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Attentional control and the Simple View of reading

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Abstract Attentional control was investigated as a possible third component of reading comprehension, along with decoding and language comprehension, within the Simple View of reading (Gough & Tunmer RASE: Remedial and Special Education 7:6–10, 1986; Hoover & Gough Reading and Writing 2:127–160, 1990). Attentional control is the ability to suppress irrelevant prepotent responses and activate relevant responses. This ability may help coordinate decoding and language comprehension during reading. In an unselected sample of 67 eight-year-olds, attentional control contributed significant variance to reading comprehension after controlling for decoding and language comprehension. Further, attentional control was similar to language comprehension in the amount of unique variance accounted for. Five contrast measures were examined (performance IQ, print exposure, articulation speed, phonemic awareness, and verbal short-term memory), but none was as good a candidate for a third component of reading comprehension as attentional control.

Keywords Attentional control · Decoding · Language comprehension · Reading comprehension · Simple View of reading

Most researchers who study reading would agree that reading is a highly complex skill. Indeed, much effort in the last 20 years has gone into breaking down this complex skill into its component skills. Phonemic awareness, working memory, phonological decoding, orthographic awareness, vocabulary, and receptive grammar (to name a few) have been identified as component skills of reading (see Carr & Levy, 1990; Greene & Royer, 1994). A better understanding of the component skills

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of reading has led not only to more powerful classroom reading instruction, but also to a better understanding of the nature and range of reading disability. Recently, however, there has been renewed interest in the *Simple View* of reading, introduced initially by Gough and Tunmer in 1986 (see also Carver, 1993; Gough, Hoover, & Peterson, 1996; Hoover & Gough, 1990). This view has focused on how reading comprehension can be characterized using the most basic and most powerfully predictive components.

The Simple View suggests that reading comprehension (R) is a product of two basic components—decoding (D) and language comprehension (C) as in the formula $R = D \times C$. Gough and Tunmer (1986) emphasized the product, rather than the linear combination, of decoding and language comprehension because if a child has zero decoding, s/he will have zero reading comprehension, no matter how good his or her language comprehension is. Similarly, if a child has zero language comprehension, s/he will have zero reading comprehension, no matter how good his or her decoding is. Hoover and Gough (1990) showed that the product contributed significant variance to the prediction of reading comprehension beyond the linear combination of decoding and language comprehension. The Simple View does not deny that skills such as phonemic awareness, vocabulary knowledge, or orthographic awareness are important to reading; rather, it suggests that they are subskills of either decoding or language comprehension (see also Cain, Oakhill, & Bryant, 2004; Conners & Olson, 1990; de Jong & van der Leij, 2002; Juel, Griffin, & Gough, 1986; Neuhaus, Roldan, Boulware-Gooden, & Swank, 2006; Vellutino, Tunmer, Jaccard, & Chen, 2007). The Simple View also suggests that the balance of influence of decoding and language comprehension shifts with reading proficiency, such that at early stages of reading, decoding is more influential than language comprehension, and at later stages, language comprehension is more influential than decoding. However, both are the main components of reading comprehension throughout reading development.

There is much empirical evidence that the combination of decoding and language comprehension accounts for a large portion of the variance in reading comprehension. Estimates range from 45 to 85% across studies using a variety of samples and measures and using both concurrent and longitudinal analyses (Byrne & Fielding-Barnsley, 1995; Catts, Hogan, & Adolf, 2005; Chen & Vellutino, 1997; Conners & Olson, 1990; Cutting & Scarborough, 2006; Dreyer & Katz, 1992; Hoover & Gough, 1990; Johnston & Kirby, 2006; Joshi & Aaron, 2000; Megherbi, Seigneuric, & Ehrlich, 2006; Savage, 2001; Storch & Whitehurst, 2002; Tiu, Thompson, & Lewis, 2003; see also Carver, 1998; de Jong & van der Leij, 2002; Keenan, Betjemann, Wadsworth, DeFries, & Olson, 2006; Proctor, Carlo, August, & Snow, 2005; Vellutino et al., 2007). Also, results have supported the notion that the balance of influence of decoding and language comprehension shifts developmentally (e.g., Carver, 1998; Catts et al., 2005; Chen & Vellutino, 1997; Vellutino et al., 2007; see Gough et al., 1996). In contrast to Hoover and Gough's (1990) results, however, in most samples it appears to matter little whether the product of decoding and language comprehension, the linear combination, or both are used to predict reading comprehension (e.g., Chen & Vellutino, 1997; Dreyer & Katz, 1992; Joshi & Aaron, 2000; Neuhaus et al., 2006; Savage, 2006). The importance of the product may depend on whether there are individuals in the sample who are at or near zero on either decoding or language comprehension.

In spite of its intuitive appeal and general empirical support, there are some weaknesses in the Simple View (see Aaron et al., 2006; Duke et al., 2005). For example, it implies that decoding and language comprehension are independent of one another, when some studies have reported that they are substantially correlated or are subserved by some of the same subcomponents (e.g., Conners & Olson, 1990; Keenan et al., 2006; Vellutino et al., 2007). The Simple View also seems to imply a unidirectional relation in which strength in decoding and language comprehension lead to strength in reading comprehension; however there is evidence that the relations are at least somewhat bidirectional (e.g., see Oakhill & Cain, 2007; Stanovich, 1986). Further, the Simple View may not apply the same way to typical and poor readers (e.g., Conners & Olson, 1990; Johnston & Kirby, 2006; Savage, 2006). Finally, and most relevant for the present study, the two main components in the Simple View (decoding and language comprehension) do not appear to account for all of the reliable variance in reading comprehension. It is this observation that has led to a discussion of whether the Simple View should include a third component (e.g., Adolf, Catts, & Little, 2006; Braze, Tabor, Shankweiler, & Mencl. 2007; Cartwright, 2002; Johnson, Jenkins, & Jewell, 2005; Joshi & Aaron, 2000; Tiu et al., 2003).

