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Is Word-Problem Solving a Form of Text Comprehension?

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Abstract

This study's hypotheses were that (a) word-problem (WP) solving is a form of text comprehension that involves language comprehension processes, working memory, and reasoning, but (b) WP solving differs from other forms of text comprehension by requiring WP-specific language comprehension as well as general language comprehension. At the start of the 2nd grade, children ($n = 206$; on average, 7 years, 6 months) were assessed on general language comprehension, working memory, nonlinguistic reasoning, processing speed (a control variable), and foundational skill (arithmetic for WPs; word reading for text comprehension). In spring, they were assessed on WP-specific language comprehension, WPs, and text comprehension. Path analytic mediation analysis indicated that effects of general language comprehension on text comprehension were entirely direct, whereas effects of general language comprehension on WPs were partially mediated by WP-specific language. By contrast, effects of working memory and reasoning operated in parallel ways for both outcomes.

Word-problem (WP) solving differs from other forms of mathematics competence because it requires students to decipher text describing a problem situation and derive the number sentence representing the situation. Only then do students perform calculations to answer the problem's question about a missing number. Deciphering the WP statement appears related to the abilities required for text comprehension (TC). Decades ago, Kintsch and Greeno (1985) posited that the general features of the TC process apply across stories, informational text, and WP statements but that the comprehension strategies, the nature of required knowledge structures, and the form of resulting structures, inferences, and problem models differ by task.

Studies have investigated connections between WP solving and TC. For example, Vilenius-Tuohimaa, Aunola, and Nurmi (2008) reported substantial concurrent shared variance in these domains, controlling for foundational reading. Swanson, Cooney, and Brock (1993) identified TC as a correlate of WP solving, controlling for working memory (WM) and knowledge of operations, WP propositions, and calculation skill. In perhaps the most pertinent study, Boonen, Van Der Schoot, Van Wesel, De Vries, and Jolles (2013) substantiated effects of two component skills, visual-schematic WP representations and compare WP relational processing, on concurrent WP solution accuracy, while accounting for visual-spatial ability and TC.

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The present study was designed to extend beyond prior work in three important ways. First, we contrasted the patterns by which potentially underlying abilities predict WP solving versus TC. This permits a more stringent test of the hypothesis that WP solving is a form of TC than is possible when focusing on one of the two outcomes or examining more simple relations between reading and math. Second, we considered a broader pool of potentially active underlying abilities: WM, reasoning, listening comprehension, processing speed, calculations, and word recognition. Also, compared to Boonen et al. (2013), we assessed WP-specific language more broadly (compare and change WP language) while indexing understanding of this language instead of inferring understanding via solution accuracy and while investigating predictive rather than concurrent relations.

In this introduction, we briefly discuss arithmetic, which is an established pathway to early WP skill (Fuchs et al., 2006, 2012). Then we turn our attention to WPs, describing potential connections between WP solving and TC and elaborating on our methodological approach. We note that understanding the nature of WP solving is important because WPs are the best school-age predictor of employment and wages in adulthood (Every Child a Chance Trust, 2009; Murnane, Willett, Braatz, & Duhaldeborde, 2001), because WPs represent a major emphasis in almost every strand of the math curriculum at every grade, and because WPs can be a persistent deficit even when arithmetic skill is adequate (Swanson, Jerman, & Zheng, 2008). So WPs may represent a distinct component of math competence, and WP difficulty may be especially difficult to prevent. Our focus on WPs was at second grade, when individual differences on the WP types assessed in this study have been established (Fuchs et al., 2013).

ARITHMETIC: A NECESSARY BUT INSUFFICIENT FOUNDATION FOR WORD PROBLEMS

Research provides insight into the cognitive processes that support arithmetic development. Reasoning is involved (Fuchs et al., 2013; Geary, Hoard, Nugent, & Bailey, 2012), perhaps due to its role in understanding arithmetic relations and principles (Geary et al., 2012). The central executive component of WM, another predictor of arithmetic development, may help children maintain simultaneous activation of problems and answers while they count solutions (e.g., Fuchs, Geary, et al., 2010, 2013). Speed of processing, also a predictor of arithmetic (Bull & Johnston, 1997; Hecht, Torgesen, Wagner, & Rashotte, 2001), may help support efficient counting to produce correct associations between problems and answers.

Such understanding about the cognitive resources that support arithmetic development has led to theoretically guided interventions to enhance development. For example, Fuchs et al. (2013) assessed the efficacy of first-grade tutoring to support at-risk students' emerging arithmetic competence. The major focus of intervention was the number knowledge and relations that provide the basis for efficient counting procedures or retrieval processes, combined with speeded strategic practice to compensate for limitations in the cognitive resources associated with poor arithmetic. Results indicated dramatically superior performance.

One might also expect this arithmetic tutoring to simultaneously enhance WP outcomes, as arithmetic is a pathway to WP skill (e.g., Fuchs et al., 2006, 2012). However, effect sizes for arithmetic tutoring on WP outcomes were substantially lower than on arithmetic outcomes. Also, while tutoring narrowed the arithmetic achievement gap, the WP achievement gap widened. This suggests that although arithmetic is foundational to WP competence, arithmetic is not a sufficient pathway.

DISTINCTIONS BETWEEN ARITHMETIC AND WP PERFORMANCE

That arithmetic is a necessary but insufficient foundation for WP solving is not surprising, given that WPs require text processing to decipher a problem situation to derive a number sentence for solution. Accordingly, studies (Fuchs et al., 2012; Swanson, 2006) indicate that although reasoning and WM support arithmetic as well as WP development, processing speed plays a unique role in arithmetic, whereas language comprehension uniquely predicts WPs.

Given that language comprehension predicts development of both WPs and TC, the question arises, Is WP solving a form of TC? Kintsch and colleagues hypothesized that WP solving involves an interaction between (a) language comprehension processes and (b) problem-solving strategies that rely on WM and reasoning (Cummins, Kintsch, Reusser, & Weimer, 1988; Kintsch & Greeno, 1985; Nathan, Kintsch, & Young, 1992). Based on theories of TC and discourse processing (Dijk & Kintsch, 1983; Graesser, 2008), the model assumes that general features of the TC process apply across stories, informational text, and WP statements but that the comprehension strategies, nature of required knowledge structures, and form of resulting structures, inferences, and problem models differ by task.

