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# What Do Phonological Processing Errors Tell About Students' Skills in Reading, Writing, and Oral Language

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**Abstract**

The kinds of errors that children and adolescents make on phonological processing tasks were studied with a large sample between ages 4 and 19 ($N$ = 3,842) who were tested on the Kaufman Test of Educational Achievement–Third Edition (KTEA-3). Principal component analysis identified two phonological processing factors: Basic Phonological Awareness and Advanced Phonological Processing. Canonical analysis and correlation analysis were conducted to determine how each factor related to reading, writing, and oral language across the wide age range. Results of canonical correlation analysis indicated that the advanced error factor was more responsible for reading, writing, and oral language skills than the basic error factor. However, in the correlation analysis, both the basic and advanced factors related about equally to different aspects of achievement—including reading fluency and rapid naming—and there were few age differences.

**Keywords**

phonological processing, phonological awareness, KTEA-3, reading, writing, spelling, oral language, achievement errors

## Introduction

Phonological processing is a meta-linguistic skill for distinguishing and manipulating spoken sound in oral language (Mattingly, 1972). Language researchers established phonological processing as a robust predictor of emerging literacy skills, as well as a method to characterize poor readers (Stanovich, 1988). Specifically, finding the relationship between phonological processing and word-level reading in reading difficulties is considered a breakthrough because most young children who are poor word-level readers have phonological difficulties (Bradley & Bryant, 1983; Torgesen, 2002). As a result, phonological processing interventions have been

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strongly recommended to support young children with potential reading difficulties (National Early Literacy Panel, 2008; National Reading Panel, 2000).

### *Errors in Phonological Processing: Do Different Error Factors Exist in Phonological Processing?*

Phonological processing involves three factors: phonological awareness, retrieval from long-term memory, and phonological memory (Wagner & Torgesen, 1987). *Phonological awareness* has garnered the most attention due, in part, to the field's acknowledgment of its prediction of reading ability and the effect of phonological awareness interventions on reading skills (Coltheart, 1983; Torgesen et al., 2001). Phonological awareness tasks can be broadly categorized by performance types, including rhyming, matching, blending, segmenting, or manipulating sounds, and by phonological units. Rhyming tasks require finding or producing a word that rhymes with a given word (e.g., tell me a word that rhymes with "bed"). Sound matching tasks require identifying words that match initial or ending sounds (e.g., which word ends with the same sound as "bed": cat, head, or bet?). Blending tasks require combining sounds (e.g., what word do these sounds make: /b/ /l/ /ĕ/ /n/ /d/?). Segmenting tasks require speaking distinct sounds (e.g., distinguish each syllable in "student"), whereas manipulating tasks require deleting, reversing, or switching sounds (e.g., say "hat" without /h/; say the sounds in "pan" backward, "nap").

Embedded within these five phonological-performance-type tasks are phonological units, ranging from words or syllables to phonemes that refer to the smallest sound element. Phonemes are typically the most difficult as they are not discrete in oral expression (Yopp, 1992). In contrast, syllables and onsets (i.e., initial consonant or cluster of consonants) or rimes (i.e., vowel and consonants that follow the onset) are more evident and may be acquired without conscious attention.

Given its difficulty, phonemic awareness predicts literacy better than bigger sound units (Engen & Høien, 2002; Hulme et al., 2002; Mann, 1993). Therefore, some researchers argue that phonemic awareness should be taught explicitly (Lundberg, Frost, & Peterson, 1988; Mann, 1986). However, assessing larger units is still important to assess phonological awareness in young children (Bridges & Catts, 2011). Moreover, older students' syllable-level errors can be a clue to detect their morphological processing because not all students follow the path of typical phonological development (Abbott & Berninger, 1993). Assessing these tasks is not necessarily discrete. Additionally, grade-level differences were found in phonological units as a predictor of literacy (Del Campo, Buchanan, Abbott, & Berninger, 2015).

The second factor, *retrieval from long-term memory*, is less predictive of literacy than phonological awareness (Nelson, Lindstrom, Lindstrom, & Denis, 2012). It has been mainly assessed through rapid automatized naming; it is a phonological recoding step in lexical access (Wagner & Torgesen, 1987) and identification (Blythe, Pagán, & Dodd, 2015). The magnitude of differences between good and poor readers on naming speed supports the importance of rapid naming as a useful measure. However, Wolf and Bowers (1999, 2000) argued that the naming process is a distinct construct from phonological processing due to its more complex and dynamic interactions of visual, lexical, and memory processing. Moreover, rapid automatized naming relates more closely to reading fluency (Cornwall, 1992; Young & Greig Bowers, 1995) and reading comprehension (Sprugevica & Høien, 2004) than to phonological processing. Also, retrieval from long-term memory seems to be a separate construct from phonological processing (Nelson et al., 2012) that tends to be measured independently (Høien-Tengesdal & Tønnessen, 2011). Consequently, for our study, we excluded retrieval from long-term memory as an aspect of phonological processing.