Although there is good agreement that the two main components of reading comprehension are decoding and language comprehension, it seems that in addition to these two subskills, reading comprehension must involve the ability to *coordinate* the processes involved in each so as to make them work together optimally. One example of such coordination would be the detection and resolution of comprehension failures. Walczyk's Compensatory-Encoding Model of reading (Walczyk, 2000; Walczyk, Marsiglia, Johns, & Bryan, 2004) suggests that when decoding is inefficient, readers use compensatory mechanisms that are specific to reading such as pausing, looking back, and rereading to assist reading comprehension. A comprehension failure due to a decoding inefficiency could prompt the use of a compensatory mechanism. The reader might pause to allow comprehension processes to resolve the failure, look back to reread a poorly decoded word, or reread a phrase or sentence. An inability to detect and resolve comprehension failures would surely present an obstacle to reading success. Detecting and resolving reading comprehension failures involves monitoring automatic reading processes, interrupting them when there is a problem, and initiating alternate processes when necessary. In other words, they involve *attentional control* during the reading process. The purpose of the present study was to investigate the possibility that a third component—attentional control—belongs in the Simple View of reading. The focus was on attentional control as a basic ability, and it was measured outside of the reading domain.

Attentional control refers to the ability to inhibit automatic or prepotent responses that are irrelevant and initiate alternative responses that are more relevant (e.g., Anderson, 2002; Baddeley, 1986; Norman & Shallice, 1986; Shallice, 1988). Several researchers have discussed the role of attentional control in reading (see Masson, 1987; Reynolds, 2000; Walczyk, 2000). For example, when a word is decoded, its meaning may be activated automatically, but if that meaning does not fit the broader context, it must be suppressed and replaced with another more relevant meaning. If the word was decoded incorrectly in the first place, processing must stop and the word must be decoded again, this time with more careful attention. In this way, attentional control involves the coordination of automatic and effortful processes in reading. It is well known that both decoding and language comprehension involve automatic and effortful processes and that over the course of reading development, some processes that are effortful become automatized (e.g., LaBerge & Samuels, 1974; Perfetti, 1985; Walczyk, 2000). The smooth coordination of automatic and effortful processes via attentional control should have a positive impact on reading comprehension.

Research suggests that individual differences in attentional control are related to reading comprehension in typical children, and that attentional control problems distinguish children with and without reading problems. For example, de Jong and Das-Smaal (1995) found that attentional control correlated significantly with reading comprehension in a sample of 555 fourth graders, accounting for 9% of the variance ($r = .30$). Also, Savage, Cornish, Manly, and Hollis (2006) studied a mixed sample of 6–11-year-olds who were high or low in frequency of ADHD characteristics as judged by teachers. They found that a "central executive" composite that was weighted heavily on response inhibition accounted for significant variance in reading comprehension (5%) after age, IQ, and attention group were accounted for. Swanson, Howard, and Saez (2006) found that children with reading disability (poor decoding, poor reading comprehension, and average IQ) performed more poorly on response inhibition tasks than skilled readers. Also, van der Schoot, Licht, Horsley, and Sergeant (2000) found that dyslexics age 9–12 were generally worse at response inhibition than controls, and that dyslexic "guessers," who read fast but inaccurately, were affected more so than "spellers," who read slowly and with more accuracy. In a subsequent study, van der Schoot et al. (2004) showed that dyslexic guessers' reading style is explained by failure to suppress inappropriate reading responses and not by a tendency to overuse context. Finally, a few studies have shown that poor response inhibition in children with reading disability is not explained by comorbid ADHD (Purvis & Tannock, 2000; Willcutt, Pennington, Olson, Chhabildas, & Huslander, 2005; but see Rucklidge & Tannock, 2002; Willcutt et al., 2001). Thus, there is good evidence that attentional control is related to reading comprehension and reading difficulty; however, it has not yet been studied in the context of the Simple View of reading.

The notion that a third component might belong in the Simple View of reading is not new. For example, several researchers have examined processing speed measures as possible third components, such as naming speed, reading speed, and perceptual speed. It has been argued that the faster letters and words can be processed during reading, the more cognitive resources are freed up and available for higher comprehension processes (Adolf et al., 2006; Neuhaus et al., 2006; see also Carver, 1993, 1998; Carver & David, 2001). Thus, processing speed should be related to reading comprehension. Although this rationale is reasonable, the empirical evidence is quite mixed. For example, Joshi and Aaron (2000) reported that letter naming speed contributed significantly to reading comprehension beyond decoding and language comprehension, but this has only been replicated consistently when a nonword rather than word or composite decoding term was used (Cutting & Scarborough, 2006; Johnston & Kirby, 2006). Cutting and Scarborough reported that reading speed contributed significantly to reading comprehension, but this finding was not replicated by Adolf et al. (2006) or Neuhaus et al. (2006) (see also Spear-Swerling, 2006). Finally, Tiu et al. (2003) reported that perceptual speed measures requiring visually scanning of text for matching letters or letter combinations significantly added to the prediction of reading comprehension beyond decoding and language comprehension, but the effect was small and was eliminated when Performance IQ was entered first in the regression. It is quite possible that processing speed has some place in the Simple View; however, more research is needed to understand the relation between various types of processing speed and reading comprehension.

Other potential third components have been investigated as well, either formally within the Simple View or within other theoretical contexts. These include Performance IQ, memory, phonemic awareness, and vocabulary (Braze et al., 2007; Cain et al., 2004; Cutting & Scarborough, 2006; Goff, Pratt, & Ong, 2005; Johnston & Kirby, 2006; Neuhaus et al., 2006; Tiu et al., 2003). Each of these has received some support, but none has been replicated reliably. In the present analysis, the primary focus was on attentional control as a third component in the Simple View; however, measures of processing speed, performance IQ, memory, and phonemic awareness were included as contrast measures and to provide an opportunity to replicate previous findings. Print exposure was also included as a contrast measure even though it has not been investigated as a third component. It was included as an experiential measure that has been previously related to reading comprehension (Cipielewski & Stanovich, 1992).

