Journal of Visualized Experiments

Decomposing the Variance in Reading Comprehension to Reveal the Unique and Common Effects of Language and Decoding

--Manuscript Draft--

Article Type:	Methods Article - JoVE Produced Video
Manuscript Number:	JoVE58557R2
Full Title:	Decomposing the Variance in Reading Comprehension to Reveal the Unique and Common Effects of Language and Decoding
Keywords:	decomposing variance, simple view of reading, reading comprehension, language, decoding, regression
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Question	**Response**
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THE FLORIDA STATE UNIVERSITY
THE FLORIDA CENTER FOR READING RESEARCH

Dear Editors, July 20, 2018

Re: JoVE58557R1

We have revised the manuscript according to your and the reviewers' comments. We have created a separate document responding to the reviewers' comments. Our responses to your comments follow:

• **Introduction: Please expand to include advantages over alternative techniques and a description of the technique in the context of the wider literature.**

RESPONSE: The Introduction has been expanded to describe advantages of the decomposition technique compared to regression analyses yielding unique effects only. Also, a description of the context of the technique in the wider body of the Simple View of Reading literature has been added.

• **Protocol Language:** Please ensure that all text in the protocol section is written in the imperative voice/tense as if you are telling someone how to do the technique (i.e. "Do this", "Measure that" etc.) Any text that cannot be written in the imperative tense may be added as a "Note", however, notes should be used sparingly and actions should be described in the imperative tense wherever possible.

1) Examples NOT in imperative voice: 3.6, 3.7, 3.8, 3.9, 4.

RESPONSE: We have edited each of these sections, as well as others, to be more explicit in our use of imperative voice for instructions.

• **Protocol Detail:** Please note that your protocol will be used to generate the script for the video, and must contain everything that you would like shown in the video. **Please add more specific details (e.g. button clicks for software actions, numerical values for settings, etc) your protocol steps.** There should be enough detail in each step to supplement the actions seen in the video so that viewers can easily replicate the protocol.

1) 1.1: It is unclear what kind of data this is. How was it obtained? What information does it contain? Please add a step or a note to mention this. Please describe in brief how the data was collected and cite any references to previous work where it is described in detail.

Response: This information is now included at the end of the Introduction and in the Representative Results section. Because the presentation in the protocol is for a methodology and ubiquitous in application, we prefer to keep this information in those other two sections.

2) 2.1: Define R2 here.

Response: A definition of the R-squared is now included.

3) 2.2: Unclear what X1 is here.
4) 2.3: Unclear what X2 is here.

Response: X1 and X2, though having substantive value for the representative results, are dummy coded as general independent variables for the purpose of highlighting the methodology of computing the unique, common, total, and unexplained variances.

5) 4: Each section should have a set of substeps under it.

Response: We have added additional substeps to section 4 to describe additional steps for creating a specific type of chart with the data (i.e., a pie chart).

• **Protocol Highlight: Highlight steps to be visualized.**

Response: We have highlighted steps to be visualized.

• **Discussion:** Focus on modifications, limitations, significance with respect to existing methods, future applications, and critical steps within the protocol.

Response: The Discussion has been rewritten to focus on these four elements, with a slightly different ordering: critical steps in the protocol, modifications, limitations and future applications, and significance with respect to existing methods.

• **Figure legends:** Please expand legends to adequately describe the figures, with a short title, followed by a short description of each panel and/or a general description.

Response: Each of the 3 figures now has a short title and a short description of what is in each part of the pie chart. These original figures are now .TIF.

• **Commercial Language and Table of Materials:** Please replace commercial sounding language with generic language.

Response: All mention of commercial products have been removed and placed in the Table of Materials. They have been replaced with the generic terms “software with a graphical user interface” and “data management software.”

We have responded to the reviewers’ comments in a separate rebuttal file and have revised the manuscript based on several comments. We have carefully proofed this revision and feel confident that it is error free.