As in Figure 1, the model assumes that memory representations of WPs have three components. The first involves constructing a coherent structure to capture the text’s essential ideas. The second component, the situation model, requires supplementing the text with inferences based on the child’s world knowledge, including knowledge about relations among quantities. The WP solver coordinates this information with the third component—knowledge about problem models or schema—to formalize the conceptual relations among quantities and guide application of solution strategies. At second grade, three dominant schemas are combine WPs (quantities are combined to form a total), compare WPs (quantities are compared to find a difference), and change WPs (an action triggers an increase or decrease in a starting amount; Riley, Greeno, & Heller, 1983).

The model poses that this process of building the propositional text structure, inferencing, identifying schema, and applying solution strategies makes strong demands on WM and reasoning. Consider a combine problem (Part 1 plus Part 2 equals Total): Joe has 3 marbles. Tom has 5 marbles. Tom also has 2 balls. How many marbles do the boys have in all? A competent WP solver processes Sentence 1 to identify that the object is marbles; the quantity is three; the actor is Joe; but Joe’s role is to be determined (TBD). These pieces of information are stored in memory. In Sentence 2, propositions are similarly coded and stored (object = marbles; quantity = 2; actor = Tom; Tom’s role = TBD). In Sentence 3, *balls* fails to match the object code in the first two sentences, signaling that 2 may be irrelevant. This is stored in memory. In Sentence 4 (the question), *how many marbles* and the phrase *in all* cues the child to identify the combine schema, assign the role of superset (Total) to the question, assign subset roles (Parts 1 and 2) to the TBD information, and reject two balls as irrelevant. Filling in these slots of the schema in this way triggers a set of strategies to find the missing information (Total). Errors are viewed as failures to produce the intended mental representations or to manage demands on WM and reasoning.

As Kintsch and colleagues discussed, however, WP solving also relies on language comprehension. Cummins et al. (1988) computationally simulated incorrect WP solving as a function of incorrect math problem-solving processing versus incorrect language comprehension. Problem representation depended more on language comprehension, and changing wording in minor ways dramatically affected solution accuracy. As Kintsch and Greeno (1985) noted, children "understand important vocabulary and language constructions prior to school entry" and "through instruction in arithmetic and WPs, learn to treat these words in a task-specific way, including extensions to ordinary usage for terms (e.g., *all or more*) to more complicated constructions involving sets (*in all* and *more than*)" (p. 111). This suggests that two forms of language comprehension are involved in WP solving. The first is general language competence, which applies across types of academic competence (e.g., WPs and other forms of TC). The second is WP-specific language, which applies specifically to WP solving.

STUDY OVERVIEW

In the present study, we considered the effects of the three cognitive/linguistic abilities addressed in the Kintsch model and for which the literature indicates a consistent role in WPs: WM span (Geary & Widaman, 1992; Hitch, 1978; Siegel & Ryan, 1989), nonlinguistic reasoning (Fuchs et al., 2012), and general language comprehension (Fuchs, Geary, Compton, Fuchs, Hamlett, Seethaler et al., 2010). We also included arithmetic as a foundational skill for WPs and processing speed due to its role in arithmetic (Fuchs et al., 2008).[1]

We examined direct effects of these abilities on WP solution accuracy but simultaneously considered whether effects of these cognitive/linguistic abilities are mediated by comprehension of WP-specific language constructions. (The WP-specific language measure did not require problem solution and thus more directly tapped language comprehension than does the WP outcome test, where only solution accuracy is scored.) In Task 1, students indicate whether compare WP questions refer to the bigger, smaller, or difference amount. This reflects understanding of the relational terminology needed to represent compare WPs via mathematical expressions. Task 2 presents relational statements in which the compared set is unknown; students identify which sentence preserves the relationship. This indexes understanding of the symmetry of *more* and *fewer*. Task 3 assesses understanding of the WP-specialized use of *more* in combination with *than* and *then* (someone has *more than*

[1]We focused on WM span involving digits and words. Although prior work indicates a role for visual-spatial WM (e.g., Boonen et al., 2013) and inhibition (e.g., Passolunghi et al., 2005), we omitted these due to time constraints and because they have not proven consistent predictors at this age range (e.g., Fuchs, Geary, Compton, Fuchs, Hamlett, Seethaler et al., 2010). We return to this omission in the discussion.

another vs. someone has a quantity and *then* gets *more*). Of course, all three tasks tax WM and reasoning (as do WPs and TC), raising the possibility that effects of WM, reasoning, and language comprehension are mediated by WP-specific language. The three tasks were, however, read aloud to students, and understanding of key language constructions, not the processes involved in operating on numbers, was required.

Our hypothesis, based on Kintsch and colleagues, was that WP solving depends on WM, reasoning, and general language comprehension and that effects of general language comprehension are partially mediated by WP-specific language. To create a stringent test of whether WP solving is a form of TC, we contrasted a parallel model using TC (instead of WP solving) as the outcome and using word recognition (instead of arithmetic) to control for foundational skill. Our second hypothesis, as per Kintsch and colleagues, was that TC also depends on WM (Carretti, Borella, Cornoldi, & De Beni, 2009; Miyake, Just, & Carpenter, 1994), reasoning (Chase, 1969), and general language comprehension (Catts, Hogan, & Adolf, 2005; Gough & Tunmer, 1986) but that, in contrast to WP solving, effects of general language comprehension on TC are entirely direct (not mediated by WP-specific language).[2]

METHOD

Participants

Participants were a representative sample of 206 children from 54 second-grade classrooms in 14 schools, At start of second grade, the mean age was 7 years 6 months; 52% were female; 78% received subsidized lunch; 59% were African American, 26% non-Hispanic White, 9% White Hispanic, and 5% other. On Wide Range Achievement Test–Arithmetic (Wilkinson, 1993), mean score was 93.04 (*SD* = 12.38); Wide Range Achievement Test–Reading, 102.10 (*SD* = 13.98); KeyMath–Revised (Connelly, 1998) –Problem Solving, 105.92 (*SD* = 9.29); Woodcock Reading Mastery Tests–Passage Comprehension (Woodcock, 1998), 100.66 (*SD* = 10.20); and Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999), 95.89 (*SD* = 12.34).

General Cognitive Predictor Measures

Processing speed—With WJ-III Visual Matching (Woodcock, McGrew, & Mather, 2001), children locate and circle two identical numbers in rows of six numbers; they have 3 min to complete 60 rows. Reliability is .91.