In the present study, attentional control was measured using the Star Counting Test (SCT), in which participants count stars on a page until they come to a signal that tells them either to continue to count in the same direction or to reverse. This test was developed by de Jong and Das-Smaal (1990, 1995) as a measure of the central executive component of working memory within Baddeley's multicomponent model of working memory. In Baddeley's model, the central executive component controls and coordinates the activities of the other working memory components, the phonological loop and the visuo-spatial sketchpad. de Jong and Das-Smaal considered the central executive component part of the broader attentional system, and thus discussed the SCT as a measure of attention, particularly in terms of Norman and Shallice's (1986) supervisory attentional system (SAS). The SAS is said to supervise or control ongoing processing by initiating, interrupting, and modifying automatic running routines to achieve higher thought or action goals. Essentially, the SCT was designed to measure how well individuals can activate and inhibit automatic processes and switch from automatic to controlled processes. For the present study, it has an advantage over many response inhibition tasks (e.g., stop signal task, go/no-go task, etc.) in that it not only measures the ability to inhibit a prepotent response (the next number in sequence) but also the ability to initiate an alternate more appropriate response (the next number in reverse sequence). It is the combination of these two functions that might best relate to the coordination of decoding and language processes in reading comprehension.

In the present study, hierarchical regression analysis was used to examine the contribution of attentional control to the Simple View of reading based on an unselected sample of eight-year-olds. Based on past research, both word identification and language comprehension should be considerably related to reading comprehension at this age. It was hypothesized that attentional control would explain significant variance in reading comprehension after accounting for the effects of decoding and language comprehension. This was done for each of the three versions of the Simple View (multiplicative, linear or additive, and combination). Also, because some studies of the Simple View of reading have shown that results vary depending on the decoding term used (Cartwright, 2007; Johnston & Kirby, 2006; Savage, 2001, 2006; but see Chen & Vellutino, 1997), parallel analyses were carried out for three different decoding terms (nonword reading, real word reading, and composite). In addition, the contributions of five different contrast measures (performance IQ, print exposure, phonemic awareness, articulation speed, and verbal short-term memory) to reading comprehension were examined in the same way. It was expected that attentional control would contribute significant variance to reading comprehension beyond that contributed by decoding and language comprehension, and that it would be at least as strong a predictor as any of the contrast variables.

Method

Participants

Participants included in the present analysis were 67 eight-year olds drawn from several area elementary schools and tested as part of a larger study. The only eligibility criteria were age, parent permission, and parent transportation to the lab for testing appointments. Thus, children with special educational needs and/or attentional problems were neither screened out nor specially recruited for the study. All participants from the larger study who had completed at least 10 of the 11 tests that were used in the present analysis were included. Mean age was 8.6 ($SD = .4$). Of the 67 participants, 52% were girls and 48% were boys, 79% were Caucasian and 21% were African American. The sample was generally middle to low in socioeconomic status based on free/reduced lunch eligibility statistics at the schools the participants attended. Two participants had repeated a grade due to academic failure, and four participants were in speech therapy. Three participants reported that English was not their first language; however, none of these reported being fluent in any language other than English. These three participants were tested in English and included in the present analysis. In general, children were being educated in a balanced literacy environment in school, which included emphasis on both analytical decoding skills and exposure to literature.

Tests

Reading comprehension

The Peabody Individual Achievement Test-Revised (PIAT-R) Reading Comprehension subtest (Markwardt, 1989) was used to measure reading comprehension. This test requires participants to read sentences silently and point to the picture depicted by the sentence. A typical sentence for an eight-year-old is "The delightful scenery is scarred with rusting junk and machinery." The sentences increase in difficulty, and testing is discontinued when the participant misses five items out of seven consecutive items. Because it is based on single-sentence passages, this measure is limited to comprehension processes that operate within or across clauses (i.e., not across sentences or paragraphs). However, it has certain advantages over other reading comprehension measures for the purposes of the present analysis. Because only pointing responses are required, the measure is less influenced by a child's oral expression ability. In addition, because the passages are limited to single sentences, the measure is less influenced by a child's background knowledge (see Keenan & Betjemann, 2006). Standard scores were used in the present analysis. Reliability estimates for eight-year-olds based on the standardization sample range from .84 (test–retest) to .97 (split-half) (Markwardt, 1989).

Word recognition

The PIAT-R Reading Recognition subtest (Markwardt, 1989) was used to measure word recognition. In this test, participants read words aloud one at a time. The words are ordered for difficulty, and the test is discontinued when the participant misses five out of seven consecutive items. Standard scores were used in the present analysis. Reliability estimates for eight-year-olds based on the standardization sample range from .96 (Kuder–Richardson) to .97 (test–retest and split-half) (Markwardt, 1989).

Nonword reading

A list of 24 one-syllable nonwords and 12 two-syllable nonwords was constructed for the study. The one-syllable nonwords were constructed using rimes from consistent neighborhoods and a variety of onsets including single consonants, digraphs, and consonant blends. The two-syllable nonwords also varied in complexity based largely on consonant blends. During testing, nonwords were presented on the computer, one at a time, and participants attempted to read each one aloud. Two points were awarded if all sounds were correct, one point was awarded if all but one sound was correct, and zero points were awarded otherwise. The score was the total points earned out of a possible 72. Alpha reliability from the study sample was .92.

Decoding composite

A composite decoding score was computed from the word recognition and nonword reading scores. These two measures correlated substantially ($r = .67$). To compute a composite score for each participant, scores on each measure were converted into standard scores based on the sample mean and standard deviation. Then the standard scores for both tasks were averaged for a composite score.

