Royer (1993) was from the second to the third grade. This difference makes sense because the pseudoword vocalizing task is more difficult generally than is the word vocalizing task. It might be the case that students need the 2 years of experience with reading and working with real words (i.e., in the second and third grades) before major gains in facility with using knowledge of print-to-sound correspondences show up on the pseudoword vocalizing task.

Sinatra provided (1989) further evidence that efficient pseudoword processing develops in the third grade. She examined second and third grade performance across two test administrations. The largest decrease was observed for subjects in the third grade.

Frederiksen and his colleagues (Frederiksen *et al.*, 1985) also examined latency performance on pseudoword vocalizing tasks across two test administrations that were separated by instruction involving speeded practice. Their high-school-age subjects, like subjects in the other studies reviewed, were consistently slower at vocalizing pseudowords than at vocalizing words. The gains these poor readers made tended to be less than those made on the word vocalizing task, but consistent decreases in RT were observed across test administrations nonetheless. The observed gains brought the latency performance of these high-school level poor readers closer to the performance observed with the college students in the Rossmessl and Theios (1982) study, which is some evidence in favor of the efficacy of speeded practice of component processes in reading.

Summary of Word-Level Processing Data. Several conclusions can be suggested from the word-level processing data. It seems that speed of processing words and pseudowords really picks up in the early grades, especially grades 2 and 3. However, for poor readers the gains are much smaller, and ability differences become more important than grade-level differences. The data show a systematic and steep drop in processing time from grade 1 to grade 5, whereupon further improvements are very small with advancing age.

Semantic Access

Category Judgments About Words. The next level beyond word and pseudoword processing involves accessing and manipulating semantic information. Several groups of researchers have examined whether there is a speeded component to semantic access (e.g., Chabot, Petros, and McCord, 1983; Chabot, Zehr, Reinzo, and Petros, 1984; Jackson and McClelland, 1979; Juel, 1983; Lesgold and Curtis, 1981; and Sinatra and Royer, 1993). These data appear in Table IV and will be summarized in this section.

The task used most frequently for measuring RT for semantic access is a category judgment task that requires the subject to determine whether or not the meaning of a word or picture is consistent with a particular category. As an instance, Lesgold and Curtis (1981) asked children in grades 1 through 3 to make category judgments about words as a way of indexing progress through an individualized instructional program. They tested the two groups of subjects at different times as they progressed through the instructional program that typically took 2.5 years to complete

Table IV. Semantic Access Times as Function of Task, Grade and Ability Level, and Time

Task	Grade	Ability	Time	MSEC	Reference
cat. judge-word	1,2	avg	1	4260	Lesgold and Curtis, 1981
cat. judge-word	1,2	avg	2	3580	"
cat. judge-word	1,2	avg	3	2960	"
cat. judge-word	1,2	avg	4	2420	"
cat. judge-word	1,2	avg	5	2480	"
cat. judge-word	1,2	avg	6	2520	"
cat. judge-word	1,2,3	avg	1	3910	"
cat. judge-word	1,2,3	avg	2	3300	"
cat. judge-word	1,2,3	avg	3	2680	"
cat. judge-word	1,2,3	avg	4	2430	"
cat. judge-word	1,2,3	avg	5	2500	"
cat. judge-word	1,2,3	avg	6	2130	"
cat. judge-word	1,2,3	avg	7	2090	"
cat. judge-word	2	avg	1	2537	Sinatra and Royer, 1993
cat. judge-word	2	avg	2	2153	"
cat. judge-word	3	avg	1	1762	"
cat. judge-word	3	avg	2	1472	"
cat. judge-word	4	avg	1	1578	"
cat. judge-word	4	avg	2	1478	"
cat. judge-word-same	2	avg		2694	Chabot <i>et al.</i> , 1983
cat. judge-word-diff	2	avg		2859	"
cat. judge-word-same	4	avg		2324	"
cat. judge-word-diff	4	avg		2254	"
cat. judge-word-same	6	avg		1714	"
cat. judge-word-diff	6	avg		1858	"
cat. judge-word	2,3,5	avg		2359	"
cat. judge-word	2,3,5	good		1942	"
cat. judge-word	2,3,5	poor		2870	"
cat. judge-pic	2,3,5	avg		1985	"
cat. judge-pic	2,3,5	good		1770	"
cat. judge-pic	2,3,5	poor		2078	"
cat. judge-pic=word	2,3,5	avg		2175	"
cat. judge-pic=word	2,3,5	good		1910	"
cat. judge-pic=word	2,3,5	poor		2513	"
cat. judge-pic=word	2	avg		3000	Juel, 1983
cat. judge-pic=word	5	avg		1827	"

(Lesgold and Curtis, 1981). The first group of subjects in grades 1 and 2 was tested on six occasions and showed consistent decreases in RT through to the fourth administration.