The third factor in phonological processing, *phonological memory*, refers to phonetical recoding to temporarily maintain information (Wagner & Torgesen, 1987). It is usually measured by the examinee repeating verbally represented stimuli (Lonigan et al., 2009). However, some researchers argue that it is almost impossible to measure pure phonological awareness or pure phonological memory as the two factors occur almost simultaneously (Bradley & Bryant, 1983; Wagner & Torgesen, 1987; Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993). This is further complicated because the demarcation between tests of phonological memory and short-term memory is often unclear. In many cases, phonological awareness tests include phonological short-term memory, but phonological short-term memory tests (e.g., digit span test) do not represent the comprehensive ability of phonological awareness. Although this perspective is still controversial (Nithart et al., 2011), and may differ based on the assessment chosen, phonological awareness and phonological memory can be viewed as one factor (Lonigan et al., 2009; Nelson et al., 2012).

## *Phonological Processing and Reading*

*Decoding and word recognition.* Reading ability consists of word reading and reading comprehension (Gough & Tunmer, 1986). We will mainly address decoding level (applying letter-sound knowledge to pronounce written words without contextual clues) and reading comprehension. Phonological processing and decoding are linked, and Wagner and Torgesen (1987) found a causal relationship of phonological processing on decoding.

According to Cunningham, Witton, Talcott, Burgess, and Shapiro (2015), phonological processing difficulties and task types should be considered when looking at which specific levels or tasks influence decoding, as they found that complex phonological tasks (e.g., phoneme deletion in pseudowords such as "frupper") as well as simple phonological tasks (e.g., phoneme identification) both predicted unique variance in decoding. In other words, not only phoneme deletion but also easy phoneme identification was a valuable, unique predictor of decoding.

Wagner et al. (1993) divided phonological awareness into two factors: analysis (deleting, segmenting, and sound matching) and synthesis (blending), confirming the importance of both types. A variety of other studies showed the importance of phoneme analysis, synthesis, and awareness for reading decoding skills (Engen & Høien, 2002; Høien-Tengesdal & Tønnessen, 2011; Nithart et al., 2011; Perfetti, Beck, Bell, & Hughes, 1987). Engen and Høien (2002), for example, analyzed factors of phonological processing for word recognition for average decoders and poor decoders in first grade. They found that the phonemic awareness factor explained about 35% of word reading, whereas the syllable awareness factor only explained an additional <1% of word reading in average decoders; results were similar for poor decoders. Even younger children showed similar results in a comparison of rimes with phonemes (Hulme et al., 2002). These two studies are noteworthy as bigger units (syllables and rimes) were almost meaningless as predictors after accounting for the variance explained by phonemes.

*Reading comprehension.* The relationship between phonological processing and reading comprehension is inconsistent. Some studies showed a direct relationship (Engen & Høien, 2002; Snider, 1997) and others did not (Apel, Wilson-Fowler, Brimo, & Perrin, 2012; Foorman, Herrera, Petscher, Mitchell, & Truckenmiller, 2015). Additionally, some studies showed age/grade differences and group differences based on their language skills (see Share, 2008).

Reading comprehension involves more sophisticated linguistic and cognitive factors than code-related literacy skills, such as letter knowledge and decoding (van den Bos, Nakken, Nicolay, & van Houten, 2007). Therefore, decoding is often considered a prerequisite of comprehension in reading (Gough & Tunmer, 1986) because proficiency in decoding letters and words frees cognitive resources for higher comprehension (Clemens, Shapiro, & Thoemmes, 2011; Kim, 2015). Nevertheless, several studies demonstrated meaningful relationships between phonological processing errors and reading comprehension. Engen and Høien (2002) found that the two were directly related among first-grade students with poor-to-average decoding skills.

Between the two factors in phonological awareness, phonemic awareness correlated higher with reading comprehension ($r = .39$) than did syllable awareness ($r = .06$). Del Campo and colleagues (2015) showed that all sound-unit factors measured by phoneme, rime, syllable, and words were significantly interrelated; word and phoneme units explained unique variance of reading comprehension in both 119 fourth- and 105 sixth graders.

But the importance of code-related skills tends to diminish as children grow older (Storch & Whitehurst, 2002). For example, Swanson, Trainin, Necoechea, and Hammill (2003) conducted a meta-analysis of the relationships between reading comprehension and nine skill categories and concluded that the importance of phonological awareness in reading comprehension had been overestimated. When other literacy variables are available to be measured, phonological processing might not be the best predictor of reading comprehension (Hammill, 2004). However, these meta-analyses did not differentiate between groups of poor readers and average or above-average readers. Most average and above-average readers master basic phonological processing skills by first grade (Kilpatrick, 2015) and the connection between the two appears to diminish. However, many poor readers still struggle with phonological processing (see Wagner & Torgesen, 1987). It seems important to differentiate between these two groups. Still, phonological processing is a predictor of code-related emergent literacy skills (Catts, Herrera, Nielsen, & Bridges, 2015) and below-average readers (Betourne & Friel-Patti, 2003).