Language comprehension

The Test of Auditory Comprehension of Language-Revised (TACL-R, Carrow-Woolfolk, 1985) was used to measure language comprehension. In three subtests, this test measures receptive vocabulary (Word Classes and Relations), comprehension of grammatical morphemes (Grammatical Morphemes), and comprehension of complex syntactic structures (Elaborated Sentences). For each part, the participant listens to a word, phrase, or sentence, and chooses the picture that best corresponds. Items are ordered for difficulty and testing is discontinued when the participant misses three consecutive items. The score used for the present analyses was the total standard score. Although this measure is not structurally parallel to the PIAT-R Reading Comprehension subtest, both measures focus on word and sentence-level comprehension as opposed to paragraph-level or cross-paragraph level comprehension. The split-half reliability of the total score for eight-year-olds based on the standardization sample is .88 and the test–retest reliability is .90 (Carrow-Woolfolk, 1985).

Attentional control

The SCT (Das-Smaal, de Jong, & Koopmans, 1993; de Jong & Das-Smaal, 1990, 1995) was used to measure attentional control. In the SCT, participants look at a page with rows of stars, pluses, and minuses printed on it. Starting with a number given to them by the tester, they count the stars from left to right beginning with the first line on the page. When they come to a plus or minus, they either continue in the same counting order or reverse order. In Part 1, plus means continue in the same order and minus means reverse order. In Part 2, plus means reverse order and minus means continue in the same order. Thus, the test requires participants to activate an automatic process (counting forward), inhibit it, and run a more controlled process (counting backward). Further, it involves using an automatic association (plus means continue and minus means reverse), as well as an effortful association (plus means reverse and minus means continue). For each part, instructions and two practice trials are followed by 12 trials. Part 1 is always completed before Part 2. The total number of trials correct out of 24 was used as the measure of attentional control. The SCT has shown good construct validity. For example, de Jong and Das-Smaal (1995) reported that aspects of the test that relate to the construct of attentional control (number of alternations in counting direction, duration of the counting process before it is stopped, and whether the meaning of the ± sign is reversed) contributed significantly to item difficulty. Also, Bayless and Roodenrys (2000) reported that children with ADHD performed more poorly on this test than children with learning disability or typical development. Further, their discriminant analysis showed that, of three measures of attentional control, the SCT measure discriminated these three groups best. Reliability of this measure as reported by de Jong and Das-Smaal (1995) is .75 (split-half); in the study sample it was .72 (split-half) and .75 (alpha).

Performance IQ

The Weschler Intelligence Scale for Children, third edition (WISC-III, Wechsler, 1991) was used to measure intelligence. Participants completed the entire scale. The Performance Scale IQ was used in the present analyses. This measure was included as a contrast measure because, using a mixed typical and reading disabled sample, Tiu et al. (2003) found that it added significant variance to the prediction of reading comprehension beyond decoding and language comprehension. Other studies have also found that nonverbal IQ is related to reading ability in school-age children (e.g., Carver, 1990). Composite reliability for eight-year-olds is .90 (Wechsler, 1991).

Print exposure

The Title Recognition Test, developed by Cunningham and Stanovich (Cunningham & Stanovich, 1990, 1991), was used to measure print exposure. This task was included in the set of contrast measures because exposure to print is sometimes related to reading comprehension (e.g., Cipielewski & Stanovich, 1992; Goff et al., 2005; McBride-Chang, Manis, Seidenberg, Custodio, & Doi, 1993; Spear-Swerling, 2006), and it was thought that an experience-based measure might add to the prediction of reading comprehension beyond decoding and language comprehension. In this task, participants read a list of 39 book titles, 25 of which are titles of actual books and 14 of which are not. Participants mark those they know are titles of actual books. The score is the number of hits minus false alarms. Reported alpha reliability for the number of correct items checked (hits) for grades 3–6 is .81–.82 (Cunningham & Stanovich, 1990, 1991). In the present sample, alpha reliability for hits was .85.

Phonemic awareness

Phonemic awareness is the awareness of the sound structure that makes up words. It was included in the present study because it is a very powerful predictor of reading (e.g., Catts, Fey, Zhang, & Tomblin, 1999; Gottardo, Stanovich, & Siegel, 1996; Hansen & Bowey, 1994; Nation & Snowling, 2004; Parilla, Kirby, & McQuarrie, 2004; see Wagner & Torgesen, 1987). Also, Johnston and Kirby (2006) found that phonemic awareness added significant variance to the prediction of reading comprehension beyond decoding and language comprehension, but this has yet to be replicated.

Two experimental measures were combined for a phonological awareness score—Phoneme Blending and Phoneme Deletion. These two measures correlated substantially ($r = .68$). Each measure was standardized based on the sample mean and standard deviation, and the standard scores were averaged for a composite score. In *Phoneme Blending*, participants listened to the experimenter pronounce single phonemes at a rate of one per second. They blended the phonemes together to make either a word or a nonword. After instructions and four practice trials, participants completed 48 trials including 12 two-phoneme trials, 24 three-phoneme trials, and 12 four-phoneme trials. Half of the trials of each phoneme length were words and half were nonwords. Trials were presented in a set random order. Responses were scored correct or incorrect and the participant's score was the percent correct. Alpha reliability was .91.

The *Phoneme Deletion* task was similar to that used by Olson, Forsberg, and Wise (1994; see also McDougall, Hulme, Ellis, & Monk, 1994). Participants listened to a tape recording in which they heard a nonword and were asked to first say the nonword and then say it again without a designated phoneme (e.g., "Say glamp………Now say glamp without the /g/………"). Deleting the phoneme always resulted in a real word. After interactive instructions and six practice trials, participants completed an easy section, a core section, and a hard section. The easy section contained eight items in which the deleted phoneme was either the first or last phoneme, but never part of a consonant blend. The task was discontinued if all of the easy section items were failed. The core section contained 24 items in which the deleted phoneme was part of a two-consonant blend either at the beginning or at the end of the word. Participants who passed at least one of the six most difficult items in the core section also completed the hard section. The hard section contained eight items in which the deleted phoneme was part of a three-consonant blend either at the beginning or the end of the word. The score for this task was the total number of points earned out of 40. Alpha reliability in the present sample was .89.