Lesgold and Curtis (1981) tested the second group on seven occasions, and a very similar pattern of decreases was observed. Large decreases (600+ msec) occurred across the first to second and second to third administrations, and a smaller (250 msec) decrease was found on the fourth

administration. Then another decrease was observed from the sixth to the seventh administration.

Sinatra and Royer (1993) also looked at changes in RT on the category judgment task as a function of passage of time (with the assumption being that increased reading instruction and reading experience will take place during the time period between testing). They tested their subjects—who were initially in the second, third, and fourth grades—on two occasions that were approximately one year apart. They found larger differences across testing times for the two lower grades, but subjects in all of the grades were faster on the second testing occasion.

Sinatra and Royer's (1993) data also allow for comparisons between the different subjects in the different grade levels. Comparisons across grade levels showed consistently lower RTs for students in the higher grade levels.

Chabot and his colleagues (Chabot *et al.*, 1983; 1984) used the category judgment task to look at RT differences between subjects at differing grade and ability levels. In a comparison of subjects in grades 2, 4, and 6 they found that for both *same* and *different* decisions the subjects in the lower grades had the longer RTs. Chabot *et al.* also found that subjects in grades 2 and 6 were slower with *different* decisions, whereas subjects in the fourth grade were slightly faster with *same* decisions.

Another group of subjects in the Chabot *et al.* (1983) study were a mixed-grade group from grades 2, 3, and 5 who were classified according to whether they were average, good, or poor readers. The observed patterns of RTs for the category judgement task showed that good readers outperformed average readers who outperformed the poor readers. The larger difference was found between the average and poor readers (511 msec), but the difference between the good and average readers were nontrivial (417 msec).

Chabot *et al.* (1984) looked at differences in RT on the category judgment task between college students classified as good or poor readers in two experiments. Notably, Chabot *et al.* found that across all of their conditions the good college readers were faster than the poor readers on the tasks. The college readers also were consistently faster than the considerably younger subjects in the other three studies which used a category judgment task, although the poor readers at the college level were quite similar to the fifth grade students tested by Sinatra and Royer (1993).

Category Judgments About Pictures. Chabot and his colleagues (Chabot *et al.*, 1983; 1984) also looked at speed of semantic access with a task that involved judging whether the meaning of a picture was consistent with a target category. Chabot *et al.* (1983) compared the RT performance of their three ability groups from their mixed-grade level group. Although the same general pattern of RTs was found (e.g., good fastest, poor slowest) for this task, the observed differences between the different ability groups were

smaller. Also, the larger difference was found between the good and average readers. Chabot *et al.* (1984) again found that the good readers at the college level were consistently faster than their poor reader peers. Again, the good and poor college readers were consistently faster than the younger subjects in the Chabot *et al.* (1983) study.

Category Judgments About Pictures and Words. A category judgment task similar to the two just described involves judging whether a word and a picture come from the same category. Chabot *et al.* (1983) again observed the same pattern of RTs for their good, average, and poor readers. As with the word task, the difference between the average and the poor readers was the largest. Juel (1983) provided data that showed differences in RT between students in the second and fifth grades. She found that the fifth grade students were faster by more than one second. The college students tested by Chabot *et al.* again demonstrated that the good readers were faster at semantic decisions than were the poor readers. Additionally, both the good and poor college readers in the Chabot *et al.* (1984) study were faster than the younger readers in the other two studies.

Matching Word Meanings. Jackson and McClelland (1979) used a different task to look at speed of semantic access differences between fast (good) and average college readers. They measured RT to decide whether two words had the same meaning. Both the fast and average readers were faster to match when the decision was *same*. More importantly, though, the average college readers were consistently slower than their *fast* peers to make either type of semantic decision.