Sincerely,

Barbara R. Foorman, Ph.D.
Francis Eppes Professor of Education
Director Emeritus, Florida Center for Reading Research
Director, Regional Educational Laboratory (REL) Southeast
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TITLE:

Decomposing the Variance in Reading Comprehension to Reveal the Unique and Common Effects of Language and Decoding

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KEYWORDS:

Decomposing variance, simple view of reading, reading comprehension, language, decoding, regression

SHORT ABSTRACT:

Here we present a protocol for decomposing the variance in reading comprehension into the unique and common effects of language and decoding.

LONG ABSTRACT:

The Simple View of Reading is a popular model of reading that claims that reading is the product of decoding and language, with each component uniquely predicting reading comprehension. Although researchers have argued whether the sum rather than the product of the components is the better predictor, no researchers have partitioned the variance explained to examine the extent to which the components share variance in predicting reading. To decompose the variance, we subtract the R^2 for the language-only model from the full model to obtain the unique R^2 for decoding. Second, we subtract the R^2 for the decoding-only model from the full model to obtain the unique R^2 for language. Third, to obtain the common variance explained by language and decoding, we subtract the sum of the two unique R^2 from the R^2 for the full model. The method is demonstrated in a regression approach with data from students in grades 1 (n = 372), 6 (n = 309), and 10 (n = 122) using an observed measure of language (receptive vocabulary), decoding (timed word reading), and reading comprehension (standardized test). Results reveal a relatively large amount of variance in reading comprehension explained in grade 1 by the common variance in decoding and language. By grade 10, however, it is the unique effect of language and the common effect of language and decoding that explained the majority of variance in reading comprehension. Results are discussed in the context of an expanded version

of the Simple View of Reading that considers unique **and** shared effects of language and decoding in predicting reading comprehension.

INTRODUCTION:

The Simple View of Reading[1] (SVR) continues as a popular model of reading because of its simplicity—reading (R) is the product of decoding (D) and language (L)—and because SVR tends to explain, on average, approximately 60% of explained variance in reading comprehension[2]. SVR predicts that correlations between D and R will decline over time and that correlations between L and R will increase over time. Studies generally support this prediction[3,4,5]. There are disagreements, however, about the functional form of SVR, with additive models (D + L = R) explaining significantly more variance in reading comprehension than product models (D × L = R)[6,7,8], and a combination of sum and product [R = D + L + (D × L) explaining the largest amount of variance in reading comprehension[3,9].

Recently the SVR model has expanded beyond regressions based on observed variables to latent variable modeling using confirmatory factory analysis and structural equation modeling. D is typically measured with untimed or timed reading of real words and/or nonwords and R is usually measured by a standardized reading test that includes literacy and informational passages followed by multiple-choice questions. L is typically measured by tests of expressive and receptive vocabulary and, especially in the primary grades, by measures of expressive and receptive syntax and listening comprehension. Most longitudinal studies report that L is unidimensional[10,11,12,13]. However, another longitudinal study[14] reports a two-factor structure for L in the primary grades and a unidimensional structure in grades 4 and 8. Recent cross-sectional studies report that a bifactor model best fits the data and predicts R[15, 16, 17, 18]. For example, Foorman *et al.*[16] compared unidimensional, three-factor, four-factor, and bifactor models of SVR in data from students in grades 4–10 and found that a bifactor model fit best and explained 72% to 99% of the variance in R. A general L factor explained variance in all seven grades and vocabulary and syntax uniquely explained variance only in one grade each. Although the D factor was moderately correlated with L and R in all grades (0.40–0.60 and 0.47–0.74, respectively), it was not uniquely correlated with R in the presence of the general L factor.

Even though latent variable modeling has expanded SVR by shedding light on the dimensionality of L and the unique role that L plays in predicting R beyond the primary grades, no studies of SVR except one by Foorman *et al.*[19] have partitioned the variance in reading comprehension into what is due uniquely to D and L and what is shared in common. This is a big omission in the literature. Conceptually it makes sense that D and L would share variance in predicting written language because word recognition entails the linguistic skills of phonology, semantics, and discourse at the sentence and text levels[20]. Similarly, linguistic comprehension must be connected to orthographic representations of phonemes, morphemes, words, sentences, and discourse if text is to be understood[21]. Multiplying D by L does not yield the knowledge shared by these components. Only decomposition of the variance into what is unique and what is shared by D and L in predicting R will reveal the integrated knowledge crucial to the success of educational interventions.