Articulation speed

The speed with which one can articulate, or speak, words is sometimes considered an indicator of mental rehearsal efficiency (e.g., Hitch, Halliday, & Littler, 1989; Kail, 1992). It was included as a contrast measure in the present study as a representative of mental speed or efficiency. As already noted, some researchers have examined efficiency indicators (e.g., naming speed, word reading speed, reading fluency, perceptual speed) as third variables in the Simple View (Adolf et al., 2006; Cutting & Scarborough, 2006; Joshi & Aaron, 2000; Tiu et al., 2003). However, articulation speed has not been investigated in this way. In the Articulation task, participants were given ten three-syllable words and asked to repeat them as fast as possible for 10 s. The mean number of repeats per 10 s was the measure of articulation speed. Alpha reliability was .95.

Verbal short-term memory

It may be argued that short-term storage is required during text reading to connect decoded words with propositions and ultimately larger knowledge structures that are being developed during reading (e.g., Cain et al., 2004; Goff et al., 2005; Swanson & Howell, 2001). Thus, verbal short-term memory is a possible third component in the Simple View. In the present task, 24 lists of five words were played by a tape recorder at a rate of one word per second. Half the words had one syllable and half had three syllables. After each list was played, participants were to say the words back as best they could. One point was awarded for each word correctly recalled, regardless of whether it was recalled in the correct order position. Out of a total possible of 120 points, percent of words recalled was computed. Alpha reliability across the 24 lists was .91.

Procedure

Participants completed the 11 tests individually in the lab as part of a larger battery. In the first session, they completed the two PIAT-R tests, the WISC-III, and the Title Recognition Test. In the second session, they completed the SCT, the phoneme blending task, the phoneme deletion task, and the articulation speed task. In the third session, they completed the nonword reading task, the TACL-R, and the verbal short-term memory task. Participants also completed several other tests in the second and third testing sessions, which were less relevant to reading comprehension and are not part of the present analysis.

Results

Descriptive statistics for the sample are provided in Table 1. The full range of scores on Reading Comprehension, Word Recognition, and Language Comprehension was represented in the sample, and the scores were normally distributed with

Table 1 Descriptive statistics for the key variables

Measure	*N*	Mean	*SD*	Range	Skew	Kurtosis
Reading comprehension	66	107.8	12.9	80–144	.23	.45
Word recognition	67	104.5	13.5	69–144	−.09	.61
Nonword reading[a]	66	52.5	13.8	10–71	−1.06	1.21
Language comprehension	67	98.3	12.5	72–123	−.27	−.68
Attentional control (SCT)[b]	63	71.8	17.4	29–100	−.63	−.07
Performance IQ	65	112.5	15.8	71–144	−.27	−.32
Print exposure (TRT)[c]	64	7.2	4.0	−1–16	−.06	−.59
Phoneme blending (%)	67	74.6	18.0	33–100	−.68	−.54
Phoneme deletion (%)	67	61.1	21.3	10–98	−.40	−.33
Articulation speed[d]	66	14.8	1.7	10–19	−.76	.81
Verbal short-term memory (%)	66	63.5	12.1	44–99	.59	.33

Note: Reading comprehension = Peabody Individual Achievement Test-Revised (PIAT-R) Reading Comprehension subtest, standard score. Word recognition = PIAT-R Reading Recognition subtest, standard score. Language comprehension = Test for Auditory Comprehension of Language-Revised (TACL-R) total deviation quotient. Performance IQ = Wechsler Intelligence Scale for Children-III (WISC-III) Performance scale IQ

[a] Total points of a possible 72

[b] Star Counting Test, percentage correct

[c] Title Recognition Test, Hits – False alarms, with maximum = 25

[d] Mean number of word repetitions per 10 s

no outliers and skewness and kurtosis values within ±1.0. Other key variables had good ranges and showed no floor or ceiling effects. A single outlier on the nonword reading task was set equal to the value at −3 standard deviations from the sample mean. Skewness and kurtosis values were within ±1.0 for all variables except nonword reading, which, though slightly larger, was still in the acceptable range (skewness = −1.06, kurtosis = 1.21).

Correlations among the variables are reported in Table 2. Most of the variables were significantly correlated with one another. Reading comprehension correlated significantly with all other variables. It correlated most strongly with word recognition, nonword reading, language comprehension, and phonemic awareness. It correlated moderately with attentional control, verbal short-term memory, articulation speed, and print exposure. It correlated more weakly with performance IQ. The proposed components of reading comprehension—decoding, language comprehension, and attentional control varied in their degree intercorrelation. Word recognition correlated moderately with language comprehension and attentional control. Both nonword reading and the composite decoding measure correlated moderately with language comprehension but only weakly with attentional control. Language comprehension and attentional control, however, did not correlate.

Table 2 Correlations among key variables

	1	2	3	4	5	6	7	8	9	10
1. Reading comprehension										
2. Decoding composite	.69**									
3. Word recognition	.71**	.91**								
4. Nonword reading[a]	.55**	.91**	.67**							
5. Language comprehension	.51**	.44**	.35**	.46**						
6. Attentional control (SCT)[b]	.42**	.27*	.30*	.23	.08					
7. Performance IQ	.26*	.12	.26*	−.03	.27*	.30*				
8. Print exposure (TRT)[c]	.33**	.37**	.35**	.34**	.36**	.24	.21			
9. Phonemic awareness	.52**	.70**	.58**	.71**	.43**	.39**	.17	.23		
10. Articulation speed[d]	.35**	.27*	.22	.28*	.25*	.25*	.14	.12	.26*	
11. Verbal short-term memory (%)	.49**	.31*	.26*	.31*	.51**	.36**	.22	.17	.39**	.40**

Note: Reading comprehension = Peabody Individual Achievement Test-Revised (PIAT-R) Reading Comprehension subtest, standard score. Decoding composite = measure combining Word Recognition and Nonword Reading. Word recognition = PIAT-R Reading Recognition subtest, standard score. Language comprehension = Test for Auditory Comprehension of Language – Revised (TACL-R) total deviation quotient. Performance IQ = Wechsler Intelligence Scale for Children – III (WISC-III) Performance scale IQ. Phonemic awareness = composite of blending (% correct) and phoneme deletion (% correct)

