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The Connection Between Reaction Time and Variation in Reading Ability: Unravelling Covariance Relationships With Cognitive Ability and Phonological Sensitivity

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Eighty-one adult participants varying in reading ability completed two choice reaction time (RT) tasks (one auditory and one visual) in conjunction with measures of phonological awareness, general cognitive ability, and word recognition ability. Replicating previous work, a significant correlation between RT and reading ability was obtained. However, several different methods of examining overlapping variance (hierarchical regression, path analysis, commonality analysis) indicated that the zero-order correlation between RT and word recognition ability was largely due to variance shared with phonological awareness and general cognitive ability. RT explained little variance in reading ability after phonological sensitivity had been partialed out and almost no unique variance after phonological sensitivity and general cognitive ability had been partialed out. In addition, the overlap in the variance of RT and phonological processing was almost entirely due to variance shared with intelligence.

There is presently an almost unprecedented consensus in the reading research literature that phonological-processing abilities are crucially related to reading acquisition (e.g., Brady & Shankweiler, 1991; Bruck, 1992; Goswami & Bryant, 1990; Gough, Ehri, & Treiman, 1992; Rack, Hulme, Snowling, & Wightman, 1994; Share, 1995; Share & Stanovich, 1995; Siegel, 1993; Stanovich, 1986b, 1988,

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1992). Recent research has built on this consensus by trying to elaborate on it and extend beyond it. One trend has been an increase in the intensity of the search for what might be termed “extraphonological” sources of variance in reading ability. There are two competing hypotheses about these nonphonological sources of variance: (a) that certain nonphonological processes might be able to explain variance in reading ability that phonological processing cannot, and (b) that these nonphonological processes, although not independent predictors, are causally prior to phonological processes because the former are more basic.

Each of these two hypotheses about the role of extraphonological processes in reading ability leads to predictions about patterns of individual differences. The prediction that follows from the first hypothesis is that individual differences in the extraphonological process should predict variance in reading ability after variance in phonological processing has been partialed out. The prediction that follows from the second hypothesis is more complex: If a certain nonphonological process is causally prior to phonological processing, then it will not predict variance in reading independent of phonological processing. Being a more distal cause, such an extraphonological process will have its reading-related variance masked by phonological processing. However, as a more distal cause than phonological processing, it still must demonstrate the same psychometric characteristics that make phonological processing such an attractive candidate as an explanation of variation in reading ability.

One of the most important of these psychometric characteristics has been termed the *assumption of specificity* (Stanovich, 1986a, 1986b)—an assumption that follows from the empirical fact that reading disability occurs across the continuum of general intelligence. The mechanism causing variation in reading ability must be at least somewhat domain-specific on this view (see Fodor, 1983). This is because the effects of the mechanism(s) causing reading disability must not extend too far into other domains of cognitive functioning, or else reading difficulty would be more strongly associated with intelligence than it actually is (and it would be impossible for reading difficulty to occur in the presence of high intelligence).

Phonological processing is an attractive theoretical candidate precisely because it is not so strongly associated with general cognitive ability that it could not serve as an independent predictor of reading ability variation (i.e., as a predictor of reading ability after general cognitive ability has been accounted for; see Stanovich, 1992). For this discussion, the important point to note is that any more distal cause of phonological-processing difficulties must in turn satisfy the assumption of specificity. That is, the variance overlap between the extraphonological source and phonological processing must not be coextensive with general intelligence or else, again, the extraphonological source as a distal cause of phonological-processing difficulties would fail the assumption of specificity. Thus, it is necessary to examine the variance overlap with general intelligence when examining Hypothesis 2 (that a nonphonological process is causally prior to phonological processes).

In this investigation, we examine an extraphonological source of variation in reading ability that has been suggested in a study by Nicolson and Fawcett (1994). Their study is interesting because the extraphonological source of variance which they identified is seemingly so basic—variance in choice reaction time (RT). In their study, participants heard a tone to which they responded as quickly as possible with a key press (simple RT). When the RTs of the participants with reading disabilities were compared to those of chronological age controls, no difference was found. In a second RT task, the participants heard two tones—one high pitched, the other low—and were instructed to press the key only in reaction to one of them (selective choice RT). Here, reading difficulty was significantly associated with RT. Nicolson and Fawcett (1994) opted for Hypothesis 1 listed previously—that a nonphonological deficit in classification speed independently contributes to reading difficulties. Our work here was inspired by their finding, although our sample was different from theirs (see following discussion).