Summary of Semantic Access Data. The data on semantic access summarized in this section suggest several conclusions. First, the data support the conclusion that speed of access to semantic information in memory is a reliable measure for differentiating skilled from less-skilled readers. The second conclusion that grade-level and experience are related to speed of access to semantic information in memory (Chabot *et al.*, 1983; Lesgold and Curtis, 1981; Sinatra and Royer, 1993). The data clearly show that students get faster with advancement through the grade levels.

Phrase and Sentence Level Processing

Beyond the level of semantic access, the next important component of reading involves processing groups of words that are integrated into a unit of meaning such as a phrase or sentence. Researchers have looked at the time it takes subjects to process phrases and sentences using a number of tasks. These data are presented in Table V and summarized in this section.

Table V. Phrase and Sentence Level Processing Time as Function of Task, Grade and Ability Level, and Time

Task	Grade	Ability	Time	MSEC	Reference
cued sent recall	4	good		3410	Hess, 1982
cued sent recall	4	poor		5454	"
cued sent recall	6	good		3269	"
cued sent recall	6	poor		3781	"
cloze task	2	avg		12200	Doehring and Hoshko, 1977
cloze task	3	avg		4100	"
cloze task	4	avg		2800	"
cloze task	5	avg		2400	"
cloze task	6	avg		2100	"
cloze task	7	avg		2400	"
cloze task	8	avg		1800	"
cloze task	9	avg		1500	"
cloze task	10	avg		1300	"
cloze task	11	avg		1300	"
judge synt	2	avg	1	6370	Sinatra, 1989
judge synt	2	avg	2	5025	"
judge synt	3	avg	1	5310	"
judge synt	3	avg	2	3512	"
judge synt	4	avg	1	3920	"
judge synt	4	avg	2	3120	"
judge synt	5	avg	1	3358	"
judge synt	5	avg	2	2797	"
judge seman	2	avg		6390	"
judge seman	2	avg		5025	"
judge seman	3	avg		4923	"
judge seman	3	avg		3324	"
judge seman	4	avg		3904	"
judge seman	4	avg		2883	"
judge seman	4	avg		3321	"
judge seman	5	avg		2912	"
judge seman	12	poor	1	2300	Frederiksen <i>et al.</i> , 1985b
judge seman	12	poor	2	1850	"
judge seman	12	poor	3	750	"
judge seman	12	poor	4	600	"
Phrase Read					
oral read	1.5	avg		1200	Doehring, 1976
oral read	1.5	avg		1300	"
oral read	2.0	avg		1200	"
oral read	2.0	avg		1200	"
oral read	2.5	avg		500	"
oral read	2.5	avg		500	"
oral read	3	avg		600	"
oral read	3	avg		600	"
oral read	4	avg		500	"
oral read	4	avg		600	"
oral read	5	avg		400	"
oral read	5	avg		400	"
oral read	6	avg		300	"

Table V. Continued

Task	Grade	Ability	Time	MSEC	Reference
oral read	6	avg		300	"
oral read	7	avg		400	"
oral read	7	avg		500	"
oral read	8	avg		300	"
oral read	8	avg		400	"
oral read	9	avg		300	"
oral read	9	avg		300	"
oral read	10	avg		200	"
oral read	10	avg		200	"
oral read	11	avg		300	"
oral read	11	avg		300	"
scan target word	5	good		1280	Katz and Wicklund, 1971
scan target word	5	good		1410	"
scan target word	5	good		1340	"
scan target word	5	good		1220	"
scan target word	5	poor		1510	"
scan target word	5	poor		1420	"
scan target word	5	poor		1550	"
scan target word	5	poor		1620	"

Cued Recall and Cloze Tasks. Hess (1982) examined the amount of time it took good and poor readers in the fourth and sixth grades to recall sentences after presented with a cue. The good readers in the sixth grade were faster than the other three groups, but the fourth grade good readers were the next fastest. In other words, poor readers in the sixth grade were slower than good readers in the fourth grade. The poor, fourth-grade readers took approximately 2 more seconds to recall the sentences than did the good readers in the fourth grade.

Doehring and Hoshko (1977) found developmental trends for speed of responding to a cloze task. Their subjects were in grades 2 through 11. Whereas their second grade subjects took over 12 seconds to respond, by the third grade subjects were only taking approximately 4 seconds. A decrease of 1300 msec was then observed in the fourth grade. Following that decrease, the magnitudes of the decreases remained considerably under one second. Performance leveled off at the tenth grade.