[a] Total points of a possible 72

[b] Star Counting Test, percentage correct

[c] Title Recognition Test, Hits – False alarms, with maximum = 25

[d] Mean number of word repetitions per 10 s

* $p < .05$, two-tailed; ** $p < .01$, two-tailed

Table 3 Proportion of variance in reading comprehension accounted for by three versions of the Simple View of reading

Model version	Decoding term		
	Composite	Word	Nonword
Product: R = D × C	.47	.56	.36
Linear combination: R = D + C	.52	.58	.38
Linear combination + Product: R = D + C + (D × C)	.53	.59	.39

Note: R = Reading comprehension, D = Decoding, C = Language comprehension

Three versions of the Simple View

The first set of regressions compared the three basic variations of the Simple View: (1) the multiplicative model, R = D × C, (2) the additive model, R = D + C, and (3) the combination model, R = D + C + (D × C). For each regression analyses, three different decoding terms were used for comparison—decoding composite, word recognition, and nonword reading. Missing values were replaced by the group mean. In all, 13 of 670 data points were missing. The proportion of variance in reading comprehension accounted for by the three models ranged from .36 to .59, as shown in Table 3. For each of the three decoding terms, the additive model accounted for more variance than the multiplicative model, and was similar to the combination model. For none of the decoding terms did the product of decoding and listening comprehension add significant variance to the linear combination (p's > .20). For this reason, and because the additive model is more parsimonious than the combination model, the additive model was adopted for further analyses (the pattern of results in further analyses was the same, however, under all three models).

The role of attentional control in reading comprehension

The second set of regression analyses tested the hypothesis that attentional control adds to the prediction of reading comprehension beyond decoding and language comprehension. To test this hypothesis, decoding and language comprehension were entered together in the first step of the regression analysis, and attentional control was added in the second step (See Table 4). Regardless of the decoding term used, attentional control added significantly to the prediction. For the composite decoding term, $\Delta R^2 = .07$, $F\ (1,\ 63) = 9.71$, $p < .005$; for the word decoding term, $\Delta R^2 = .05$, $F\ (1,\ 63) = 8.39$, $p < .01$; and for the nonword decoding term, $\Delta R^2 = .10$, $F\ (1, 63) = 11.57$, $p < .005$.

Next, an analysis of the unique and common variance associated with the three-predictor variables was carried out (see Fig. 1). In this analysis, all three predictor variables were given equal status; that is, there was no ordering of predictor variables as there was in the hierarchical regression. Regardless of which decoding term was used, the largest portion of the variance explaining reading comprehension was common variance (i.e., variance common to two or more of the predictors). The balance of unique variance depended somewhat on which decoding term was used. When the composite and word decoding terms were used, they accounted for more

Table 4 Hierarchical regression analysis predicting reading comprehension using three different decoding terms

Step	Decoding term								
	Composite			Word			Nonword		
	R	R^2	ΔR^2	R	R^2	ΔR^2	R	R^2	ΔR^2
1. D + C	.72	.52		.76	.58		.62	.38	
2. Attentional control	.76	.58	.07**	.79	.63	.05**	.69	.48	.10**
2. Performance IQ	.73	.53	.02	.76	.58	.00	.65	.42	.03
2. Print exposure	.72	.52	.00	.76	.58	.00	.62	.39	.01
2. Phon. awareness	.72	.52	.00	.76	.58	.00	.63	.40	.02
2. Artic. speed	.73	.54	.02	.78	.60	.02	.64	.41	.03
2. Verbal STM	.75	.56	.04*	.79	.62	.04**	.66	.43	.05*
3. Verbal STM[a]	.77	.60	.02	.81	.65	.02	.70	.50	.02
3. Attentional control[b]	.77	.60	.04*	.81	.65	.03*	.70	.50	.06*

Note: D + C = Decoding (D) and language comprehension (C) entered simultaneously. Verbal STM = Verbal short-term memory

[a] Verbal short-term memory entered in Step 3 after Attentional control in Step 2

[b] Attentional control entered in Step 3 after Verbal short-term memory in Step 2

* $p < .05$; ** $p < .01$

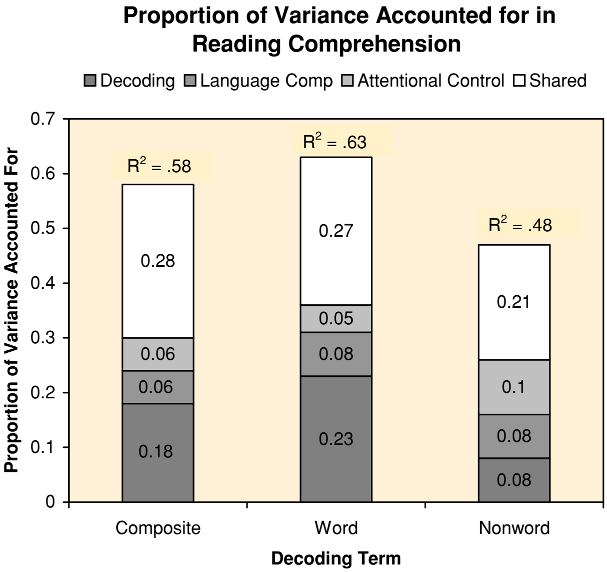

Fig. 1 Proportion of unique and shared variance in reading comprehension accounted for by decoding, language comprehension, and attentional control

unique variance than language comprehension or attentional control, with the latter two being fairly similar. However, when the nonword decoding term was used, the three predictors were similar in the amount of unique variance accounted for.

Contrast measures

Next, the five contrast measures were examined in terms of their possible contribution to reading comprehension. In turn, each of these measures was entered in Step 2 of the regression, after decoding and language comprehension (See Table 4). Only verbal short-term memory contributed significant variance to reading comprehension after the effects of decoding and linguistic comprehension. When the composite decoding term was used, $\Delta R^2 = .04$, $F\,(1, 63) = 5.79$, $p < .05$; when the word decoding term was used, $\Delta R^2 = .04$, $F\,(1, 63) = 7.27$, $p < .01$; and when the nonword decoding term was used, $\Delta R^2 = .05$, $F\,(1,63) = 5.58$, $p < .05$.