The one study by Foorman *et al.*[19] that decomposed the variance of reading comprehension into what is unique and what is shared in common by D and L employed a latent variable modeling approach. The following protocol demonstrates the technique with data from students in grades 1, 7, and 10 based on single observed variables for D (timed decoding), L (receptive vocabulary), and R (standardized reading comprehension test) to make the decomposition process easy to understand. The data represent a subset of the data from Foorman *et al.*[19].

PROTOCOL:

Note: The steps below describe decomposing total variance in a dependent variable (Y) into **unique variance**, **common variance**, and **unexplained variance** components based on two selected independent variables (called X_1 and X_2 for this example) using software with a graphical user interface and data management software (see **Table of Materials**).

1. Reading Data into Software with a Graphical User Interface

1.1. Click on **File.**

1.1.1. Hover the mouse over **Open.**

1.1.2. Click on **Data.**

1.2. Locate the relevant data file on the computer.

1.2.1. If the file type is not consistent with the software with a graphical user interface, click on **Files of Type** and select the appropriate file format.

1.3. Click on **Open.**

2. Estimate the Variance Explained in the Dependent Variable (*Y*)

2.1. **Total Variance Explained based on Two Independent Variables — Total R^2.**

Note: An R^2 value is known as the coefficient of determination and represents the proportion of variance for a dependent variable that is explained by a set of independent variables.

2.1.1. Click on **Analyze** and hover the mouse over **Regression** and select **Linear.**

2.1.2. Click on the dependent variable in the variable list. Then click on the arrow next to **Dependent**.

2.1.3. Click on the two independent variables (X_1 and X_2) in the variable list. Then click on the arrow next to **Independent(s)**.

2.1.4. Click **OK**.

2.1.5. Click on the viewer window of the software.

2.1.5.1. Use the mouse to scroll to the section called **Model Summary**. Record the value under the column **R Square** and label this value Total R^2.

2.2. **Total Variance Explained based on X_1**

2.2.1. Repeat steps 2.1.1 through 2.1.4 using only X_1 in the independent variable list.

2.2.2. Click on the viewer window of the software.

2.2.2.1. Use the mouse to scroll to the section called **Model Summary**. Record the value under the column **R Square** and label this value X_1R^2.

2.3. **Total Variance Explained based on X_2.**

2.3.1. Repeat steps 2.1.1 through 2.1.4 using only X_2 in the independent variable list.

2.3.2. Click on the viewer window of the software.

2.3.2.1. Use the mouse to scroll to the section called **Model Summary**. Record the value under the column **R Square** and label this value X_2R^2.

3. Computing the Unique, Common, and Unexplained Variance Components

3.1. Open the data management software.

3.2. Enter the labels **Total R^2**, **X_1R^2**, and **X_2R^2** in cells A1, B1, and C1, respectively.

3.3. Enter the Total R^2 value from step 2.1.5.1 in cell A2.

3.4. Enter the X_1R^2 value from step 2.2.2.1 in cell B2.

3.5. Enter the X_2R^2 value from step 2.3.2.1 in cell C2.

3.6. Calculate the Unique Variance of Variable 1 (UX_1R^2) in the data management software.

3.6.1. In Cell D2 type: "=A2-C2" (*i.e.,* Total R^2 minus X_2R^2). In Cell D1 label this value UX_1R^2.

3.7. Calculate the Unique Variance of Variable 2 (UX_2R^2) in the data management software.

3.7.1. In Cell E2 type: "=A2-B2" (*i.e.,* Total R^2 minus X_1R^2). In Cell E1 label this value UX_2R^2.

3.8. Calculate the Common Variance between Variables 1 and 2 (C$X_1X_2R^2$) in the data management software.

3.8.1. In Cell F2 type: "=A2-D2-E2" (*i.e.,* Total R^2 minus UX_1R^2 minus UX_2R^2). In Cell F1 label this value C$X_1X_2R^2$.