## *Phonological Processing and Writing*

*Spelling.* Spelling has been strongly linked with phonological processing among young children. Longitudinal studies show support for the influence of phonological processing skills in early spelling (Stuart & Masterson, 1992). Additionally, deficits in phonological awareness have been linked to spelling problems in students, but there was not a significant correlation between the two beyond Grade 1 (Apel et al., 2012; de Jong & van der Leij, 1999; Walker & Hauerwas, 2006).

In two longitudinal studies, Bryant, MacLean, Bradley, and Crossland (1990) found that young children's rhyming at 4 years 7 months directly related to phoneme awareness and strongly predicted their spelling and reading at age 6 years 7 months. Lundberg, Olofsson, and Wall (1980) found that among blending, segmenting, rhyming, sound matching, and manipulation tasks, reversing phonemes measured in kindergarteners was the most predictive of spelling and reading when they were in first grade.

*Written expression.* Written expression research in literacy has gained recent attention after a period of decline (Erdoğan, 2011; Williams & Mayer, 2015). Vernon and Ferreiro (1999) found a strong relationship between phonological awareness in various sound units and writing. Children with better writing tended to show better performance on matching initial sounds (Diamond, Gerde, & Powell, 2008). Abbott and Berninger (1993), however, did not find a strong correlation between phoneme segmentation/deletion tasks and composition in narrative and expository types, compared with orthographic skills in Grades 1 to 6. Possibly, deletion was too difficult for most primary-grade participants, while being already mastered by the intermediate-grade participants. Their participants in Grades 1 and 2 showed an approximately .40 correlation between composition quality (excluding writing fluency) and phoneme segmentation, but above Grade 3, the correlation decreased.

Erdoğan (2011) found phonological awareness measured at the beginning of Grade 1 could predict writing ability at the middle of their first semester, but could not predict the same ability at the end of the semester and beyond. Recently, Del Campo et al. (2015) researched the links between linguistic units (e.g., syllable, phonemes) in deletion tasks and writing errors including spelling, sentence writing fluency, and written text composition in students (Grades 4 and 6). In the study, phonological processing explained the variance in writing, but grade differences emerged; only phoneme deletion tasks predicted writing in Grade 4 students, but syllable, rime, and phoneme deletion tasks predicted writing in Grade 6 students.

## Phonological Processing Errors and Oral Language

*Listening comprehension.* Phonological processing deals with oral sounds. Yet, there is no consensus about the relationship between phonological factors and listening comprehension (Lepola, Lynch, Laakkonen, Silvén, & Niemi, 2012).

Among oral language factors, researchers have primarily studied vocabulary (Kendeou, van den Broek, White, & Lynch, 2009; Zubrick, Taylor, & Christensen, 2015). However, the National Institute of Child Health and Human Development (NICHD) Early Child Care Research Network (2005) asserted that oral language measured only by vocabulary is too narrow to clarify the connection between phonological processing and oral language. Instead, oral language should be measured broadly to predict code-related skills as Farnia and Geva (2013) found a significant correlation between phonological processing factors (awareness and memory) and listening comprehension in both ELL (English Language Learner) and EL1 (English Monolingual) students in Grades 1 to 6.

Researchers found age differences between phonological memory digit recall, word list matching and recall, and non-word recall related to listening comprehension (Chrysochoou & Bablekou, 2011). The link between the two, however, may be more applicable to poor readers in Grades 2 to 4 (Mann, Cowin, & Schoenheimer, 1989; Wise, Sevcik, Morris, Lovett, & Wolf, 2007).

*Oral expression.* Hipfner-Boucher, Milburn, Weitzman, Greenberg, and Pelletier (2014) reported that narrative expression was highly related to phonological awareness and phonological awareness was correlated with expressive vocabulary. Farnia and Geva (2013) also found meaningful correlations: (a) between phonological processing and syntactic abilities (between 10% to 15%), and (b) between phonological processing and vocabulary.

Overall, the direct link between phonological processing and comprehension/expression has been less researched than emergent literacy skills. Most studies investigated *whether* phonological processing is related to comprehension/expression instead of *how* phonological processing factors can influence comprehension/expression.

## The Present Study

Vernon and Ferreiro (1999) pointed out the importance of phonological processing error analysis. For example, although it has its merits, the Response to Intervention (RTI) model does not tell practitioners how they should intervene with students' educational needs (Willis & Dumont, 2006). Hence, specific recommendations based on critical error analyses are important for practitioners to choose the most efficient phonological assessment (Kilpatrick, 2012).

Furthermore, if phonological errors exist, it is important to determine how those error types relate to global oral and written language variables. Although, as discussed above, many researchers have measured phonological memory and phonological awareness separately, they are highly correlated (Bradley & Bryant, 1983; Del Campo et al., 2015; Hecht, Torgesen, Wagner, & Rashotte, 2001). In reality, however, many studies use the term "phonological awareness" based on early theoretical constructs. Thus, in this present study, phonological error factors were investigated based on data beyond those early theory constructs.