Specifically, we sought to examine whether RT was an independent (of phonological variance) predictor of reading ability in a sample of adults and whether any overlapping or nonoverlapping variance was additionally independent of general cognitive ability. In short, we sought to examine Hypotheses 1 and 2 using stimulus classification speed as the potential nonphonological source of processing variance. To increase the variance in our sample, we oversampled poorer readers for the investigation. The statistical analyses were structured to isolate the issues previously outlined. First, we examined whether RT explains variance in word recognition skill that phonological processing does not. If it does explain extra variance, then this can be viewed as support for Hypothesis 1 (that this extraphonological process isolates a separate locus of reading variation from phonological processing). Next, we examined whether any overlap in the predictive power of RT and phonological awareness is independent of general cognitive ability. Such an outcome would be supportive of Hypothesis 2 (that this extraphonological source might be viewed as a more distal contributor to phonological-processing efficiency—perhaps as an indicator of underlying temporal-processing efficiency; see Nicolson, Fawcett, & Dean, 1995; Tallal, Sainburg, & Jernigan, 1991).

METHOD

Participants

Eighty-one adult participants (ages 16–54) were recruited for this study. Sixteen participants were recruited from the population of a large publicly funded university and participated for a fee of $40. Sixty-five participants were obtained through the educational assessment laboratory at the same university. The participants were referred or self-referred to the assessment lab. Only those individuals who were referred with no diagnosis other than a potential learning disability were considered as participants. However, on assessment, not all of these individuals were found to be experiencing reading difficulties. In fact, approximately one third of these participants had reading ability scores that overlapped with the distribution of scores in the nonreferred sample. All participants had an estimated IQ (based on a prorating of three to four subtests of the Wechsler Adult Intelligence Scale–Revised (WAIS–R; Wechsler, 1981: Block Design, Vocabulary, Digit Span, and Digit Symbol) greater than 70. The mean age of the participants was 27.1 years (*SD* = 8.4). As indicated in Table 1, the oversampling of the subjects from the Educational Assessment Laboratory resulted in a sample of slightly below average IQ and below-average reading ability.

Tasks

Participants were administered measures of IQ (three to four subtests of the WAIS–R), single word reading (Wide Range Achievement Test–3 [WRAT–3; Jastak & Wilkinson, 1984] Reading subtest), and pseudoword reading (Word Attack subtest of the Woodcock Reading Mastery Test; Woodcock, 1987). In addition to this battery, we administered a test of phonological awareness (Rosner Auditory Analysis Test, or Rosner; Rosner & Simon, 1971) and two choice RT tasks, one using auditory stimuli and one using visual stimuli. The latter three tasks were administered as follows.

Rosner. In this task, the participant was told, "I am going to say a word, and I want you to say it the same way I do. Then I am going to tell you what part to take

TABLE 1
Participant Characteristics

Variable	*M*[a]	*SD*
Age	27.1	8.4
IQ	95.3	13.0
WRAT–3 Reading (percentile)	39.7	30.7
Woodcock Word Attack (percentile)	40.1	29.3
Rosner AAT (raw score)	28.6	9.1
Auditory Reaction Time Task		
Reaction time (ms)	369.0	99.0
Errors	4.8	4.9
Visual Reaction Time Task		
Reaction time (ms)	573.0	103.0
Errors	2.8	2.7

Note. WRAT–3 = Wide Range Achievement Test–3; Rosner AAT = Rosner Auditory Analysis Test.
[a]n = 81.

off, and then I want you to say what's left." The participant is then given 2 practice items followed by the 40 items of the test. Participants are asked to delete syllables, single phonemes from initial and final positions in words, and single phonemes from blends. The 40 items were arranged in approximate order of difficulty, and testing was discontinued after five consecutive error responses. The maximum score on the task was 40, and the split-half reliability (Spearman–Brown corrected) was .97. The mean score on the task was 28.6 (SD = 9.1).