3.9. Calculate the Unexplained Variance (*e*) in the data management software.

3.9.1. In Cell G2 type: "=1-A2" (*i.e.,* 1-Total R^2). In Cell G1 label this value *e.*

4. **Plot the UX_1R^2, UX_2R^2, C$X_1X_2R^2$, and *e* values**

Note: Values in cells D2, E2, F2, and G2 are plotted.

4.1. Click and drag the mouse over Cells D2, E2, F2, and G2 to highlight the data.

4.2. Click on **Insert** on the ribbon of the data management software.

4.3. Click on **Charts | Pie Chart | 2-D Pie Chart.**

REPRESENTATIVE RESULTS:

The objective of this study was to investigate the contributions of unique and common variance of language (L) and decoding (D) to predicting reading comprehension (R) in grades 1, 7, and 10 in Florida, a state whose demographics are representative of the nation as a whole. There were two hypotheses regarding predictions of the variance explained in reading comprehension. First, after the primary grades, the unique contribution of D will significantly decrease, and the unique contribution of L will increase. Second, the unique contribution of L and the shared contributions of D and L will significantly account for the majority of variance beyond the primary grades.

Participants were 372 students in grade 1, 299 students in grade 7, and 122 students in grade 10 in general education classrooms from 18 schools in two large urban districts in Florida (one in northern Florida and the other in central Florida). The study followed guidelines for human subjects and parental consent was obtained. The ethnicity breakdown across grades for the study was: Approximately 30% Black; 30% Hispanic; 30% White; 5% Asian, 3% multicultural; 2% Other. The range of participation in the federal lunch program at the 18 participating schools was from 21.5% to 100%, with a median of 59%.

Single, observable measures for D, L, and R were selected for the regression analyses. The measure of decoding was time-limited (45 s) sight word decoding from the Test of Word Reading Efficiency-2[22]. L was measured by a receptive vocabulary test, the Peabody Picture Vocabulary Test (PPVT-4)[23], widely used in the participating schools. In this measure, students saw four pictures and point to the one that depicts the word the examiner says. R was assessed with a nationally-normed reading comprehension test, the Gates-MacGinitie Reading Test-4 (GMAT-

4)[24]. The GMAT-4 is administered in small groups of 10 students in grade 1. Students read parts of a passage and indicate the picture that corresponds to the passage. The GMAT-4 is group-administered in grades 7 and 10. Passages consisted of both L literary and informational text and questions are both literal and inferential and appear in a multiple-choice format. Students could look back at the passage. For all three measures, coefficients for reliability were above 0.90. A planned missing data design with three forms was used to reduce testing time. The D and L measures were administered in one session and the reading comprehension test in another session.

The regression analysis for grade 1 accounted for 60% of the total variance in reading comprehension, with the proportion due to D being 43% and the proportion due to L being 36%. These variance estimates are the squared correlation between the predictor and outcome, which is why their sum (43 + 36 = 79) was greater than the total amount of variance explained (60%). The difference (79 – 60 = 19) was the amount of common variance. When the variance in grade 1 was decomposed into unique and common effects, D uniquely explained 24% of the variance in R and L uniquely explained 17% (see **Figure 1**). The common variance of D and L was 19%.

[Place **Figure 1** here]

In grade 7, the regression analysis accounted for 53% of the total variance in reading comprehension, with the proportion due to D being 25% and the proportion due to L being 46%. **Figure 2** shows that D uniquely explained 7% of the variance in R and that L explained 28%. The common variance of D and L in explaining variance in R was 18%.

[Place **Figure 2** here]

In grade 10, the regression analysis accounted for 61% of the total variance in reading comprehension, with the proportion due to D being 19% and the proportion due to L being 54%. **Figure 3** shows that the D uniquely accounted for 6% of the variance, whereas L uniquely accounted for 42% of the variance. The common variance of D and L in explaining variance in R was 13%.

[Place **Figure 3** here]

FIGURE LEGENDS:

Figure 1. Total percent of variance explained in grade 1 reading comprehension decomposed into unique and common effects of language and decoding and unexplained variance.

Figure 2. Total percent of variance explained in grade 7 reading comprehension decomposed into unique and common effects of language and decoding and unexplained variance.

Figure 3. Total percent of variance explained in grade 10 reading comprehension decomposed into unique and common effects of language and decoding and unexplained variance.