Many language factors are dynamically interrelated and their effect can vary by age or grades levels. However, most studies use different assessment tests, ages or grades, groups, and methods of analysis, hindering us from drawing a useful conclusion. Thus, we also want to look at differences in error patterns across ages including special groups (e.g., ADHD, language disability, reading disability, writing disability, mild intellectual disability, and gifted). In studying poor reading groups, it is important to note their heterogeneity (Cain & Oakhill, 2006; Stanovich, 1988). Moreover, some difficulties overlap, with more than half of the students with specific reading disabilities also having writing disabilities (A. S. Kaufman, Kaufman, & Breaux, 2014).

Consequently, it is meaningful to investigate phonological processing errors for the entire sample instead of separating special groups from typical groups, even if the number of special groups would be too small to affect the results. In sum, this study focuses on error factors in phonological processing and how each error factor relates to performance in various oral and written language composites across ages (4-19) among U.S. students.

## Method

*Participants.* The participants in this study were students tested during the standardization of the Kaufman Test of Educational Achievement–Third Edition (KTEA-3; A. S. Kaufman & Kaufman, 2014) between August 2012 and July 2013. Demographic data for these samples are provided in the *KTEA-3 Technical and Interpretive Manual* (A. S. Kaufman et al., 2014). About half of the sample was tested on KTEA-3 Form A and half on KTEA-3 Form B.

The total sample ($N$ = 3,842) included 1,988 females and 1,854 males in grades Pre-K-12 (median grade = 4) who ranged in age from 4 to 19 years ($M$ age = 10.4; $SD$ = 3.9). The sample was 54.9% White, 20.5% Hispanic, 14.7% African American, 3.9% Asian, and 6% "Other" (e.g., Native American). Parent's education (mostly mothers, used as an estimate of socioeconomic status) was 32.0% with < 12 years of schooling, 32.2% with high school diplomas or a GED, 34.5% with 1 to 3 years of college or technical school, and 1.3% with 4-year college degrees or more. All participants lived in the United States with 24.1% residing in the Midwest, 14.1% in the Northeast, 39.5% in the South, and 22.2% in the West. Our sample was broken up into three age bands: 4 to 5, 6 to 11, and 12 to 19. Each of the three age bands had very similar distributions on the demographic variables of sex, ethnicity, parent's education, and geographic region. Furthermore, all age bands and the total sample closely matched the percentages in each category as reported by the U.S. Census Bureau's American Community Survey 2012 1-year period estimates (Ruggles et al., 2010; although citation is 2010, reported census data are from 2012).

## Measures

*KTEA-3.* The KTEA-3 was individually implemented. It is in line with Common Core State Standards (A. S. Kaufman et al., 2014). All the composites used in this study have error categories. The test includes phonological processing subtests, decoding (pseudoword reading and word recognition) subtests, comprehension (listening and reading) subtests, expression (oral and written) subtests, and spelling subtests.

The Phonological Processing subtest on the KTEA-3 consists of five different tasks or error categories: blending, rhyming, sound matching, segmenting, and deleting. The subtest deals with four different phonological units: words, syllables, rime-onsets, and phonemes. Although all the words within the subtest are real words, when students are asked to retrieve words on rhyming tasks, they are allowed to answer with non-words (e.g., when asked to name a word that rhymes with "see," "gree" is a correct answer). Blending and segmenting tasks contain word, syllable, and phoneme units whereas sound matching and deleting tasks only contain phonemes as shown in Table 1.

**Table 1.** The Number of Phonological Units in Each Task Type in KTEA-3 (Form A) Phonological Processing Subtest.

| | Task type | | | | |
|---|---|---|---|---|---|
| Unit | Blending | Rhyming | Sound matching | Deleting | Segmenting |
| Phoneme | 5 | — | 6 | 11 | 10 |
| Non-phoneme (word/ syllable/rime-onset) | 5 | 8 | — | — | 5 |
| Total items | 10 | 8 | 6 | 11 | 15 |

*Note.* KTEA-3 = Kaufman Test of Educational Achievement–Third Edition.

## Results

### *Principal Component Analysis*

For the KTEA-3 Phonological Processing subtest, errors were categorized into five task types: blending, rhyming, sound matching, deleting, and segmenting. The number of errors in each category was transformed into one of three descriptive labels based on a normative comparison: weakness (bottom 25%), average (middle 50%), and strength (top 25%). This was then dichotomized into an error score of 0 (weakness) or 1 (average or strength).

Data were analyzed in three steps. First, to test whether the error factor structure of phonological processing in our total sample shared a relationship with errors in other tests, we used principal component analysis (PCA) to derive factor scores. To create the factor scores, polychoric correlation matrices were generated for each subtest. Because the comprehension, expression, and phonological processing subtests include a small number of error scores, principal component analysis was used to extract the factors for these subtests. Additionally, a combination of parallel analysis (Horn, 1965), a visual inspection of the scree plot (Cattell, 1966), and content review of the factor structure were used to determine the number of factors to extract. Two factors were extracted for the phonological processing test.