Judging the Appropriateness of Targets and Sensibleness of Sentences. Sinatra (1989) examined the time it took subjects in grades 2, 3, and 4 to judge whether or not a target was a *syntactically* appropriate choice for a sentence. She tested her subjects on two occasions separated by approximately one year. She found that subjects in the third grade were about a

second faster than subjects in the second grade, and that subjects in the fourth grade were nearly 1400 msec faster than the third grade subjects. The comparisons in RT across the two test administrations also showed the largest gain in speed for subjects who were initially in the third grade (1798 msec). The subjects who were initially in the fourth grade made a more modest gain of 800 msec.

Both Sinatra (1989) and Federiksen *et al.* (1985) looked at RT to judge the *semantic* appropriateness of a target for a given sentence. Sinatra's subjects (who were the same as those in the previous task) in the third grade were nearly 1.5 seconds faster than the second grade subjects, and the fourth grade subjects were about 1 second faster than the third grade subjects. Sinatra also compared her subjects' performance across test times that were about 1 year apart. The larger decreases in RT were found with the two younger groups, but the students initially in the fourth grade did show a decrease of about 1 second.

Federiksen *et al.* (1985) also examined performance across two testing occasions and additionally looked at the effect of the probability of the target. Their subjects were poor readers at the high school level who were in an instructional intervention program that focused on speeded practice. For both high and low probability targets, subject make substantial gains across test occasions. Whereas subjects were initially taking approximately 2 seconds to perform the task, after the intervention their average performance was well under 1 second. The high school subjects were consistently faster than the considerably younger subjects in the Sinatra and Royer (1993) study.

Oral Reading. Doebling (1976) examined the oral reading rates for phrases that varied somewhat in complexity. His subjects were students in grades 1.5 through 11. The most important trend in Doebling's data has to be with the decrease in oral reading rate that occurs during the second grade. Whereas the reading rates hovered around 1.2 seconds in the second half of the first grade and in the first half of the second grade, subjects tested in the second half of the second grade were twice as fast. The data do not show any reliable decreasing trends again until the eighth grade when performance with both phrase types remains below 500 msec.

Cirilo and Foss (1980) examined how the time to read a sentence depended on the importance of the sentence and the position in the passage. Their college-level subjects took longer to read the more important sentences and longer to read the sentences that appeared earlier in the passage.

Schwanenflugel and Shoben (1983) looked at how the sentence reading times of college students were affected by whether the sentence was concrete or abstract, and whether or not the sentence was embedded within

a larger context. They found that the concrete versus abstract manipulation did not have an effect in the presence of context, but in the absence of context subjects took longer to read the abstract sentences.

We reviewed several other studies that varied aspects of sentence stimuli and then reported college student reading times (e.g., Garrod and Sanford, 1977; Haberlandt and Haith, 1978, Wisher, 1976). For the purposes of the present review, it is not important to discuss the intricacies of each of those studies. Instead, we note that those studies show that sentence reading times do vary at the college level as a function of both structure and meaning.

Matching and Scanning Tasks. Freedman and Forster (1985) looked at time to match sentences that were either identical or varied by one word. The sentences were also either grammatically correct or incorrect. They found that the college students took longer to match sentences that were ungrammatical than to match sentences that were grammatically correct.

Katz and Wicklund (1971) examined differences between good and poor readers in the fifth grade scanning sentences of either two or three words for target words. Although the poor readers were consistently slower than the good readers, both groups took longer to scan the 3 word sentences and were longer to respond *no*.

Summary of Phrase and Sentence Processing Data. Several conclusions can be drawn from the data presented in this section. First, the most important finding seems to be that processing sentences varies as a function of many factors that remain important through college. Another critical finding is that experience facilitates the speed of processing sentences (e.g., Frederiksen *et al.*, 1985; Sinatra and Royer, 1993). Finally, it seems that large gains in speed are made in the second grade (Doehring, 1976; Doehring and Hoshko, 1977; Sinatra and Royer, 1993).

Text-Level Processing

The final set of tasks reviewed involved text-level processing. Text was defined as units of discourse that contained multiple sentences. There were several studies reviewed that examined speed of processing text. The data from these studies are summarized in this section and in Table VI.