To determine the relative strength of prediction of reading comprehension by verbal short-term memory vs. attentional control, the proportion of variance accounted for after decoding and language comprehension was compared. Verbal short-term memory contributed 4–5% to the variance in reading comprehension, whereas attentional control contributed 5–10%. Further, each predictor was entered into the regression equation in Step 3 after the other had been entered in Step 2 (see Table 4). Verbal short-term memory did not add significantly to the prediction when entered in Step 3, after the effects of decoding, language comprehension, and attentional control, $\Delta R^2 = .02$, $p > .05$ for all decoding terms. In contrast, attentional control added significant variance to reading comprehension when entered in Step 3, after the effects of decoding, language comprehension, and verbal short-term memory, with ΔR^2 ranging from .03 to .06, all ps $< .05$.

Discussion

The main purpose of the present analysis was to examine attentional control as a possible third component of reading comprehension, along with decoding and language comprehension. As a preliminary step, three specific versions of the Simple View were compared—the multiplicative model, originally proposed by Gough and Tunmer (1986), the additive or linear model, used often in the literature, and the combination model, as modified from the multiplicative model by Hoover and Gough (1990). In the present sample, the multiplicative model did not explain as much variance as either the additive model or the combination model. In the combination model, the product of decoding and language comprehension only added a nonsignificant 1% variance to reading comprehension beyond that accounted for by the linear combination. Although Hoover and Gough (1990) found this increment for children in grade 3 to be somewhat larger (6.7%) and statistically significant, the present results are similar to those of Chen and Vellutino (1997), Dryer and Katz (1992), and Tiu et al. (2003). These researchers reported nonsignificant increments ranging from .1 to 1.4%, for children of about the same age. Differences in results between Hoover and Gough's (1990) study and the other studies may be attributable to sample composition. The participants in Hoover and Gough's (1990) study were bilingual, whereas those in the other three studies were monolingual. The bilingual sample may have had more zero-level performers due to limited English proficiency, which may have strengthened the product term (see Tiu et al., 2003). Though in the present study the simpler additive model was used for further analyses, it is recognized that the combination model may be particularly useful when there are zero-level performers in the sample.

In the present study, the amount of variance accounted for in the additive model ranged from 38 to 58% depending on which decoding term was used. Nonword reading resulted in the lowest proportion of variance accounted for (38%), followed by the composite (52%) and word recognition (58%). Chen and Vellutino (1997) and Johnston and Kirby (2006) also found that for third graders, a real word decoding term resulted in greater total variance in reading comprehension accounted for than a nonword decoding term. This pattern is consistent with the assertion by Hoover and Gough (1990; see also Gough & Hillinger, 1980) that the relevant decoding term for beginning readers is nonword reading, whereas the relevant decoding term for more skilled readers is real word reading. Hoover and Gough suggested that nonword reading is more relevant for beginning readers who are trying to read new words much of the time. However, real word reading is more relevant for more skilled readers who are reading known words. Also, Johnston and Kirby (2006, p. 355) suggested that the real word decoding term "includes more reading-related processes, such as orthographic processes" in addition to phonological processes. The fact that the real word decoding term (along with language comprehension) accounted for more variance than the nonword decoding term in these studies probably reflects that the eight-year-olds in the present study were no longer beginning readers and were using both phonological and orthographic processes in reading.

The main analyses in the present study investigated the role of attentional control in predicting reading comprehension. Hierarchical regression analyses showed that attentional control, as measured by the Star Counting Task, did contribute significant variance to the prediction of reading comprehension, after decoding and language comprehension had been entered. The amount of variance accounted for ranged from 5 to 10% depending on which decoding term was used, but in all cases it was statistically significant. Thus, the hypothesis that attentional control is a third component of reading comprehension in the Simple View was supported statistically.

As expected, some of the variance accounted for by the three components was common variance and some was unique. The balance of unique variance varied somewhat depending on which decoding term was used. When the composite term or word recognition term was used, decoding had a larger unique contribution than language comprehension or attentional control. When the nonword reading term was used, the unique contribution of decoding was similar to that of language comprehension and attentional control. Interestingly, in all cases, the unique contribution of attentional control was similar to that of language comprehension. The generally greater amount of unique variance attributable to decoding relative to language comprehension and attentional control was to be expected based on the age/reading level of the participants. For example, Catts et al. (2005) reported that the unique contributions of decoding and language comprehension, respectively, shifted from 27 and 9% in second grade to 13 and 21% in fourth grade to 2 and 36% in eighth grade. Data from the present study of eight-year-olds closely match those of the second graders from Catts et al. The nature of the reading comprehension test also may have been a contributing factor. Cutting and Scarborough (2006) showed that the balance of variance accounted for by decoding and language comprehension can vary with the specific reading comprehension test used (see also Johnson et al., 2005). Because it is restricted to single sentence passages, the PIAT-R Reading Comprehension subtest used in the present study may be more dependent on decoding than on language comprehension or attentional control.

Among the eight-year-olds in the present study, attentional control contributed less unique variance than word recognition, and about the same amount as language comprehension. Its relative contribution could change, however, as children get older and become better readers. Possibly, its relative contribution would decrease as word identification becomes more automatic and requires fewer cognitive resources. As this happens, there may be less of a demand for the coordination of decoding and language comprehension processes. This is only a conjecture, but research involving older children could explore this idea.