Students in the total sample ($N = 3,842$) with incomplete data corresponding to the phonological processing test were removed from the PCA, creating a sample of 3,030 participants. Factor loadings of the PCA are shown in Table 2.

Loadings were all moderate to strong (0.62-0.85) and there was a clear division between the two factors. Factor 1 consists of the three phonological subtests of blending (0.85), rhyming (0.63), and matching (0.62). These three phonological errors are similar in that they can refer to an individual's awareness (e.g., identification and synthesis) of sound units in words rather than the ability to decompose the units. Factor 2 consists of the two phonological errors, deleting (0.65) and segmenting (0.87). Both of these phonological errors are concerned mainly with analysis processing of phonemes. Based on our results and reasoning, the two error factors were identified as Basic Phonological Awareness and Advanced Phonological Processing. In considering further analyses it was not clear if the data should be analyzed using the total sample or by using different age grouping. Additional PCA were conducted using separate age bands (4-5, 6-11, and 12-19) and grade bands (Pre-K-4, 5-8, and 9-12) to decide which factor structure was more appropriate. The additional age and grade bands are shown in Table 2.

Slightly different factor loadings were found in the age 6 to 11 band; however, when we examined the factors as a function of the grade band, this difference was isolated to the 5 to 8 grade band (usually ages 10-13). The fact that the youngest and oldest age groupings yield such a similar structure suggests that the changes in the middle group may not be developmentally meaningful. The clean division between the two error factors identified in the total sample indicates that

**Table 2.** Principal Component Analysis for Phonological Processing Error Factors in KTEA-3.

| | Overall | | Age 6-11 | | Age 12-19 | | Grades Pre-K-4 | | Grades 5-8 | | Grades 9-12 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *n* = 3,030 | | *n* = 1,552 | | *n* = 1,400 | | *n* = 1,231 | | *n* = 1,025 | | *n* = 764 | |
| Error category | Factor 1 | Factor 2 | Factor 1 | Factor 2 | Factor 1 | Factor 2 | Factor 1 | Factor 2 | Factor 1 | Factor 2 | Factor 1 | Factor 2 |
| Blending | **.85** | −.20 | **.69** | −.11 | **.88** | −.19 | **.68** | −.07 | −.03 | **.98** | **.75** | .00 |
| Rhyming | **.63** | .22 | **.77** | −.03 | **.53** | .37 | **.72** | .01 | **.69** | .17 | **.60** | .17 |
| Matching | **.62** | .21 | **.69** | .08 | **.64** | .22 | **.74** | .00 | **.77** | .08 | **.86** | −.06 |
| Deleting | .20 | **.65** | .50 | .34 | .08 | **.72** | .47 | .42 | **.63** | .19 | .00 | **.88** |
| Segmenting | −.10 | **.87** | −.05 | **.96** | −.08 | **.85** | −.08 | **.97** | **.70** | .14 | .02 | **.87** |

*Note.* In total sample, 78 participants aged 4 and 5 were included. Standardized regression coefficients greater than 0.50 are denoted in bold. KTEA-3 = Kaufman Test of Educational Achievement–Third Edition.

the age 6 to 11 and 12 to 19 group samples should be used for further analyses as representative of all ages.

## *Canonical Correlation Analysis Between Phonological Processing Errors and KTEA-3 Reading Subtests*

In the second step of our analysis, we examined the relationship between students' phonological processing errors and their scores on the KTEA-3 reading, writing, and oral tests. Sample populations for these analyses required that students have complete scores on both the phonological and correlated test, and, as a result, the samples for all three correlation analyses had different sizes.

A canonical correlation analysis was conducted to assess the multivariate relationship between these two phonological processing error factor scores and a variable set comprised of the KTEA-3 subtests that measure reading. Because the number of canonical functions generated from a canonical correlation analysis will equal the small number of variables in a given variable set (Pituch & Stevens, 2016; Sherry & Henson, 2005), the analysis generated two canonical functions. Looking at both functions in an overall model, the Wilks's Λ of .775, $F(14, 4816) = 46.57$, $p < .0001$, indicated a statistically significant relationship between the two variable sets. Furthermore, the overall squared canonical correlation $(R_c^2)$ was .223. Thus, looking across the two functions, the full model explained 22% of the shared variance between the two variable sets.

While the overall model indicated a statistically significant relationship between the phonological process errors and the reading subtests, this does not indicate that both canonical functions play an equal role in explaining this relationship. To examine how well each function explains the relationship between the variable sets, a sequential likelihood ratio test (Fan & Konold, 2010) was conducted across the model. Based on this test, Function 2 was not a statistically significant function, $F(6, 2409) = 46.57$, $p = .6851$. Therefore, only the first function was considered in the rest of the analysis.