Auditory choice reaction time task. This test was presented on one of two identical Macintosh Classic II computers. Stimuli were presented and RTs measured using the program SuperLab v1.68 (Cedrus, 1992). Manual responses were recorded using the standard keyboard. The *B* and *N* keys were covered with a blue and a red sticker, respectively. Auditory stimuli were developed on the same Macintosh computer using SoundEdit Pro v1.0 (Beck, Petersen, Sensendorf, Chaplin, Pompa, & Konar, 1992). The auditory stimuli consisted of two pure tones, one of 340 Hz and the other of 1500 Hz, each with a duration of 75 ms. Participants pressed the red key for the "high" tone and the blue key for the "low" tone. The interval between trials was randomly varied between 500; 1,000; 1,500; 2,000; and 2,500 ms. There were 10 practice trials with feedback given, 2 at each of the five intertrial intervals. This was followed by 100 experimental trials with no feedback, 20 each at each intertrial interval, randomly arranged. RTs less than 100 ms or greater than 1,500 ms were eliminated from the RT analysis and treated as errors. Less than 2% of the responses were longer than three standard deviations above the mean for that participant but less than 1,500 ms. Following Tabachnick and Fidell (1983), these responses were replaced by a value equal to the next highest score plus one unit of measurement, thus preserving its rank within the distribution without disturbing the distribution either by deleting the score or by retaining it in its original form. Mean scores on the task are indicated in Table 1.

Visual choice reaction time task. The design of this task was identical to the auditory choice reaction time task, differing only in the stimuli used. The visual stimuli were developed with ClarisWorks 2.1CD v3.0 (Holdaway, Hearn, Lindsay, & Hoke, 1994). Participants were briefly shown one of two simple visual, nonlinguistic stimuli (a circle with a slash through it and three squares—similar to the stimuli used by Reed, 1989). The participant was instructed to press a specific key for each stimulus (either the red or blue key) as quickly as possible. Participants pressed the red key for the squares and the blue key for the circle with the slash. As in the auditory choice reaction time task, there were 100 experimental trials, 20 at each intertrial interval. RTs and errors were analyzed as in the auditory reaction time task. Mean scores on the task are indicated in Table 1.

Procedure

All testing was done in a single session lasting 3 to 5 hr (including a lunch break). Participants also completed other tasks that were not part of this investigation. The tests were given in a prescribed order: WRAT–3 Reading subtest, Block Design WAIS–R subtest, Woodcock Word Attack subtest, Vocabulary WAIS–R subtest, Digit Span WAIS–R subtest, Digit Symbol WAIS–R subtest, auditory choice reaction time task, Rosner, and visual choice reaction time task.

RESULTS AND DISCUSSION

A correlation matrix showing the relationships among all of the main variables in the study is displayed in Table 2. The two reading measures (WRAT–3 Reading and Woodcock Word Attack) had highest correlations with the Rosner (.63 and .73) and with IQ (.65 and .55). The high correlations with phonological awareness confirm earlier findings (e.g., Bruck, 1992; Gottardo, Stanovich, & Siegel, 1997; Read & Ruyter, 1985) indicating that phonological awareness is a correlate of word recognition not only in children but also in adults. The two reading measures (WRAT–3 Reading and Woodcock Word Attack) displayed significant correlations with auditory (–.40 and –.47) and visual (–.31 and –.32) RTs, replicating the previously observed zero-order correlation mentioned in the introduction. It appears that a significant relationship between RT and reading ability exists in our sample, as in previous studies (Hayes, Hynd, & Wisenbaker, 1986; Nicolson & Fawcett, 1994). In a series of converging analyses, we now explore differing interpretations of the relationship by examining covariance relationships with phonological awareness and general cognitive ability.