Words-Per-Minute Data. Although the data reviewed thus far has been RT data measured in milliseconds or seconds, one common way of looking at speed of processing text is in terms of words-per-minute (WPM). With

Table VI. Text Level Processing Times as Function of Task, Grade and Ability Level, and Time

Task	Grade	Ability	WPM/MSEC	Time	Reference
read familiar text	1,2,3	avg	34	1	Lesgold and Curtis, 1981
read familiar text	1,2,3	avg	56	2	"
read familiar text	1,2,3	avg	73	3	"
read familiar text	1,2,3	avg	92	4	"
read familiar text	1,2,3	avg	75	5	"
read familiar text	1,2,3	avg	96	6	"
read familiar text	1,2,3	avg	97	7	"
read familiar text	1,2	avg	32	1	"
read familiar text	1,2	avg	65	2	"
read familiar text	1,2	avg	84	3	"
read familiar text	1,2	avg	104	4	"
read familiar text	1,2	avg	84	5	"
read familiar text	1,2	avg	111	6	"
read harder text	1,2	avg	30	1	"
read harder text	1,2	avg	43	2	"
read harder text	1,2	avg	62	3	"
read harder text	1,2	avg	60	4	"
read harder text	1,2	avg	81	5	"
read harder text	1,2	avg	89	6	"
read unfam text	1,2	avg	24	1	"
read unfam text	1,2	avg	27	2	"
read unfam text	1,2	avg	48	3	"
read unfam text	1,2	avg	49	4	"
read unfam text	1,2	avg	56	5	"
read unfam text	1,2	avg	53	6	"
read unfam text	1,2	avg	76	7	"
read unfam text	1,2	avg	29	1	"
read unfam text	1,2	avg	27	2	"
read unfam text	1,2	avg	54	3	"
read unfam text	1,2	avg	66	4	"
read unfam text	1,2	avg	65	5	"
read unfam text	1,2	avg	65	6	"
read coherent para	1	good	72400	1	Stanovich <i>et al.</i> , 1984
read coherent para	1	good	39100	2	"
read coherent para	1	poor	86100	1	"
read coherent para	1	poor	54400	2	"
read random para	1	good	86500	1	"
read random para	1	good	71400	2	"
read random para	1	poor	90000	1	"
read random para	1	poor	89400	2	"
reading-text	4	good	39300		Hess, 1982
reading-text	4	poor	68300		"
reading-text	6	good	35600		"
reading-text	6	poor	52600		"

WPM data, the larger measures indicate greater speed. Lesgold and Curtis (1981) measured WPM for first and second graders who were tested as they advanced through an instructional program for reading. Lesgold and Curtis (1981) measured time across six or seven occasions to read passages that varied in familiarity and difficulty. With familiar text, both the groups (i.e., those tested on seven and those tested on six occasions) went from approximately 33 WPM to approximately 100 WPM. With the unfamiliar text, both groups started out and ended with lower WPM scores. In other words, these young readers remained faster at reading familiar text as they progressed through their reading instruction, but steady increases were noted with both types of text. One group (the one tested on six occasions) also was timed reading text at a difficulty level greater than that of the familiar and unfamiliar text. The gains in reading speed were fairly consistent with only one period of no gain and a modest gain found from the fifth to sixth administration.

Stanovich, Cunningham, and Freeman (1984) examined the reading times (in msec) of good and poor first grade students in the Fall and in the Spring. They additionally looked at the effects of passage coherency (coherent versus random) on reading times. They found that the good readers were consistently faster at reading the paragraphs than were the poor readers. With the coherent text, both the good and poor readers made significant gains in reading speed from the Fall to Spring test administrations. With the random text, both groups were slower than with the coherent text, and both groups made much smaller gains in reading speed from the Fall to Spring.

Hess (1982) looked at passage reading time for fourth and sixth grade good and poor readers. The poor readers at both grade levels were considerably slower than their good reader peers, and the sixth grade students were faster than the fourth grade in both ability groups. The difference in reading times between the two ability groups was greater in the fourth grade.

Kintsch and Monk (1972) measured college students' inference and reading times based on simple or complex paragraphs. They found that subjects took longer to read the more complex text, but that time to make an inference was slightly shorter when it was based on the complex text.

Summary of Text Processing Data. There are several conclusions that can be made from the text processing data. The most obvious conclusion seems to be that speed of processing text increases with school experience. Another conclusion is that text reading speed is affected by such factors as familiarity, difficulty, and coherency. The Kintsch and Monk (1972) study suggests that these variables remain important determinants of text processing ability up through the college level.