WM Span—Two subtests from the WM Test Battery for Children (WMTB-C; Pickering & Gathercole, 2001), Counting Recall and Listening Recall, were used. Each subtest has six items at span levels 1–6 to 1–9. Passing four items at a level moves the child to the next. Each level increases the number of items to be remembered by one. Failing three items terminates the subtest. The score was trials correct. For Listening Recall, children determine

[2]Statistical mediation seeks to identify a mechanism or process that underlies the relation between an independent and dependent variable. In a mediational model, the hypothesis is that the independent variable influences the mediator variable, which in turn influences the dependent variable, and that the indirect effect of the independent variable via the mediator on the outcome is also significant. Thus, the mediator variable clarifies the nature of the relation between the other two variables. For example, Fuchs et al. (2013) found that student improvement in fact-based retrieval, not improvement in counting procedures, partially mediated the effect of speeded strategic counting practice on arithmetic outcomes.

if a sentence is true; after making true/false determinations for each of a series of sentences, they recall the last word of each sentence. For Counting Recall, children count a set of four, five, six, or seven dots on a card; after counting each of a series of cards, they recall the number of counted dots on each card. We considered these measures of the central executive separately, based on prior work showing their predictive value differs, depending on type of outcome (Fuchs, Geary, Compton, Fuchs, Hamlett, Bryant, Seethaler, et al., 2010). Stability is .83 and .85.

Nonlinguistic reasoning—With WJ-III Concept Formation (Woodcock et al., 2001), children identify rules for concepts when shown illustrations of instances and noninstances of the concept. Pictures are of different shapes in different sizes and colors. Children earn credit by identifying the rule that governs each concept. Cutoff points determine the ceiling. The score is the number of correct responses. Reliability is .93.

Language comprehension—Woodcock Diagnostic Reading Battery–Listening Comprehension (Woodcock, 1997) measures understanding of sentences or passages. Students supply the word missing at the end of sentences/passages that progress from simple verbal analogies and associations to discerning implications. Reliability is .80.

Academic Control Variables

Arithmetic—From the Mathematics Assessment Battery (Fuchs, Hamlett, & Powell, 2003), Arithmetic Combinations includes Sums to 12, Sums to 18, Minuends to 12, and Minuends to 18. Each subtest has 25 items, for which students have 1 min to write answers. We used the total number of correct answers across the subtests. Alpha on this sample was .95.

Word recognition—With Word Identification Fluency (Fuchs, Fuchs, & Compton, 2004), children have 1 min to read a single page of 50 high-frequency words randomly sampled from 100 high-frequency words from the Dolch preprimer, primer, and first-grade levels. If they hesitate on a word for 4 s, the tester tells them to proceed. If they finish in less than 1 min, the score is prorated. Test–retest reliability is .86.

WP-Specific Language Measures

The Word Problem-Specific Language Assessment (Fuchs, DeSelms, & Deason, 2012) includes two subtests. On each, testers read WPs aloud while students follow along on paper. Students can request rereadings and write responses on paper. The first subtest, Bigger/Smaller WP Language, assesses understanding of WP language that determines bigger and smaller quantities, with two item types. With the first (eight items), students identify whether the quantity referred to in the WP's question is the bigger number, smaller number, or difference between the numbers (e.g., Linda has 3 toys. She has 8 fewer toys than Jane. How many toys does Jane have?). With the second type (eight items), students identify which of four sentences matches the meaning of a sentence describing a compare relationship (e.g., *Sue has 4 fewer stickers than Jan*, response options are: Jan has 4 fewer stickers than Sue; Jan has 4 more stickers than Sue; Sue has 4 more stickers than Jan; None of the above). Items of the first type were presented before the second type. Across 16 items, alpha on this sample was .86.

The second subtest, Compare/Change WP Language, assesses understanding of WP language that determines whether a problem compares two quantities or describes a change in quantity for one object; that is, the use of *more* combined with *than* versus *then* (e.g., someone having *more than* another vs. someone having a quantity and *then* getting *more*). For example, students hear: Robin had 4 pieces of candy. Then she went to the store and bought 8 more pieces. How many pieces of candy does she have now? or Robin had 4 more pieces of candy than Jose. Jose has 7. How many does Robin have? The tester asks, Does the problem tell us about the difference between two amounts of candy or about a starting amount of candy that changes? The order of compare and change problems was mixed. Alpha on this sample was .70.

Outcomes

WPs—Second-Grade Word Problems (Fuchs et al., 2009) includes 18 problems representing combine, compare, and change schemas, with missing information in all three positions of the schema's number sentence, with and without irrelevant information. Solutions require one-digit addition or subtraction. Testers read a WP aloud; students follow along on paper and have 1 min to write an answer before testers read the next WP. Each WP is scored for correct math (1 point) and label (1 point) to reflect processing of the WP statement and understanding of the problem's theme. Alpha on this sample was .86.

TC—Woodcock Reading Mastery Tests–Revised–Normative Update (Woodcock, 1998)–Passage Comprehension uses a maze procedure. For the first set of items, the tester presents a rebus; children point to the corresponding picture. Next, children point to the picture representing words on a page. Then children read a sentence or passage silently and identify the missing word. Items assess understanding the text's essential ideas (the propositional text structure) or the ability to build the situation model (supplement the text with inferences based on world knowledge). Split-half reliability is .91.

Procedure

Testers were trained to criterion on each measure and used standard administration directions. In the fall, testing occurred individually on word recognition, processing speed, WM, nonlinguistic reasoning, and general language comprehension; the arithmetic measure was administered in classrooms or small groups. In spring, TC was administered individually; the WP-Specific Language and WPs measures were administered in classrooms or small groups. Interscorer agreement on each measure exceeded 98%. Individual sessions were audiotaped; 15% of tapes were selected randomly, stratifying by tester, for accuracy checks by independent scorers. Agreement exceeded 99%.

RESULTS

See Table 1 for means, standard deviations, and correlations (all $p < .001$). Sample-based z scores were used in analyses, which examined total, direct, and indirect effects of foundational academic skill and cognitive/linguistic abilities on WPs and on TC. We used Preacher and Hayes's (2008) SPSS mediate macro to obtain estimates, with bootstrapping (5,000 draws to estimate standard errors) applied to construct 95% confidence intervals for indirect effects.

Effects on WPs

Tables 2 and 3 summarize total, direct, and indirect effects of arithmetic and cognitive/linguistic abilities on WPs. As bolded at the end of Table 2, the direct effects of arithmetic, reasoning, and general language comprehension on WPs were significant while controlling for direct and indirect effects of all variables in the model. As in Table 3, the total effect (direct plus indirect effects) on WPs was again significant for arithmetic, reasoning, and general language comprehension, and the omnibus test of the total effect on WPs was significant, $R^2 = .52$, $F(6, 199) = 36.33$, $p < .001$.