TABLE 2
Intercorrelations Among the Primary Variables

Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1. IQ							
2. WRAT–3 Reading	.65						
3. Woodcock Word Attack	.55	.81					
4. Rosner AAT	.53	.63	.73				
5. ART Reaction Time	–.45	–.40	–.47	–.38			
6. ART Errors	–.11	–.16	–.16	–.20	–.01		
7. VRT Reaction Time	–.40	–.31	–.32	–.19	.69	-.01	
8. VRT Errors	–.10	.03	.03	.04	.07	.34	.20

Note. $p < .05$, two-tailed, for correlations greater than .22 in absolute magnitude. WRAT–3 = Wide Range Achievement Test–3; Rosner AAT = Rosner Auditory Analysis Test; ART = Auditory Reaction Time Task; VRT = Visual Reaction Time Task.

The interrelationships among the reading measures, phonological awareness, and RT were examined in a series of hierarchical regression analyses. To utilize the most potent RT index possible, we created a composite score of RTs from both of the choice RT tasks (RTs on the two tasks displayed a correlation of .69). RTs for both tasks were converted to *z* scores, and the average of the two was computed for each participant.

In Table 3, all possible forced hierarchical orderings of the predictor variables are examined for each of the two standardized reading measures—one tapping decoding (Woodcock Word Attack) and one tapping word recognition skill (WRAT–3 Reading). In the first set of analyses, it is clear that the Rosner and the RT tasks acted very differently as predictors. After IQ had been entered into the equation, the Rosner still accounted for a substantial amount of additional variance (11.4% and 26.0%), whereas the composite RT index accounted for only 1.0% and 4.0% additional variance (the former not significant). When IQ and RT were both entered into the equation, the Rosner was a potent unique predictor (accounting for 10.9% and 24.5% unique variance, respectively). However, when IQ and Rosner were in the equation, the RT composite was a weak predictor—accounting for only 0.5% and 2.5% additional variance, respectively.

TABLE 3
Summaries of Hierarchical Regression Analyses R^2 Change

	Criterion Variables	
Step and Variable	*WRAT–3 Reading*	*Word Attack*
1. IQ	.425**	.304**
2. Rosner AAT	.114**	.260**
3. Composite reaction time	.005	.025**
2. Composite reaction time	.010	.040*
3. Rosner AAT	.109**	.245**
1. Composite reaction time	.151**	.186**
2. IQ	.284**	.159**
3. Rosner AAT	.109**	.245**
2. Rosner AAT	.290**	.388**
3. IQ	.103**	.015*
1. Rosner AAT	.400**	.526**
2. Composite reaction time	.041**	.052**
3. IQ	.103**	.015*
2. IQ	.139**	.038**
3. Composite reaction time	.005	.025**

Note. WRAT–3 = Wide Range Achievement Test–3; Rosner AAT = Rosner Auditory Analysis Test.
$^*p < .05$. $^{**}p < .01$.

The second series of hierarchical regressions highlights the somewhat different patterns of prediction displayed by the Rosner and by IQ. The Rosner is a more potent predictor of pseudoword reading (38.8% unique variance) than of word reading (29.0% unique variance) after the RT composite had been entered into the equation. The opposite was true of IQ. After the RT composite had been entered into the equation, it was a more potent predictor of word reading (28.4% unique variance) than of pseudoword reading (15.9% unique variance).

The third series of hierarchical regressions demonstrates that, to the modest degree that RT predicts reading independently of phonological awareness, it is because of the overlap of variance of RT and intelligence. Specifically, after the Rosner had been entered into the equation, the composite RT measure accounted for 4.1% and 5.2% additional variance in word reading and pseudoword reading, respectively. However, once IQ was entered into the equation, these figures dropped to 0.5% and 2.5% (not significant in the former case).