DISCUSSION

In the introduction to this article we noted that component-processing theories assumed that component reading skills mature, to some extent, from the bottom up. That is, the theories suggest that a skill like letter recognition must become largely data-driven before word recognition can reach maximum efficiency. Likewise, the theories suggest that a reader must be highly proficient at word identification before fast and efficient semantic activation can occur. Whereas Perfetti's theory does not assume that the text-modeling components will become data-driven processes, the idea that these components will be limited in their efficiency until the lower-level processes become data-driven is consistent with the theory.

The predictions from component-processing theories are generally supported by the data summarized from the tables. For instance, if we look at the letter and word data by averaging over tasks and study, we see that a grade 1 student processes a letter in about 3.3 seconds, whereas a grade 1 student processes a word in about 4.6 seconds. By grade 3, students are processing letters in about 1.6 seconds and words in about 2.5 seconds. Interestingly enough, by grade 6 there is no longer a difference in the speed with which a student processes a single letter and a word consisting of multiple letters, accomplishing both in around a second. As an aside, the fact that readers can process a word as fast as a letter is probably attributable to the same processes that underlie the "word superiority effect" (e.g., Reicher, 1969; Wheeler, 1970). The essence of the word superiority effect is that letters experienced as part of a word are processed faster than are letters presented in nonword strings. The effect has been interpreted as indicating that frequently encountered words come to be processed as a unit rather than as individual elements. However, the fact that some words are *ultimately* processed as fast as letters does not discredit the idea that letter processing proficiency must develop first. As the data in the article suggest, considerable letter processing competency must develop before comparable competence at word processing is possible.

Whereas the results presented in this article are consistent with predictions from component-processing theories, there is an important limitation to their interpretation. Unfortunately, there is a confound between the component-process level and the stimulus complexity. That is, words are more complex than letters and sentences more complex than words. Thus, the growth of competence in the various tasks could be attributable to stimulus complexity rather than to aspects of the cognitive system responsible for skilled reading. However, it also makes sense to think of a simple process as one that involves simple stimuli. In other words, evidence that we master processing simpler stimuli before more complex stimuli is still

evidence in favor of component-processing theories. It is just that these theories may not be confined to language-related processing. However, that is an empirical question for other researchers.

The second purpose of our review was to provide indices of normative performance that could be used in diagnosing reading difficulties. Researchers interested in examining component-processing theory as an approach to reading diagnostics can examine the summaries of data presented in our tables and get a sense of how long it takes reader of varying ages to perform specific reading tasks. Moreover, many of our tables indicate how long it takes good and poor readers of the same age to perform reading tasks. These data can then be compared to the data obtained from a particular reader, and a determination can be made as to whether the readers seem to be lagging behind in the development of one or more skill. Having identified skills that are deficient relative to normative performance, the researcher can then target instructional activities at the deficient skills in an attempt to improve reading performance. Success in these activities would be of considerable value to reading specialists working with children who are having difficulties in learning to read, and it would provide support for the validity of component processing theory as a description of the way skilled reading develops.

REFERENCES

- Biemiller, A. (1977-1978). Relationship between oral reading rates for letters, words, and simple text in the development of reading achievement. *Reading Res. Quart.* 13: 223-253.
- Bowey, J. A. (1985). Contextual facilitation in children's oral reading in relation to grade and decoding skill. *J. Exp. Child Psychol.* 40: 23-48.
- Carr, T. (1981). Building theories of reading ability: On the relation between individual differences in cognitive skills and reading comprehension. *Cognition* 9: 73-113.
- Carr, T. H., and Levy, B. A. (1990) (eds.). *Reading and Its Development: Component Skills Approaches*, Academic Press, San Diego, CA.
- Chabot, R. J., Petros, T. V., and McCord, G. (1983). Developmental and reading ability differences in accessing information from semantic memory. *J. Exp. Child Psychol.* 35: 128-142.
- Chabot, R. J., Zehr, H. D., Reinzo, O. V., and Petros, T. V. (1984). The speed of word recognition subprocesses and reading achievement in college students. *Reading Res. Quart.* 19(2): 147-161.
- Cirilo, R. K., and Foss, D. J. (1980). Text structure and reading time for sentences. *J. Verbal Learning Verbal Behav.* 19: 96-109.
- Curtis, M. E. (1980). Development of components of reading skill. *J. Educ. Psychol.* 72(2): 656-669.
- Doehring, D. G. (1976). Acquisition of rapid reading responses. *Monogr. Soc. Res. Child Dev.* 41(2, Serial No. 165).
- Doehring, D. G., and Hoshko, I. M. (1977). A developmental study of the speed of comprehension of printed sentences. *Bull. Psychonomic Soc.* 9(4): 311-313.
- Frederiksen, J. R., Warren, B. M., and Rosebery, A. S. (1985a). A componential approach to training reading skills: Part 1. Perceptual units training. *Cognit. Instr.* 2(2): 91-130.