In considering whether a mediating effect is significant, it is necessary to establish that the effect of the independent variable on the potential mediator (path *a*) and the effect of the potential mediator on the outcome (path *b*) are significant while controlling for effects of all independent variables. As bolded at the top of Table 2, the effects of Bigger/Smaller WP Language and Compare/Change WP Language on WPs (path *b*) were significant. The bolded paths in the middle panel of Table 2 (path *a*) show that WM listening recall, reasoning, and general language comprehension had significant effects on Bigger/Smaller WP Language and that general language comprehension had a significant effect on Compare/Change WP Language. This left four potentially mediating effects.

The final step is to test whether the indirect effect of each potential mediator on WPs is significant while controlling for independent variables and potential mediators in the model. As bolded in Table 3, each of the four indirect effects was significant (95% confidence intervals do not cover 0). Also, the omnibus test of direct effect was significant, $R^2 = .26$, $F(6, 197) = 19.38$, $p < .001$, indicating arithmetic and the cognitive/linguistic predictors together made a significant contribution over indirect effects via WP Language.

See top panel of Figure 2 for significant direct (solid lines), mediating effects (dotted lines), and total effects (gray boxes) on WPs. Foundational mathematics skill (arithmetic) plus reasoning and general language comprehension exerted direct effects on WPs. Reasoning and general language comprehension (not arithmetic) also affected WPs indirectly: concept formation via Bigger/Smaller WP Language and general language comprehension via both forms of WP-specific language. WM listening recall affected WPs indirectly, via Bigger/smaller WP Language.

Effects on TC

See Tables 4 and 5 for total, direct, and indirect effects on TC. As bolded at the end of Table 4, direct effects of word recognition, reasoning, and general language comprehension on TC were significant, controlling for all direct and indirect effects. As bolded in Table 5, the total effect was significant for these same variables. Also, the omnibus test of the total effect on TC was significant, $R^2 = .68$, $F(6, 199) = 69.55$, $p < .001$.

As bolded at top of Table 4, Bigger/Smaller WP language but not Compare/Change WP Language had a significant effect on TC (path *b*), eliminating Compare/Change WP language as a mediator. The bold paths (middle panel of Table 4; paths *a*) show that WM listening recall, reasoning, and general language comprehension had significant effects on Bigger/Smaller WP-Specific Language. As bolded in Table 5, two of these three indirect effects on TC were significant: WM listening recall and reasoning, both via Bigger/Smaller WP-Specific Language. The omnibus test of direct effect was significant, $R^2 = .47$, $F(6, 197) = 48.92$, $p < .001$, so word recognition and the general cognitive predictors made a significant contribution over the indirect effects.

These effects are illustrated in the bottom panel of Figure 2. Foundational reading skill (word recognition) plus reasoning and general language comprehension exerted direct effects on TC. Reasoning also affected TC indirectly, via Bigger/Smaller WP Language, as did WM listening recall. Notably, effects of general language comprehension on TC were entirely direct (not mediated via WP-specific language).

DISCUSSION

Similar Role for Reasoning, WM, and General Language Comprehension

Kintsch and Greeno (1985) posited that general features of the TC process apply across stories, essays, and WP statements. Accordingly, we found that nonlinguistic reasoning, general language comprehension, and WM supported WP solving as well as TC, with many similarities.

The direct effects of nonlinguistic reasoning and general language comprehension were significant for both outcomes, with beta coefficients of .20 and .11 for WPs and .14 and .17 for TC. This was also the case for total effects (direct plus indirect effects), with coefficients of .25 and .16 for WPs and .15 and .18 for TC. Also, WM appeared involved in supporting both outcomes, again in similar ways. Although the direct effect for each WM measure failed to achieve statistical significance, the beta coefficients summed across counting recall and listening recall to .17 for WPs and .12 for TC. Moreover, for each outcome, the indirect effect of listening recall via bigger/smaller language comprehension was significant, with similar coefficients of .04 and .03.

It is not surprising that WM plays a role in both forms of TC. Previous studies show that TC depends on WM (Carretti et al., 2009; Miyake et al., 1994). Readers with strong WM execute TC processes (word encoding, lexical access, syntactic analysis, semantic analysis) without depleting WM resources; this is not the case for individuals with weaker WM (Miyake et al., 1994). Researchers posit a dual role for WM, whereby TC requires holding recently processed text to make connections to earlier input and maintaining the gist of information to construct an overall text model.

The literature also provides support for the importance of WM in WPs. Good versus poor WP solvers differ on WM (Passolunghi & Siegel, 2004; Swanson & Sachse-Lee, 2001), and individual differences in WM account for variance in WPs, when controlling for other cognitive resources (Fuchs, Geary, Compton, Fuchs, Hamlett, & Bryant, 2010; Swanson &

Beebe-Frankenberger, 2004). In theories of mathematics generally and WPs specifically (Kintsch & Greeno, 1985; LeFevre et al., 2010), WM features prominently. As the WP narrative is processed to construct a coherent representation of the problem model, new sets are formed online. When a proposition is completed that triggers a set-building strategy, the relevant propositions are assigned places in the schema. As new sets are formed, previous sets that had been active in the memory buffer are displaced.

The present study adds to this literature by suggesting that WM's role in WPs and in TC is mediated by some but not all forms of WP-specific language comprehension. The effect of WM was *not* mediated by language that helps determine whether WPs belong to the compare or change schema. Our measure of compare/change WP language indexes confusion between the use of *more*/*than* versus *more*/*then*, as in *John had 5 more fish than Mary* versus *John had 5 fish. Then he got 2 more*. This kind of language comprehension requires sensitivity to two specific language constructions. It does not, however, transparently tax WM.

By contrast, the effect of WM was mediated by the syntactic constructions that help decipher which object in a text is bigger (e.g., Rachel drew 8 pictures. She drew 6 more than Carl. How many pictures did Carl draw?, where the task is to decide whether Carl has the bigger or smaller quantity). This type of language comprehension represents a complex, multistep process. In this example, the child must hold on line Rachel's amount of 8 while deciding, based on a complicated construction that involves a pronoun and does not specifically state Carl's amount, whether Carl has more or less than Rachel; then the student has to hold the comparison (Rachel has more than Carl) on line while determining which character is referred to in the question: the one with the bigger or smaller amount.

This process transparently taxes WM, and results provide empirical support for the idea that the effects of WM on TC are mediated via children's understanding of bigger/smaller WP language. Although this language comprehension task was contextualized specifically within WPs, it affected WP solving and TC in parallel ways, with almost identical beta coefficients. This suggests the need to work deliberately on the WM demands created during TC, perhaps with activities designed to increase WM span in the context of reading tasks that challenge WM. Future research might explore whether increasing WM span in the context of WP narratives, in ways that reflect theoretical understanding about how WM operates to support TC, improves WP solving as well as TC.