DISCUSSION:

There are three critical steps in the protocol for decomposing the variance in R into unique and common variance due to L and D. First, subtract the R^2 in the L-only model from the full model to obtain the unique R^2 for D. Second, subtract the R^2 for the D-only model from the full model to obtain the unique R^2 for L. Third, to obtain the common variance explained by L and D, subtract the sum of the two unique R^2 from the R^2 for the full model.

Modifications to the protocol would be necessary if latent variables for D and L replaced the dummy codes for the observed measures of timed decoding and receptive vocabulary used here and if control variables such as socio-economic status (SES), gender, and race/ethnicity are added to the model. Alternatives to plotting the results in pie charts can also be considered, such as using Venn diagrams. Pie charts were used here so that percentages of unexplained variance as well as unique and common variances could be displayed.

There are limitations to the application of the method as shown in this study. To simplify the protocol, we selected one observable measure each for D, L, and R instead of using the latent variable modeling approach we usually take to control measurement error[19]. We eliminated control variables such as SES, gender, and race/ethnicity and used cross-sectional data with a planned missing data design rather than complete longitudinal data. We focused on decomposing variance at the individual student level rather than clustering students within classrooms and schools. Finally, the method shown in the protocol for decomposing variance into percentages of unique and common effects of L and D in predicting R yields descriptive results. There is no easy way to obtain a formal statistical test of the significance of the common variance.

This technique for decomposing the variance in R into the unique and common effects due to L and D has significant advantages over existing methods of looking solely at unique effects. Most importantly, the technique illustrates how individual difference characteristics covary and how one unique effect may pale in comparison to the effect shared with another characteristic. The analyses resulting from the current protocol showed that substantial amounts of variance in reading comprehension were due to the *common* effects of D and L (ranging from 19% in grade 1 to 13% in grade 10) that appeared to come at the expense of the unique contribution in D over the grades. In other words, the regression results showed a decline in the proportion of variance accounted for by D from 43% in grade 1 to 25% in grade 7 to 19% in grade 10. However, when the variance was decomposed, the unique contribution of D in grade 1 was only 24% and that declined in grades 7 and 10 to 7% and 6%, respectively. This finding has important educational implications because the emphasis on decoding in interventions in the elementary grades comes from the unique effect of D in regression results in spite of the weak effects of decoding interventions in the upper elementary and secondary grades in a meta-analysis[25]. The amount of **common** variance that D and L together explain in predicting reading comprehension, especially in the elementary grades, suggests that more instructional emphasis should be placed on the integration of linguistic knowledge at the word-level[26,27].

Regression results for L showed a fairly constant picture of L contributing substantial proportions of variance to reading comprehension across the grades, 36% in grade 1 to 54% in grade 10. However, when the method of decomposing the variance was used, the unique contribution of L over the grades showed a dramatic increase from 17% in grade 1 to 28% in grade 7, to 42% in grade 10. The finding that L accounts for so much variance in R in the secondary grades is even more apparent in the SVR studies conducted from a latent variable modeling approach[16,17,19] and suggests the value of instruction on the linguistic elements that make text cohesive[26,28].

ACKNOWLEDGMENTS:

The research reported here was supported by the Institute of Education Sciences, U.S. Department of Education, through a subaward to Florida State University from Grant R305F100005 to the Educational Testing Service as part of the Reading for Understanding Initiative. The opinions expressed are those of the authors and do not represent views of the Institute, the U.S. Department of Education, the Educational Testing Service, or Florida State University.

DISCLOSURES:

The authors declare that they have no competing financial interests.