- Frederiksen, J. R., Warren, B. M., and Rosebery, A. S. (1985b). A componential approach to training reading skills: Part 2. Decoding and use of context. *Cognit. Instr.* 2(3 & 4): 271-338.
- Freedman, S. E., and Forster, K. I. (1985). The psychological status of overgenerated sentences. *Cognition* 19: 101-131.
- Friederich, F. J., Schadler, M., and Juola, J. F. (1979). Developmental changes in units of processing in reading. *J. Exp. Child. Psychol.* 28: 344-358.
- Garrod, S., and Sanford, A. (1977). Interpreting anaphoric relations: The integration of semantic information while reading. *J. Verbal Learning Verbal Behav.* 16: 77-90.
- Gough, P. B. (1972). One second of reading. In Kvananaugh, J. F., and Mattingly, I. G. (eds.), *Language by Eye and Ear*, MIT Press, Cambridge, MA.
- Graesser, A. C., Hoffman, N. L., and Clark, L. F. (1980). Structural components of reading time. *J. Verbal Learning Verbal Behav.* 19: 135-151.
- Haberlandt, R. E., and Hatih, M. M. (1978). Verbs contribute to the coherence of brief narratives: Reading related and unrelated sentence triples. *J. Verbal Learning Verbal Behav.* 17: 419-425.
- Hess, A. M. (1982). An analysis of the cognitive processes underlying problems in reading comprehension. *J. Reading Behav.* 14(3): 313-333.
- Hogaboam, T. W., and Perfetti, C. A. (1978). Reading skill and the role of verbal experience in decoding. *J. Educ. Psychol.* 70(5): 717-729.
- Hunt, E. (1980). The foundations of verbal comprehension. In Snow, R. E., Federico, and Montague, W. E. (eds.), *Aptitude, Learning, and Instruction: Vol. 1. Cognitive Process and Analyses of Aptitude*, Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 87-104.
- Hunt, E., Lunneborg, C., and Lewis, J. (1975). What does it mean to be high verbal? *Cognit. Psychol.* 7: 194-227.
- Jackson, M. D. (1980). Further evidence for a relationship between memory access and reading ability. *J. Verbal Learning Verbal Behav.* 19: 683-694.
- Jackson, M. D., and McClelland, J. L. (1979). Processing determinants of reading speed. *J. Exp. Psychol.: General* 108: 151-181.
- Juel, C. (1983). The development and use of mediated word identification. *Reading Res. Quart.* 18(3): 306-327.
- Katz, L., and Wicklund, D. A. (1971). Word scanning rate for good and poor readers. *J. Educ. Psychol.* 62(2): 138-140.
- Kintsch, W., and Monk, D. (1972). Storage of complex information in memory: Some implications of the speed with which inferences can be made. *J. Exp. Psychol.* 94(1): 25-32.
- LaBerge, D., and Samuels, S. J. (1974). Toward a theory of automatic information processing in reading. *Cognit. Psychol.* 6: 293-332.
- Lesgold, A. M., and Curtis, M. E. (1981). Learning to read words efficiently. In Lesgold, A. M., and Perfetti, C. A. (eds.), *Interactive Processes in Reading*, Erlbaum, Hillsdale, NJ, pp. 329-360.
- Levy, B. A., and Hinchley, J. (1990). Individual and developmental differences in the acquisition of reading skills. In T. H., Carr, and Levy, B. A., *Reading and Its Development: Component Skills Approaches*, Academic Press, San Diego, CA, pp. 81-128.
- Mackworth, J. F., and Mackworth, N. H. (1974). How children read: Matching by sight and sound. *J. Reading Behav.* 6(3): 295-303.
- Mason, M. (1975). Reading ability and letter search time: Effects of orthographic structure defined by single-letter positional frequency. *J. Exp. Psychol.: General* 104: 146-166.
- Mason, M. (1982). More about the letter-frequency effect. *Percept. Psychophys.* 31(6): 589-590.
- Perfetti, C. A. (1983). Individual differences in verbal processes. In Dillon, R. F., and Schmeck, R. R. (eds.), *Individual Differences in Cognition* (Vol. 1), Academic Press, New York, pp. 65-104.
- Perfetti, C. A. (1985). *Reading Ability*, Oxford University Press, New York.
- Perfetti, C. A. (1988). Verbal efficiency in reading ability. In Daneman, M., Mackinnon, G. E., and Waller, T. G. (eds.), *Reading Research: Advances in Theory and Practice* (Vol. 6), Academic Press, New York, pp. 109-143.