A more complete picture of the covariance relationships can be obtained by conducting a commonality analysis on each of the two reading measures. The analysis at the top of Table 4 presents a commonality analysis of the covariance relationships when IQ, the Rosner, and the composite RT measure are analyzed as predictors of performance on the WRAT–3 Reading subtest. Commonality analysis (see Kerlinger & Pedhazur, 1973) presents a decomposition of the variance overlap between a predictor and a criterion variable in terms of variance shared with other predictors and variance unique to that predictor variable. For example, the squared multiple correlation between IQ and WRAT–3 Reading was .425. This 42.5% variance in word reading that is explained by IQ is decomposed into 10.5% variance shared with both Rosner and composite RT, 3.6% shared specifically

TABLE 4
Commonality Analyses Using Wide Range Achievement Test–3 Reading Raw Scores as the Criterion Variable

	Predictor Variables		
	IQ	*AAT*	*CRT*
Unique	.103	.109	.005
Common to IQ and AAT	.181	.181	
Common to IQ and CRT	.036		.036
Common to AAT and CRT		.005	.005
Common to IQ, AAT, and CRT	.105	.105	.105
Total R^2 for variable	.425	.400	.151
Unique		.290	.041
Common to AAT and CRT		.110	.110
Total R^2 for variable		.400	.151

Note. AAT = Rosner Auditory Analysis Test; CRT = Composite auditory and visual reaction times.

with composite RT, 18.1% shared specifically with the Rosner, and 10.3% of the explained variance that is unique to IQ.

A perusal of the results displayed at the top of Table 4 indicates the following trends: The three variables share a moderate amount of variance overlap with word reading skill (10.5%); both IQ and the Rosner explain a substantial proportion of unique variance in word reading skill (10.3% and 10.9%, respectively). In contrast, composite RT has negligible unique variance (0.5%). Composite RT has some predictive variance overlap specifically with IQ (3.6%) but little with the Rosner (0.5%). The Rosner and IQ have substantial overlap in their predictive variance (18.1%).

The two-variable commonality analysis at the bottom of Table 4 illustrates the dangers of analyzing an extraphonological source of processing variance without converging information on general cognitive ability. From that analysis, it appears that there may be modest support for each of the hypotheses outlined in the introduction. Choice RT explains 4.1% unique variance in word recognition skill, indicating that it may play some role as an independent predictor (independent of phonological processing, that is) of reading ability. The existence of this unique variance might be taken as modest support for Hypothesis 1. However, the commonality analysis at the top of Table 4 indicates that fully 87.8% (.036 divided by .041) of that unique variance is actually variance shared with intelligence. Similarly, the 11.0% variance shared with phonological processing might be viewed as supportive of Hypothesis 2 (RT as causally prior to phonological differences). However, such an interpretation would again be misleading. Fully 95.5% (0.105 divided by .110) of this common variance is variance shared with intelligence. The 11.0% variance overlap thus does not meet the requirements of the assumption of specificity.

The commonality analysis displayed in top half of Table 5 (using Woodcock Word Attack as the criterion variable) reveals similar trends. The main difference is that the Rosner predicts much more unique variance, and IQ predicts much less. As with the analysis done on word reading (Table 4), composite RT accounted for little unique variance (2.5%). Of the total variance in pseudoword reading explained by RT, 66.1% (.123 divided by .186) was shared with both IQ and the Rosner.

The two-variable commonality analysis at the bottom of Table 5 indicates that, as with WRAT–3 Reading subtest, analyzing an extraphonological source of processing variance without converging information on general cognitive ability could be misleading. About half of the small amount of unique variance explained by RT (.023 of .048) is shared with intelligence, and fully 89.1% of the variance that RT shares with phonological awareness is shared with intelligence (.123 divided by .138).

One final way to conceptualize the relationships among these three variables is in terms of a path analysis. Figure 1 presents the results of such an analysis in which word recognition (WRAT–R Reading subtest score) was the criterion variable. Performance on the Rosner is an endogenous variable predicting word recognition, and IQ and choice RT are exogenous predictors of both word recognition and Rosner

TABLE 5
Commonality Analysis Using Woodcock Word Attack Raw Scores as the Criterion Variable

	Predictor Variables		
	IQ	*AAT*	*CRT*
Unique	.015	.245	.025
Common to IQ and AAT	.143	.143	
Common to IQ and CRT	.023		.023
Common to AAT and CRT		.015	.015
Common to IQ, AAT, and CRT	.123	.123	.123
Total R^2 for variable	.304	.526	.186
Unique		.388	.048
Common to AAT and CRT		.138	.138
Total R^2 for variable		.526	.186

Note. AAT = Rosner Auditory Analysis Test; CRT = Composite auditory and visual reaction times.