Table 3 presents two types of canonical function coefficients. The first set of coefficients ($B$) is the standardized canonical function coefficients for each variable on Function 1. These coefficients provide a mechanism to examine the contribution of a given variable to the function. The second set of coefficients, structure coefficients ($r_s$), represents the zero-order correlation between a variable and the canonical function score for the variable set (or canonical variate). As noted earlier, the structure coefficients are zero-order correlations. Therefore, the square of these coefficients, similar to $r^2$-type effect sizes, can be used to indicate the amount of variance shared between the variable and canonical variate for that set of variables (Sherry & Henson, 2005). To aid the reader, these coefficients are presented as percentages.

**Table 3.** Canonical Correlation Analysis Between Phonological Processing Errors and KTEA-3 Reading Subtests.

| Variable | Function I (overall, *n* = 2,417) | | | Function I (ages 6-11, *n* = 997) | | | Function I (ages 12-19, *n* = 1,417) | | |
|---|---|---|---|---|---|---|---|---|---|
| | $B$ | $r_s$ | $r_s^2$ (%) | $B$ | $r_s$ | $r_s^2$ (%) | $B$ | $r_s$ | $r_s^2$ (%) |
| Phonological Processing Errors | | | | | | | | | |
| Basic Phonological Awareness | 0.619 | *0.710* | 50.44 | 0.577 | *0.684* | 46.72 | 0.632 | *0.717* | 51.37 |
| Advanced Phonological Processing | 0.710 | *0.790* | 62.36 | 0.738 | *0.821* | 67.47 | 0.703 | *0.779* | 60.62 |
| $R_c$ | | 0.472 | 22.30 | | 0.472 | 22.27 | | 0.475 | 22.53 |
| Reading Subtests | | | | | | | | | |
| Letter and Word Recognition | 0.105 | *0.852* | 72.66 | 0.055 | *0.834* | 69.47 | 0.137 | *0.862* | 74.22 |
| Reading Comprehension | 0.338 | *0.831* | 69.04 | 0.305 | *0.795* | 63.19 | 0.349 | *0.849* | 72.05 |
| Nonsense Word Decoding | 0.333 | *0.850* | 72.20 | 0.387 | *0.882* | 77.72 | 0.294 | *0.826* | 68.29 |
| Word Recognition Fluency | 0.032 | *0.586* | 34.36 | 0.022 | *0.555* | 30.75 | 0.062 | *0.636* | 40.46 |
| Decoding Fluency | 0.161 | *0.784* | 61.47 | 0.239 | *0.840* | 70.61 | 0.101 | *0.745* | 55.52 |
| Silent Reading Fluency | 0.050 | *0.612* | 37.44 | 0.072 | *0.604* | 36.17 | 0.041 | *0.615* | 37.81 |
| Reading Vocabulary | 0.205 | *0.835* | 69.71 | 0.145 | *0.791* | 62.49 | 0.237 | *0.859* | 73.75 |

*Note.* Structure coefficients ($r_s$) greater than |.45| are in italics. KTEA-3 = Kaufman Test of Educational Achievement–Third Edition; $B$ = standardized canonical function coefficient; $r_s$ = structure coefficient; $r_s^2$ = squared structure coefficient.

Focusing on the phonological processing errors variable set, both the basic and advanced types of phonological process errors have large standardized canonical function and structure coefficients, with Advanced Phonological Processing errors being the largest contributor. All of the coefficients were positive, indicating that as the error scores increase (decreasing number of phonological errors), scores on the canonical variate would also increase. Advanced Phonological Processing errors explained 62.36% of the variation in the canonical variate for phonological processing errors, whereas Basic Phonological Awareness errors explained 50.44%.

When considering the KTEA-3 reading subtests, Reading Comprehension, Nonsense Word Decoding, Reading Vocabulary, Letter and Word Recognition, and Decoding Fluency were the primary contributors to the reading canonical variate. Secondary contributions were made by Silent Reading Fluency and Word Recognition Fluency. All of the coefficients were positive, indicating that as scores on the subtests increase, scores on the canonical variate would also increase. A note of caution when interpreting the KTEA-3 reading subtests results. Based on an initial review of the standardized canonical function coefficient, Reading Comprehension has the strongest relationship with the canonical variate, followed closely by Nonsense Word Decoding, Reading Vocabulary, and Letter and Word Recognition. However, a review of the structure coefficients provides a slightly different ordering, with Letter and Word Recognition being the strongest predictor, followed closely by Nonsense Word Decoding, Reading Vocabulary, and Reading Comprehension. This result is due to the high correlations among these variables, a statistical issue known as multicollinearity. Because structure coefficients are not impacted by multicollinearity, Letter and Word Recognition should be considered the strongest predictor in the set of variables.