In addition to attentional control, five contrast variables were examined in relation to the Simple View of reading. Four of the five contrast variables did not contribute significant variance to the prediction of reading comprehension. The present finding that performance IQ did not add significant variance is in contrast with that of Tiu et al. (2003). The sample in the Tiu et al. study was on average two years older than that in the present study, and was composed of children with speech/language or reading difficulties and their siblings. However, both studies reported that performance IQ added approximately 2% of the variance to the prediction of reading comprehension. With nearly twice the sample size as in the present study, the Tiu et al. (2003) study had adequate power to detect this small effect as statistically significant. Still, the present study's results suggest that performance IQ is not as important a predictor of reading comprehension as attentional control. If entered into the hierarchical regression after attentional control, the effect of performance IQ was only .1–.8%, whereas if entered after performance IQ, the effect of attentional control was 5–7%, p's $< .01$. Using Full scale IQ, Cutting and Scarborough (2006) found only up to .5% variance accounted for in reading comprehension.

The present finding that phonemic awareness did not add significant variance to the prediction of reading comprehension is consistent with that of Neuhaus et al. (2006), who found that, for third graders, phonemic awareness had its effect on decoding rather than on reading comprehension. However, the finding is in contrast with that of Johnston and Kirby (2006). In their third graders, a phonemic awareness composite contributed a significant 4% variance to reading comprehension regardless of whether word or nonword decoding term was used. In the present study, phonemic awareness contributed 0–2% of the variance. Slight differences across the studies in the tasks used might explain the different results. In the present study, phonemic awareness correlated with reading comprehension ($r = .53$), but the variance it shared with reading comprehension was also shared with either decoding ($r = .55$–$.71$) or language comprehension ($r = .43$), such that it did not contribute unique variance to reading comprehension. The pattern of correlations was similar in the Neuhaus et al. (2006) study. Possibly, small changes in any of the tasks could shift this pattern, uncovering a unique contribution of phonemic awareness to reading comprehension. Even so, the present analysis suggests that attentional control is a stronger independent predictor of reading comprehension than phonemic awareness. Although it correlated substantially with reading comprehension ($r = .42$) it correlated much more weakly with both decoding ($r = .23$–$.30$) and language comprehension ($r = .08$).

In addition to Performance IQ and phonemic awareness, no significant unique contribution to reading comprehension was made by print exposure or articulation speed. Neither of these had been examined in the context of the Simple View prior to the present study (but see Goff et al., 2005). However, articulation speed was included in the present analysis as a measure of processing efficiency, and other efficiency or speeded measures have been investigated within the Simple View (e.g., naming speed, reading speed, and perceptual speed). The present results add to an already mixed picture of the role of speeded measures in the Simple View. As noted earlier in this paper, more research is needed on the role of processing speed in the Simple View of reading. Work that refines the type of speed measure that best fits in the Simple View of reading may be particularly useful. It may be that measures of isolated word or stimulus processing speed are not as good candidates for a Simple View component as speed measures that reflect the *coordination* of decoding and language comprehension processes. Measures such as naming speed or word reading speed may have their effect on decoding rather than directly on reading comprehension (see Johnston & Kirby, 2006; Neuhaus et al., 2006). On the other hand, speed of connected text reading might be more likely to have influence beyond decoding because it is an index of how well decoding and comprehension processes are coordinated. Indeed, in one study that included both naming speed and text reading speed measures (Cutting & Scarborough, 2006), text reading speed contributed significant variance to reading comprehension beyond decoding and language comprehension, whereas naming speed did not.

The one contrast variable that did contribute significantly to the prediction of reading comprehension was verbal short-term memory. This result is consistent with those of Goff et al. (2005) and Cain et al. (2004), who also reported that memory contributed significantly to reading comprehension in the Simple View model. They are inconsistent, however, with Cutting and Scarborough (2006), who reported that it did not. The percent variance contributed by memory ranged across these studies from 1 to 6.9%. Possibly, the difference across studies is due to different memory measures being used. Cain et al. (2004) argued that verbal working memory (storage and processing) is more importantly related to reading comprehension than storage-only measures or nonverbal measures. Their verbal working memory composite accounted for the most unique variance of any of these studies (6.9%). However, they also reported an unusually low contribution of decoding and language comprehension (26.3% compared to the usual 45–85%). In their study, there was more available variance in reading comprehension left to be taken up by memory. Although the present results do not resolve the issue of exactly how memory relates to reading comprehension within the Simple View model, they do suggest that further research on the role of memory in the Simple View is warranted. All the same, the present results suggest that verbal short-term memory is less important to reading comprehension than is attentional control. When attentional control was entered in the regression before verbal short-term memory, the significant effect of verbal short-term memory was eliminated. However, when verbal short-term memory was entered before attentional control, the effect of attentional control remained significant at 3–6%.

Thus, the present analysis highlights the importance of attentional control to reading comprehension and places it as a strong candidate for inclusion in an expanded Simple View of reading. Within the Simple View of reading, attentional control was more important than Performance IQ, phonemic awareness, print exposure, articulation speed, and verbal short-term memory. The importance of attentional control to the model may be due to its role in coordinating decoding and language comprehension processes (e.g., in detecting and repairing comprehension failures). Although processing speed may impact reading comprehension by making more cognitive resources available, it does not do the coordination work that attentional control is hypothesized to do. This may be why attentional control emerged as a stronger component of reading comprehension than either articulation speed or verbal short-term memory in the present analysis. More research is needed, however, to sort out the role of various types of processing speed and memory in relation to the Simple View and to replicate the present findings involving attentional control. Indeed, modification of the Simple View of reading would first require a better-developed theoretical basis for expanding the Simple View, independent evidence that a third component (i.e., attentional control) is not part of either decoding or language comprehension, and clearer evidence that problems in the third component (i.e., attentional control) can cause problems in reading comprehension. The present study provides statistical evidence for attentional control as a third component, but further theoretical and empirical work is needed.

Statistically, the present results suggest that the top students in reading comprehension must be good in decoding, language comprehension, and attentional control, because all three contribute independently to the variance in reading comprehension. If a student is poor in at least one of these skills, his or her reading comprehension will be compromised. Although these results certainly await replication, if substantiated, they would suggest that reading instruction should include emphasis not only on developing decoding and language comprehension skills (see Roberts & Scott, 2006) but also on developing attentional control within the reading context.

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