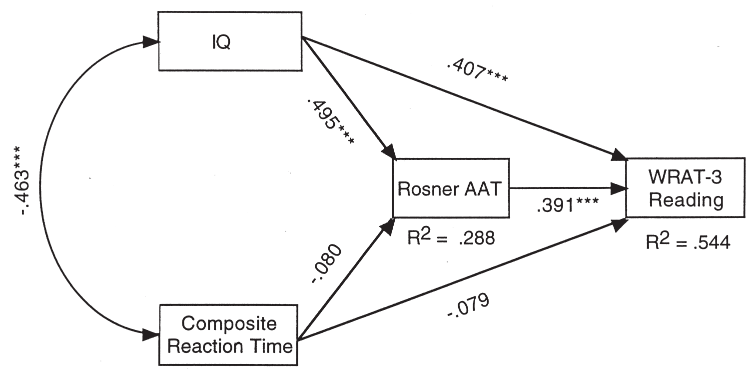

FIGURE 1 Path analysis predicting Wide Range Achievement Test–3 (WRAT–3) Reading Subtest performance from scores on the Rosner Auditory Analysis Test (AAT), scores on the intelligence test, and choice RT. R^2 = percent of variance accounted for on each endogenous variable by all preceding predictor variables. Standardized beta weights are shown on each path. *** = .001.

performance. The path diagram indicates that both IQ and the Rosner were significant independent predictors of word recognition, but choice RT was not. IQ was a significant independent predictor of the Rosner, but RT was not. The diagram indicates why RT has significant zero-order correlations with both the Rosner ($r = -.31$) and the WRAT–3 Reading subtest ($r = -.39$) but is not a significant independent predictor of either variable. Choice RT is essentially a spurious correlate of each of these variables because of its moderately strong relationship with IQ (the unanalyzed correlation of –.46 indicated by the double-headed arrow).

In summary, although we replicated Nicolson and Fawcett's (1994) finding that reading ability is correlated with choice RT, we found little evidence that stimulus classification time is an extraphonological source of variance that needs to be integrated within a comprehensive theory of reading disability. First, RT was not a unique predictor in our study. It explained little variance in reading ability after phonological awareness had been partialed out and almost no unique variance after phonological awareness and general cognitive ability had been partialed out. Second, it did not appear to be more distally related to phonological-processing differences (e.g., as in hypotheses about timing deficits). The overlap in the variance of RT and phonological processing was almost entirely due to variance in intelligence shared by both variables.

Of course, one critical caveat that must be attached to our findings is that they are restricted to the population of readers studied. Our participants were adults—slightly older than the sample studied by Hayes et al. (1986) and substantially older than the 15-year-olds studied by Nicolson and Fawcett (1994). It remains a possibility that the relationships involving these variables are different among younger participants. An additional difference was that the poor readers in the Nicolson and Fawcett investigation had aptitude/achievement discrepancies, whereas the poorer readers in our investigation tended not to have such discrepancies (tending more toward "garden- variety" poor readers; see Gough & Tunmer, 1986). The relation between RT and reading difficulties could well be different in these two groups, although we remain skeptical of this possibility based on past work indicating that the nature of processing within the word recognition module is quite similar for poor readers of high and low general ability (Felton & Wood, 1992; Fletcher et al., 1994; Francis, Shaywitz, Stuebing, Shaywitz, & Fletcher, 1996; Share, 1996; Stanovich, 1996; Stanovich & Siegel, 1994). Finally, it is true that we may have overestimated all correlations involving reading ability because we oversampled poorer readers in this investigation. This caveat, although applicable to this investigation, is attributable to virtually every other study of the cognitive correlates of reading ability (e.g., Fletcher et al., 1994; Shankweiler et al., 1999), including the Nicolson and Fawcett investigation that inspired the analyses presented here.

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