A secondary aspect of the relationship between phonological processing error scores and KTEA-3 reading subtests is the stability of relationship across ages. To investigate this analysis, two additional canonical correlation analyses were examined, one comprised of ages 6 to 11 ($n$ = 997) and one for ages 12 to 19 ($n$ = 1,417). Like the overall results, each of the overall models were statistically significant, with a Wilks's $\Lambda$ of 0.773, $F(14, 1976) = 19.37$, $p < .0001$, for ages 6 to 11 and a Wilks's $\Lambda$ of 0.773, $F(14, 2816) = 27.57$, $p < .0001$, for ages 12 to 19. These results indicate that, for the overall model, the relationship between the phonological processing error scores and the KTEA-3 reading subtests is stable across the age categories.

To examine how well each function explains the relationship between the variable sets, a sequential likelihood ratio test (Fan & Konold, 2010) was conducted for each age-based canonical correlation model. Based on these tests, Function 2 was not a statistically significant function for either ages 6 to 11, $F(6, 989) = 0.87$, $p = .5139$, or ages 12 to 19, $F(6, 1409) = 0.38$, $p = .8903$. A review of the squared canonical correlation $(R_c^2)$ of the second function (.005, .002) supported this conclusion. Therefore, similar to the overall results, only the first function was considered in the rest of the analysis.

Table 3 includes the results for canonical correlation coefficients for both age groups. Similar to the overall result, both the basic and advanced types of phonological processing errors have large standardized canonical function and structure coefficients. Advanced Phonological Processing errors are the largest contributor in both age groups. However, Advanced Phonological Processing errors explain more of the variation in the canonical variate (67.47%) in the 6 to 11 age group than in the 12 to 19 age group (60.62%).

Moving to the KTEA-3 reading subtests, like the overall results, Letter and Word Recognition, Reading Comprehension, Nonsense Word Decoding, Decoding Fluency, and Reading Vocabulary were the primary contributors to the reading canonical variate across both age groups. Secondary contributions were made by Silent Reading Fluency and Word Recognition Fluency. All of the coefficients were positive, indicating that an increase in scores on the subtests would also increase scores on the canonical variate. Interestingly, the ordering of the variables changed across age groups. In ages 6 to 11, the top three predictors, based on the structure coefficients, were Nonsense Word Decoding, Letter and Word Recognition, and Decoding Fluency. However, in the age 12 to 19 group, Letter and Word Recognition is the top predictor followed by Reading Vocabulary and Reading Comprehension.

### *Canonical Correlation Analysis Between Phonological Processing Errors and KTEA-3 Writing Subtests*

A similar analysis was next conducted between the same two factors of phonological processing error factor scores and a variable set comprised of the KTEA-3 subtests that measure writing. The analysis generated two canonical functions. Looking at both functions in an overall model, the Wilks's $\Lambda$ of .834, $F(6, 5376) = 85.13$, $p < .0001$, indicated a statistically significant relationship between the two variable sets. Furthermore, the overall squared canonical correlation $(R_c^2)$ was .166. Thus, looking across the two functions, the full model explained 17% of the shared variance between the two variable sets.

As with the previous canonical analysis, Function 2 was not a statistically significant function, $F(2, 2689) = 0.30$, $p = .744$. Therefore, only the first function was considered in the rest of the analysis. Table 4 presents the two types of canonical function coefficients.

Results of this analysis found a similar pattern as those in the previous analyses. All of the coefficients were positive, indicating that as the error scores increase (decreasing number of phonological errors), scores on the canonical variate would also increase. Advanced Phonological Processing was found to be the largest contributor accounting for 63.68%, whereas Basic Phonological Awareness errors explained 48.58%.

**Table 4.** Canonical Correlation Analysis Between Phonological Processing Errors and KTEA-3 Writing Subtests.

| | Function I (overall, $n$ = 2,693) | | | Function I (ages 6-11, $n$ = 1,261) | | | Function I (ages 12-19, $n$ = 1,429) | | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | $B$ | $r_s$ | $r_s^2$ (%) | $B$ | $r_s$ | $r_s^2$ (%) | $B$ | $r_s$ | $r_s^2$ (%) |
| Phonological Processing Errors | | | | | | | | | |
| Basic Phonological Awareness | 0.607 | *0.697* | 48.58 | 0.547 | *0.646* | 41.73 | 0.647 | *0.730* | 53.29 |
| Advanced Phonological Processing | 0.723 | *0.798* | 63.68 | 0.770 | *0.840* | 70.56 | 0.688 | *0.766* | 58.67 |
| $R_c$ | | 0.407 | 16.58 | | 0.393 | 15.62 | | 0.419 | 17.52 |
| Writing Subtests | | | | | | | | | |
| Written Expression | 0.424 | *0.861* | 74.13 | 0.421 | *0.856* | 73.27 | 0.428 | *0.865* | 74.82 |
| Spelling | 0.662 | *0.945* | 89.30 | 0.668 | *0.946* | 89.49 | 0.658 | *0.945* | 89.30 |
| Writing Fluency | 0.025 | 0.386 | 14.90 | 0.022 | 0.366 | 13.40 | 0.021 | 0.399 | 15.92 |

*Note.* Structure coefficients ($r_s$) greater than |.45| are in italics. KTEA-3 = Kaufman Test of Educational Achievement–Third Edition; $B$ = standardized canonical function coefficient; $r_s$ = structure coefficient; $r_s^2$ = squared structure coefficient.