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Figure

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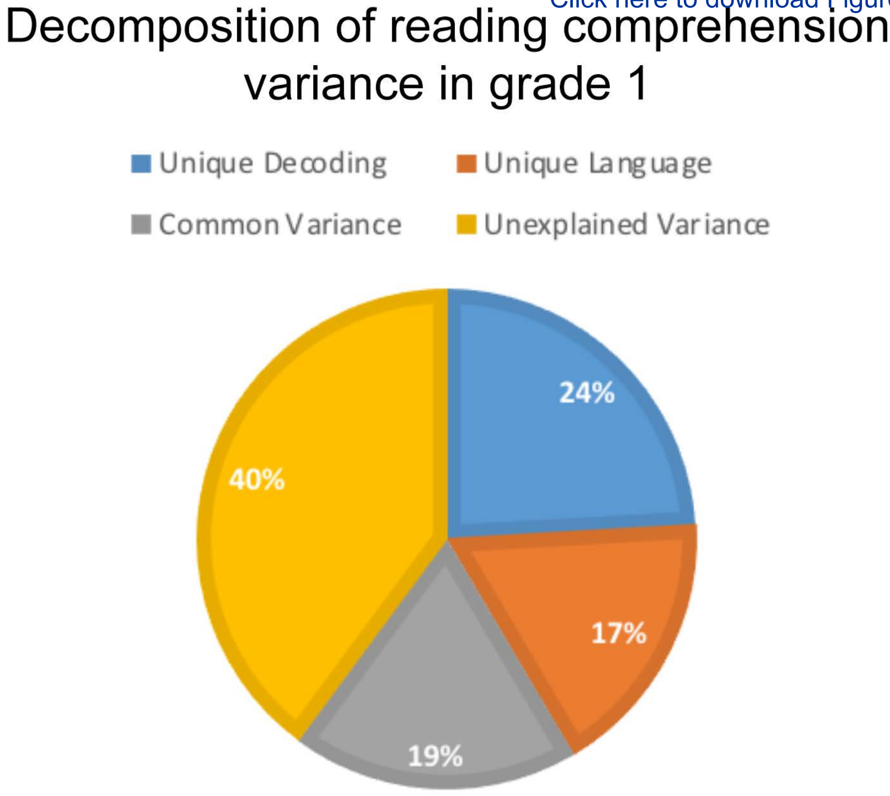

Figure

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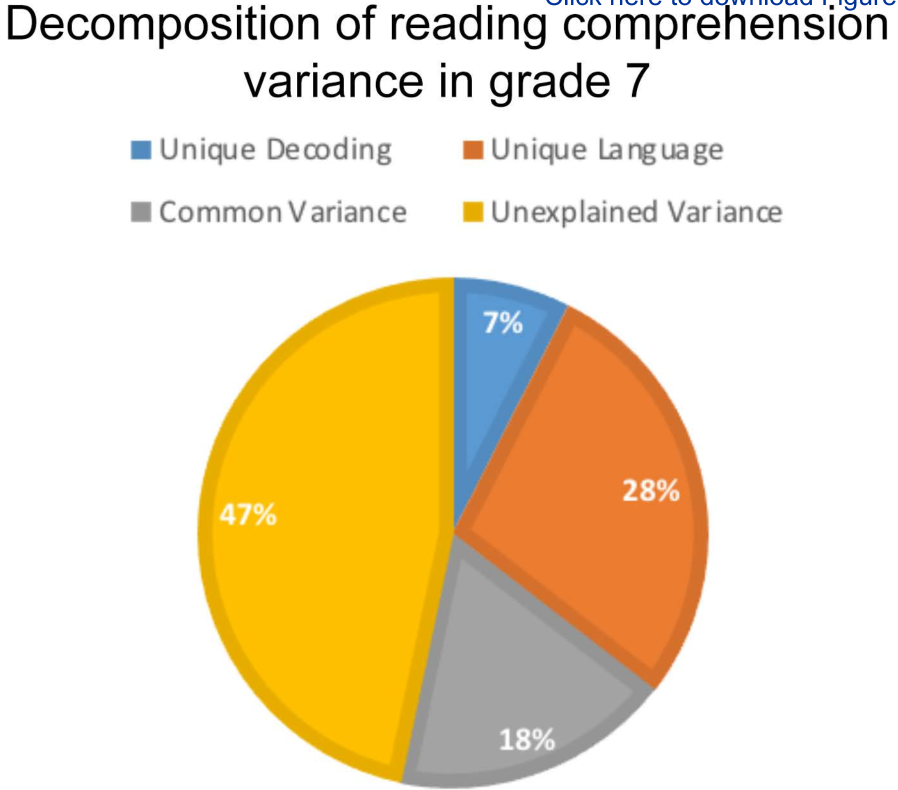