Nonlinguistic reasoning also uniquely predicted both outcomes in similar ways—directly and indirectly via bigger/smaller language. We operationalized nonlinguistic reasoning by asking children to identify the rule guiding a concept, when shown illustrations of instances and noninstances of that concept. For example, given a picture of circles or squares, both of which are yellow or red but only one of which is small, the child has to identify which circle is most different. This form of reasoning reflects the ability to distinguish instances from noninstances of a class, by distinguishing relevant from irrelevant features of that class. This kind of reasoning is central to the development of vocabulary and appreciation of subtle differences in the meaning of language. So it is not surprising that nonlinguistic reasoning exerted a direct effect on WPs and TC, especially because previous research has identified nonlinguistic reasoning as a predictor of WP solving (e.g., Fuchs et al., 2006) and TC (Chase, 1969, although this dated study was the only relevant one we identified). What's more surprising is that this effect occurred in the context of WM and general listening comprehension as competing predictors. In these ways, findings provide support for the role of nonlinguistic reasoning separately from the role of vocabulary in language comprehension.

This is noteworthy because results also indicate that effects of this form of nonlinguistic reasoning are partially mediated via WP-specific language (bigger/smaller WP language), not only in predicting WP solving but also in supporting TC. Findings thus suggest that the language demands associated with both outcomes are complex and reflect semantic as well as syntactic textual demands. This suggests that the ability to reason analytically in formulating rules about classes of objects represents an important foundation for TC beyond general language comprehension.

More generally, results support the idea that WP solving is a form of TC. They also suggest that intervention strategies focused on enhancing at-risk children's text processing, in ways that are sensitive to students' potential limitations in WM, nonlinguistic reasoning, and general language comprehension, may simultaneously benefit WP solving and TC. Future research might explore this possibility.

Need to Treat Key Vocabulary and Language Constructions in a Task-Specific Way

Although Kintsch and Greeno (1985) hypothesized that reasoning, WM, and general language comprehension are involved in many similar ways in handling WP statements and other forms of text, they also suggested that successful WP solvers must treat important vocabulary and language constructions in a task-specific way. We also found support for this view. The effects of general language comprehension on TC were entirely direct, whereas these effects were partially mediated by WP-specific language in predicting WP solving. The direct effect on TC ($\beta = .17$) was somewhat larger than the direct effect on WPs ($\beta = .11$), but the total effect of general language comprehension for the two outcomes was similar (.18 vs. .16). This is due to the additional *in*direct effects of general language comprehension on the WP outcome: an additional beta of .03 via bigger/smaller WP language and .02 via compare/change WP language. So a second form of language competence—WP-specific language comprehension—was required for WP solving but not TC. Moreover, in predicting WPs, language comprehension was the only cognitive/linguistic ability for which indirect effects occurred via both forms of WP-specific language.

In these ways, results suggest that to prevent WP difficulty, a focus on WP-specific language comprehension may be a productive intervention strategy. This represents a novel direction in WP intervention, which has been dominated by WP-solving strategies designed to compensate for at-risk children's weaknesses in reasoning and WM. For example, schema-based instruction (Fuchs et al., 2009; Jitendra et al., 2009), a demonstrably efficacious approach for improving WP solving, teaches students to use efficient reasoning strategies in analyzing WP statements to identify problem schema. It also teaches students efficient problem-solution routines to reduce the burden on WM.

By contrast, addressing at-risk children's vulnerabilities in WP-specific language comprehension has not been evaluated. The need to do so is supported not only by results of the present study but also by research showing that children's understanding of WP-specific language partially mediates the effects of schema-based instruction (Schumacher & Fuchs, 2012). Future research should examine the effects of schema-based instruction with and without an intervention component that explicitly teaches children strategies for handling the complex WP-specific constructions in WPs. This is important because WPs are a critical component of the mathematics curriculum. Present findings not only suggest novel directions for expanding the framework for WP intervention but also suggest that the robustness of WP solving as a predictor school and employment outcomes may be due to the possibility that WPs simultaneously index mathematics reasoning, computational skills, and TC.

Even so, it is important to note WP solving is important for navigating the challenges of life outside of school. In everyday life, however, mathematics problem-solving situations are not typically presented via written problem statements. Rather, they are contextualized in situations that naturally embed information across multiple sources that must be retrieved and integrated while deciphering that information to formulate a number sentence for problem solution. This suggests the need for research on the role of cognitive/linguistic predictors of everyday mathematics problem solving versus WP solving (presented via text) and on how the development of these two forms of problem solving differ from or correspond with the development of TC.

Closing Thoughts about TC and Its Connections to WP Solving

Before closing, we offer some comments on the topic of TC generally and on a potential difference between TC and WP solving. First, with respect to TC generally, the Simple View of Reading (Gough & Tunmer, 1986) posits that TC is the product of word recognition and language comprehension. Students use word recognition to translate print into language; language comprehension helps them make sense of that linguistic information. Early text comprehension is largely constrained by word recognition skill. Once that is automatized, TC approximates language comprehension and largely depends on language comprehension (Catts et al., 2005). Our results corroborate the importance of language comprehension in TC, even as the direct effect of word recognition supports the importance of word-level skill. Nevertheless, with word recognition and language comprehension controlled in the model, WM and nonlinguistic reasoning accounted for additional variance in predicting TC. This suggests the need to consider these abilities in modeling development of TC and creating theoretically guided interventions. Results also raise the question, Is the Simple View of Reading perhaps too simple?

Second, regarding a key difference between TC and WP solving, the effect of word recognition on TC was larger than the effect of arithmetic on WP solving: .54 vs. .29. This difference was substantially larger than was the case for any cognitive or linguistic predictor. So the difference in total variance explained in TC versus WP solving (68% vs. 52%) was due to the contribution of foundational skill. This indicates that teaching word recognition should have a larger effect on TC than teaching arithmetic has on WP solving.

In fact, a large-scale randomized control trial revealed limited transfer from calculation skill to WP solving, when calculation instruction deliberately avoided contextualizing number concepts in WPs (Fuchs et al., 2014).