- Perfetti, C. A. (1992). The representation problem in reading acquisition. In Gough, P., Ehri, L., and Treiman, R. (eds.), *Reading Acquisition*, Erlbaum, Hillsdale, NJ.
- Perfetti, C. A., and Hogaboam, T. (1975). Relationship between single word decoding and reading comprehension skill. *J. Educ. Psychol.* 67(4): 461-469.
- Reicher, G. (1969). Perceptual recognition as a function of meaningfulness of stimulus materials. *J. Exp. Psychol.* 81: 275-280.
- Rossmessl, P. G., and Theios, J. (1982). Identification and pronunciation effects in a verbal reaction time task for words, pseudowords, and letters. *Mem. Cognit.* 10(5): 443-450.
- Royer, J. M., and Sinatra, G. M. (1994). A cognitive theoretical approach to reading diagnostics. *Educ. Psychol. Rev.* 6: 81-113.
- Schwanenflugel, P. J., and Schoben, E. J. (1983). Differential context effects in the comprehension of abstract and concrete verbal materials. *J. Exp. Psychol.: Learning, Mem. Cognit.* 9(1): 82-102.
- Shwantes, F. M. (1981a). Effect of story context on children's ongoing word recognition. *J. Reading Behav.* 13(4): 305-311.
- Shwantes, F. M. (1981b). Locus of the context effects in children's word recognition. *Child Dev.* 52: 895-903.
- Schwantes, F. M. (1983). Relationship between context effects and mode of lexical access during word recognition. *Reading Res. Quart.* 18(3): 295-305.
- Sinatra, G. M. (1989). Design and Initial Validation of a Computer-Administered System for the Assessment of Reading Competencies. Unpublished doctoral dissertation, University of Massachusetts, Amherst.
- Sinatra, G. M., and Royer, J. M. (1993). The development of cognitive component processing skills that support skilled reading. *J. Educ. Psychol.* 85: 509-519.
- Sloboda, J. A. (1976). Decision times for word and letter search: A wholistic word identification model examined. *J. Verbal Learning Verbal Behav.* 15(1): 93-101.
- Sloboda, J. A. (1977). The locus of the word-priority effect in a target-detection task. *Mem. Cognit.* 5(3): 371-376.
- Stanovich, K. E. (1981). Relationships between word decoding speed, general name-retrieval ability, and reading progress in first-grade children. *J. Educ. Psychol.* 73(6): 809-815.
- Stanovich, K. E. (1990). Concepts in developmental theories of reading skill: Cognitive resources, automaticity, and modularity. *Dev. Rev.* 10: 72-100.
- Stanovich, K. E., Cunningham, A. E., and Freeman, D. J. (1984). Relation between early reading acquisition and word decoding with and without context: A longitudinal study of first-grade children. *J. Educ. Psychol.* 76(4): 668-677.
- Stanovich, K. E., Nathan, R.G., and Vala-Rossi, M. (1986). Developmental changes in the cognitive correlates of reading ability and the developmental lag hypothesis. *Reading Res. Quart.* 21(3): 267-283.
- Wheeler, D. D. (1970). Processes in word recognition. *Cognit. Psychol.* 1: 59-85.
- Wiegel-Crump, C. A., and Dennis, M. (1986). The effects of syntactic expectations during reading. *J. Educ. Psychol.* 68(5): 597-602.

Copyright of Educational Psychology Review is the property of Kluwer Academic Publishing and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.