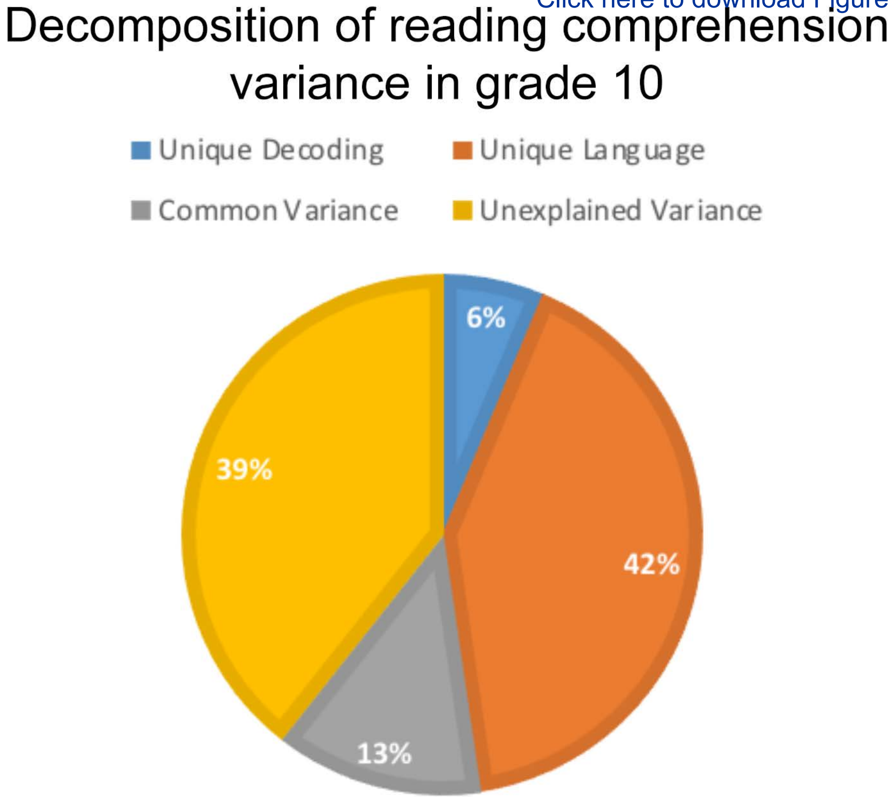
Decomposition of reading comprehension variance in grade 10
Unique Decoding
Unique Language
Common Variance
Unexplained Variance
6%
42%
13%
39%

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Response to reviewers

Reviewer 1

1. The term “language” has now been used consistently throughout the manuscript. Also explained is that the authors use both expressive and receptive vocabulary measures in their latent variable modeling studies but that a single observed measure of vocabulary—receptive vocabulary because of what the Florida schools routinely use—was used in the protocol to demonstrate the variance decomposition technique.
2. The utility of the decomposition analysis over the regression analysis has now been more clearly stated.
3. Discussion of misguided interventions has been eliminated as has the sentence about language impairment.
4. The revision has been reread and is error-free.

Reviewer 2

1. The language regarding the importance of how the decomposition analysis can illustrate how individual difference characteristics covary has now been incorporated into the manuscript. Thank you!
2. The possibility of using Venn diagrams has been added to the Discussion.
3. Modifications of the technique to include control variables such as SES, gender, race/ethnicity have now been mentioned.
4. The limitation of using single observed variables to demonstrate the technique has been mentioned and the explanation for demonstrating with the PPVT has been included (i.e., this is the measure widely used in Florida schools for receptive vocabulary). The authors routinely use both expressive and receptive vocabulary measures in their latent variable modelling studies.
5. In the individual models of RC = L or RC = D, then the R-squared is definitely the standardized coefficient squared and this point has been added to the manuscript. In the model of RC = L + D then the R-squared is the multiple R (i.e., the multiple correlation) squared. To reduce confusion, the term “multiple regression” has been changed to “regression.”
6. Common variance is derived based on the steps outlined in the protocol and there isn’t an easy way to obtain a formal statistical test.