Accordingly and with 48% of the variance in WP solving left unexplained, work is required to understand the cognitive/linguistic and foundational skills that support WP development. Yet, even for TC, 32% of the variance was not explained. Therefore, additional variables, not included in Kintsch's model or the present study, account for both outcomes. One likely candidate is instructional quality. Another is students' background knowledge, which has a strong effect on TC (Compton, Miller, Gilbert, & Steacy, 2013), although its role in WP solving requires investigation. A third potential contributor is what is referred to *Habits of Mind* (Perfetti, Landi, & Oakhill, 2005; Rapp, Van Den Broek, McMaster, Kendeou, & Espin, 2007), which reflects the ambitiousness of the standard of coherence students apply to persist through academic challenge. The relevance of such variables should be investigated in more complex models aimed at understanding differences and similarities between TC and WP solving.

Results should also be interpreted with four study limitations in mind. First, indexing TC at second grade is challenging. Few good measures exist. We selected a commercial measure widely used in second grade. At the same time, no commercial WP measures with adequate behavior sampling at this age exist, so we relied on an experimental WP task. Moreover, TC is by nature a broader construct than WP solving. These differences may produce distinctions in predictions for the two outcomes, and we measured each construct with a particular measure, when different TC measures may produce varying patterns of performance (Eason, Goldberg, Young, Geist, & Cutting, 2012). So future studies should rely on latent variables, with multiple measures of each construct. Second, future research should measure knowledge of vocabulary specific to TC measures; this would further strengthen the test of our hypothesis about distinctions between TC and WP solving. Third, some prior work has focused on other forms of WM as predictors of WP solving: visual-spatial WM (e.g., Boonen et al., 2013) and inhibition (e.g., Passolunghi, Marzocchi, & Fiorillo, 2005). Future studies should address our omission of these variables to estimate how their inclusion affects the contributions of other predictors, and effects at higher grades, as the difficulty of WPs increase, should also be examined. Finally, conclusions about causality should be avoided because our methods are at root correlational.

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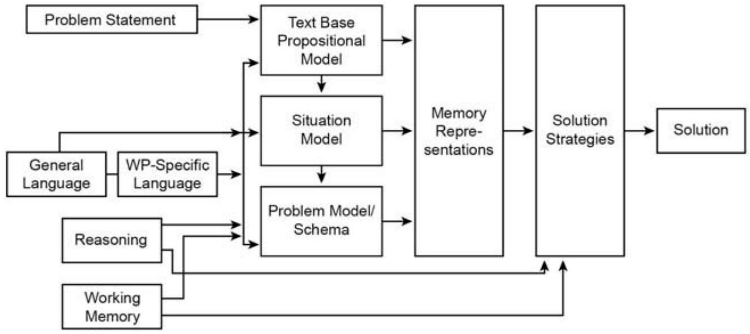

FIGURE 1.
Conceptual framework.

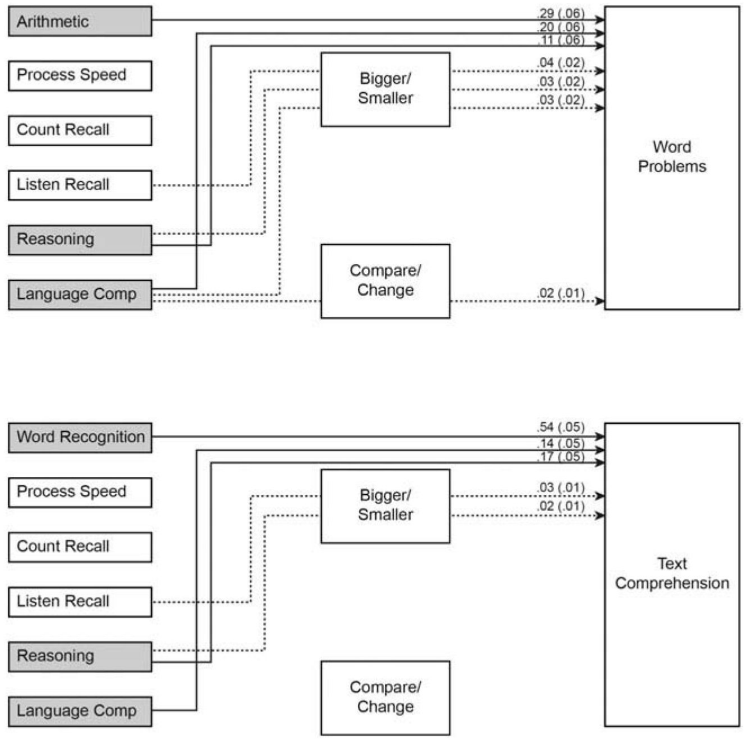

FIGURE 2.

Significant direct effects for foundational academic skill and general cognitive abilities (solid lines), significant indirect effects via WP language (dotted lines), and significant total effects (shaded boxes) on word problems (top panel) and text comprehension (bottom panel).

TABLE 1

Means and Standard Deviations for Raw Scores and Nationally Norm-Referenced Standard Scores and Correlations

	Raw Scores		Standard Scores		Correlations										
Variables	**M**	**(SD)**	**M**	**(SD)**	**A**	**W**	**WR**	**SC**	**P**	**CR**	**LR**	**CF**	**LC**	**B**	**C**
Arithmetic (A)	5.79	(3.08)	—												
Word Problems (W)	6.36	(3.95)	—		.53										
Word Recognition (WR)	57.66	(20.08)	—	.42	.35										
Text comprehension (TC)	19.59	(4.85)	100.66	(10.20)	.44	.55	.73								
Processing Speed (P)	11.09	(2.86)	93.26	(16.16)	.43	.48	.31	.44							
Counting Recall (CR)	14.37	(5.31)	94.51	(17.76)	.34	.43	.30	.41	.45						
Listening Recall (LR)	6.53	(4.20)	91.74	(20.21)	.35	.49	.33	.46	.34	.43					
Concept Formation (CF)	10.48	(6.42)	89.52	(13.50)	.23	.51	.22	.45	.37	.27	.46				
Language Comp (LC)	17.50	(4.74)	89.87	(15.71)	.26	.46	.38	.54	.33	.27	.41	.41			
Bigger/Smaller WP Lang (B)	11.76	(4.98)	96.23	(14.16)	.25	.50	.26	.44	.34	.29	.45	.41	.37		
Comp/Change WP Lang (C)	4.84	(9.09)	11.58	(2.53)	.23	.36	.20	.28	.17	.14	.24	.26	.28	.28	

Note. n = 206. Arithmetic is Arithmetic Combinations from the Mathematics Assessment Battery (Fuchs, Hamlett, & Powell, 2003). Word Problems is Second-Grade Word Problems (Fuchs et al., 2009). Word Recognition is Word Identification Fluency (Fuchs et al., 2004). Informational text comprehension is Passage Comprehension from Woodcock Reading Mastery Tests-R-N/U (Woodcock, 1998). Processing Speed is WJ-III Visual Matching (Woodcock et al., 2001). Listening Recall is from the Working Memory Test Battery–Children (WMTB; Pickering & Gathercole, 2001). Concept Formation is WJ-III Concept Formation (Woodcock et al., 2001). Counting Recall is from WMTB. Listening Comprehension is Woodcock Diagnostic Reading Battery–Listening Comprehension (Woodcock, 1997; standard score M = 100; SD = 15. Bigger/Smaller WP Language and Comp/Change WP Language are from Word Problem-Specific Language Assessment (Fuchs, DeSelms, & Deason, 2012).

TABLE 2

Coefficients for Paths a, Paths b, and Paths c' on Word Problems

Path	Coefficient (SE)	t value (p)
Paths *b*: Effect of potential mediators on word-problem outcome		
Bigger/Smaller → Word Problems	**.18 (.06)**	**3.25 (.001)**
Compare/Change → Word Problems	**.11 (.05)**	**2.10 (.037)**
Paths *a*: Effect of independent variables on potential mediators		
Arithmetic → Bigger/Smaller	.02 (.07)	0.26 (.796)
Arithmetic → Compare/Change	.14 (.08)	1.87 (.063)
Processing Speed → Bigger/Smaller	.12 (.07)	1.57 (.119)
Processing Speed → Compare/Change	−.01 (.08)	−0.07 (.754)
Counting Recall → Bigger/Smaller	.04 (.07)	0.56 (.579)
Counting Recall → Compare/Change	−.03 (.08)	−0.31 (.754)
Listening Recall → Bigger/Smaller	**.24 (.08)**	**3.23 (.001)**
Listening Recall → Compare/Change	.07 (.08)	0.88 (.380)
Reasoning → Bigger/Smaller	**.18 (.07)**	**2.58 (.011)**
Reasoning → Compare/Change	.13 (.08)	1.67 (.096)
Listening Comprehension → Bigger/Smaller	**.14 (.07)**	**2.03 (.043)**
Listening Comprehension → Compare/Change	**.17 (.08)**	**2.24 (.026)**
Paths *c*': Direct effect of independent variables on word-problem outcome		
Arithmetic → Word Problems	**.29 (.06)**	**5.21 (<.001)**
Processing Speed → Word Problems	.09 (.06)	1.59 (.114)
Counting Recall → Word Problems	.11 (.06)	1.86 (.063)
Listening Recall → Word Problems	.06 (.06)	1.05 (.294)
Reasoning → Word Problems	**.20 (.06)**	**3.53 (<.001)**
Listening Comprehension → Word Problems	**.11 (.06)**	**2.05 (.042)**

Note. In all models, the effects of the other predictor variables were controlled. Arithmetic is Arithmetic Combinations from the Mathematics Assessment Battery (Fuchs, Hamlett, & Powell, 2003). Word Problems is Second-Grade Word Problems (Fuchs et al., 2009). Word Recognition is Word Identification Fluency (Fuchs et al., 2004). Informational text comprehension is Passage Comprehension from Woodcock Reading Mastery Tests-R-N/U (Woodcock, 1998). Processing Speed is WJ-III Visual Matching (Woodcock et al., 2001). Listening Recall is from the Working Memory Test Battery–Children (WMTB; Pickering & Gathercole, 2001). Concept Formation is WJ-III Concept Formation (Woodcock et al., 2001). Counting Recall is from WMTB. Listening Comprehension is Woodcock Diagnostic Reading Battery–Listening Comprehension (Woodcock, 1997; standard score $M = 100$; $SD = 15$. Bigger/Smaller WP Language and Comp/Change WP Language are from Word Problem-Specific Language Assessment (Fuchs, DeSelms, & Deason, 2012).

TABLE 3

Independent Variables' Total and Indirect Effects (Via Potential Mediators) on Word-Problem Outcome

Path		*Indirect Effect (Path* ab*)*	*t Value* (p)[a] *Bootstrapped 95% CI*[b]
Arithmetic	**Total Effect**	**.31 (.06)**	**5.40 (<.001)**
	Indirect effect via Bigger/Smaller	.00 (.01)	[−.0179, .0256]
	Indirect effect via Compare/Change	.02 (.01)	[−.0001, .0367]
Processing Speed	Total Effect	.11 (.06)	1.88 (.061)
	Indirect effect via Bigger/Smaller	.02 (.02)	[−.0012, .0499]
	Indirect effect via Compare/Change	−.00 (.01)	[−.0168, .0152]
Counting Recall	Total Effect	.11 (.06)	1.88 (.0617)
	Indirect effect via Bigger/Smaller	.01 (.01)	[−.0141, .0315]
	Indirect effect via Compare/Change	−.00 (.01)	[−.0189, .0121]
Listening Recall	Total Effect	.12 (.06)	1.89 (.060)
	Indirect effect via Bigger/Smaller	**.04 (.02)**	**[.0156, .0811]**
	Indirect effect via Compare/Change	.01 (.01)	[−.0066, .0273]
Reasoning	**Total Effect**	**.25 (.06)**	**4.29 (<.001)**
	Indirect effect via Bigger/Smaller	**.03 (.02)**	**[.0091, .0646]**
	Indirect effect via Compare/Change	.01 (.01)	[−.0008, .0360]
Listen Comprehension	**Total Effect**	**.16 (.06)**	**2.79 (.006)**
	Indirect effect via Bigger/Smaller	**.03 (.02)**	**[.0042, .0543]**
	Indirect effect via Compare/Change	**.02 (.01)**	**[.0014, .0414]**

Note. In all models, the effects of other predictors were controlled. Confidence intervals (CIs) that do not cover zero are statistically significant. Arithmetic is Arithmetic Combinations from the Mathematics Assessment Battery (Fuchs, Hamlett, & Powell, 2003). Word Problems is Second-Grade Word Problems (Fuchs et al., 2009). Word Recognition is Word Identification Fluency (Fuchs et al., 2004). Informational text comprehension is Passage Comprehension from Woodcock Reading Mastery Tests-R-N/U (Woodcock, 1998). Processing Speed is WJ-III Visual Matching (Woodcock et al., 2001). Listening Recall is from the Working Memory Test Battery–Children (WMTB; Pickering & Gathercole, 2001). Concept Formation is WJ-III Concept Formation (Woodcock et al., 2001). Counting Recall is from WMTB. Listening Comprehension is Woodcock Diagnostic Reading Battery–Listening Comprehension (Woodcock, 1997; standard score M = 100; SD = 15. Bigger/Smaller WP Language and Comp/Change WP Language are from Word Problem-Specific Language Assessment (Fuchs, DeSelms, & Deason, 2012).

[a] *t* value (*p*) is for Total Effect.

[b] Bootstrapped 95% confidence interval (CI) is for indirect effects.

TABLE 4

Coefficients for Paths a, Paths b, and Paths c’ on Text Comprehension

Path	Coefficient (SE)	t Value (p)
Paths *b*: Effect of potential mediators on text comprehension outcome		
Bigger/Smaller → Text comprehension	**.10 (.05)**	**2.18 (.030)**
Compare/Change→ Text comprehension	.02 (.04)	0.48 (.632)
Paths *a*: Effect of independent variables on potential mediators		
Word Recognition → Bigger/Smaller	.05 (.07)	0.74 (.460)
Word Recognition → Compare/Change	.08 (.08)	1.01 (.315)
Processing Speed → Bigger/Smaller	.11 (.07)	1.61 (.109)
Processing Speed → Compare/Change	.03 (.08)	0.36 (.720)
Counting Recall → Bigger/Smaller	.04 (.07)	0.50 (.617)
Counting Recall → Compare/Change	−.02 (.08)	−0.23 (.822)
Listening Recall → Bigger/Smaller	**.24 (.07)**	**3.21 (.002)**
Listening Recall → Compare/Change	.09 (.08)	1.09 (.279)
Reasoning → Bigger/Smaller	**.19 (.07)**	**2.59 (.010)**
Reasoning → Compare/Change	.13 (.08)	1.64 (.104)
Listening Comprehension → Bigger/Smaller	.13 (.07)	1.81 (.072)
Listening Comprehension → Compare/Change	**.16 (.08)**	**2.02 (.044)**
Paths *c*’: Direct effect of independent variables on story text comprehension outcome		
Word Recognition → Text comprehension	**.54 (.05)**	**12.04 (< .001)**
Processing Speed → Text comprehension	.08 (.05)	1.72 (.088)
Counting Recall → Text comprehension	.08 (.05)	1.61 (.110)
Listening Recall → Text comprehension	.04 (.05)	0.70 (.484)
Reasoning → Text comprehension	**.14 (.05)**	**2.85 (.005)**
Listen Comprehension → Text comprehension	**.17 (.05)**	**3.43 (< .001)**

Note. In all models, the effects of the other predictor variables were controlled. Arithmetic is Arithmetic Combinations from the Mathematics Assessment Battery (Fuchs, Hamlett, & Powell, 2003). Word Problems is Second-Grade Word Problems (Fuchs et al., 2009). Word Recognition is Word Identification Fluency (Fuchs et al., 2004). Informational text comprehension is Passage Comprehension from Woodcock Reading Mastery Tests-R-N/U (Woodcock, 1998). Processing Speed is WJ-III Visual Matching (Woodcock et al., 2001). Listening Recall is from the Working Memory Test Battery–Children (WMTB; Pickering & Gathercole, 2001). Concept Formation is WJ-III Concept Formation (Woodcock et al., 2001). Counting Recall is from WMTB. Listening Comprehension is Woodcock Diagnostic Reading Battery–Listening Comprehension (Woodcock, 1997; standard score M = 100; SD = 15. Bigger/Smaller WP Language and Comp/Change WP Language are from Word Problem-Specific Language Assessment (Fuchs, DeSelms, & Deason, 2012).

TABLE 5

Independent Variables' Total and Indirect Effects (Via Potential Mediators) on Text Comprehension

Path		***Indirect Effect (Path* ab)**	***t Value* (p)[a] *Bootstrapped 95% CI*[b]**
Word Recognition	**Total Effect**	**.55 (.05)**	**12.13 (< .001)**
	Indirect effect via Bigger/Smaller	.01 (.01)	[−.0063, .0202]
	Indirect effect via Compare/Change	.00 (.00)	[−.0051, .0104]
Processing Speed	Total Effect	.10 (.05)	1.97 (.050)
	Indirect effect via Bigger/Smaller	.01 (.01)	[−.0088, .0303]
	Indirect effect via Compare/Change	−.00 (.00)	[−.0052, .0080]
Counting Recall	Total Effect	.08 (.05)	1.66 (.098)
	Indirect effect via Bigger/Smaller	.00 (.01)	[−.0088, .0186]
	Indirect effect via Compare/Change	−.00 (.00)	[−.0071, .0055]
Listening Recall	Total Effect	.06 (.05)	1.25 (.213)
	Indirect effect via Bigger/Smaller	**.03 (.01)**	**[.0046, .0511]**
	Indirect effect via Compare/Change	.00 (.01)	[−.0057, .0119]
Reasoning	**Total Effect**	**.16 (.05)**	**3.34 (.001)**
	Indirect effect via Bigger/Smaller	**.02 (.01)**	**[.0026, .0419]**
	Indirect effect via Compare/Change	.00 (.01)	[−.0072, .0150]
	Listen Comprehension: Total Effect	**.18 (.05)**	**3.80 (<.001)**
	Indirect effect via Bigger/Smaller	.01 (.01)	[.0000, .0325]
	Indirect effect via Compare/Change	.00 (.01)	[−.0085 *to*.0175]

Note. In all models, the effects of other predictors were controlled. Confidence intervals (CIs) that do not cover zero are statistically significant. Arithmetic is Arithmetic Combinations from the Mathematics Assessment Battery (Fuchs, Hamlett, & Powell, 2003). Word Problems is Second-Grade Word Problems (Fuchs et al., 2009). Word Recognition is Word Identification Fluency (Fuchs et al., 2004). Informational text comprehension is Passage Comprehension from Woodcock Reading Mastery Tests-R-N/U (Woodcock, 1998). Processing Speed is WJ-III Visual Matching (Woodcock et al., 2001). Listening Recall is from the Working Memory Test Battery–Children (WMTB; Pickering & Gathercole, 2001). Concept Formation is WJ-III Concept Formation (Woodcock et al., 2001). Counting Recall is from WMTB. Listening Comprehension is Woodcock Diagnostic Reading Battery–Listening Comprehension (Woodcock, 1997; standard score M = 100; SD = 15. Bigger/Smaller WP Language and Comp/Change WP Language are from Word Problem-Specific Language Assessment (Fuchs, DeSelms, & Deason, 2012).

[a] *t* value (*p*) is for Total Effect.

[b] Bootstrapped 95% confidence interval (CI) is for indirect effects.