When we consider the KTEA-3 writing subtests, Written Expression and Spelling were the primary contributors to the writing canonical variate. Secondary contributions were made by Writing Fluency. An investigation of the stability of relationship across ages found that both age bands 6 to 11, $F(6, 2512) = 37.28$, $p < .0001$, and ages 12 to 19, $F(6, 2848) = 48.02$, $p < .0001$, were statistically significant. These results indicate that, for the overall model, the relationship between the phonological processing error scores and the KTEA-3 writing subtests is stable across the age categories.

When we consider the different age bands, the second function was not found to be significant for ages 6 to 11, $F(2, 1257) = 0.47$, $p = .625$, or ages 12 to 19, $F(2, 1425) = 0.11$, $p = .893$. Therefore, similar to the overall results, only the first function was considered in the rest of the analysis.

Table 4 includes the results for canonical correlation coefficients for both age groups. Similar to the overall result, both the basic and advanced types of phonological processing errors have large standardized canonical function and structure coefficients. Advanced Phonological Processing errors are the largest contributor in both age groups; however, it explains more of the variation in the canonical variate in the 6 to 11 age group (70.56%) than in the 12 to 19 age group (58.67%).

Moving to the KTEA-3 writing subtests across age bands, for both ages 6 to 11 and 12 to 19 Written Expression and Spelling were the primary contributors to the writing canonical variate, while secondary contributions were made by Writing Fluency. All of the coefficients were positive, indicating that an increase in scores on the subtests would also increase scores on the canonical variate.

## *Canonical Correlation Analysis Between Phonological Processing Errors and KTEA-3 Oral Subtests*

A final analysis was conducted between phonological processing error factor scores and a variable set comprised of the KTEA-3 subtests that measure oral language. The analysis generated two canonical functions. Looking at both functions in an overall model, the Wilks's Λ of .844,

**Table 5.** Canonical Correlation Analysis Between Phonological Processing Errors and KTEA-3 Oral Subtests.

| | Function 1 (overall, *n* = 2,915) | | | Function 1 (ages 6-11, *n* = 1,460) | | | Function 1 (ages 12-19, *n* = 1,425) | | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | *B* | $r_s$ | $r_s^2$ (%) | *B* | $r_s$ | $r_s^2$ (%) | *B* | $r_s$ | $r_s^2$ (%) |
| Phonological Processing Errors | | | | | | | | | |
| Basic Phonological Awareness | 0.612 | *0.701* | 49.14 | 0.633 | *0.726* | 52.70 | 0.597 | *0.682* | 46.51 |
| Advanced Phonological Processing | 0.719 | *0.795* | 63.20 | 0.694 | *0.779* | 60.68 | 0.736 | *0.806* | 64.96 |
| $R_c$ | | 0.391 | 15.29 | | 0.367 | 13.49 | | 0.418 | 17.46 |
| Oral Subtests | | | | | | | | | |
| Listening Comprehension | 0.638 | *0.867* | 75.17 | 0.577 | *0.833* | 69.39 | 0.687 | *0.889* | 79.03 |
| Oral Expression | 0.429 | *0.747* | 55.80 | 0.443 | *0.768* | 58.98 | 0.412 | *0.715* | 51.12 |
| Associational Fluency | 0.066 | *0.473* | 22.37 | 0.091 | *0.456* | 20.79 | 0.029 | *0.468* | 22.09 |
| Object Naming Facility | 0.096 | 0.428 | 18.32 | 0.018 | 0.406 | 16.48 | 0.140 | 0.441 | 19.45 |
| Letter Naming Facility | 0.138 | 0.390 | 15.21 | 0.267 | *0.489* | 23.91 | 0.063 | 0.307 | 9.42 |

*Note.* Structure coefficients ($r_s$) greater than |.45| are in italics. KTEA-3 = Kaufman Test of Educational Achievement–Third Edition; *B* = standardized canonical function coefficient; $r_s$ = structure coefficient; $r_s^2$ = squared structure coefficient.

$F(10, 5816) = 51.46$, $p < .0001$, indicated a statistically significant relationship between the two variable sets. Furthermore, the overall squared canonical correlation ($R_c^2$) was .153. Thus, looking across the two functions, the full model explained 15% of the shared variance between the two variable sets.

Unlike with the previous canonical analyses, Function 2 was found to be a statistically significant function, $F(4, 2909) = 2.68$, $p = .03$; however, in considering including the second function in our analysis we first looked at results across the age groups. While the second function was found to be significant for ages 12 to 19, $F(4, 1419) = 3.13$, $p = .014$, similar to the previous analyses it was not found to be significant for ages 6 to 11, $F(4, 1454) = 1.28$, $p = 2.76$. We do not believe that eliminating a significant portion of our participants' results (the ages of 6-11), especially given that most meaningful changes in phonological processing occur in this age band, significantly inform our results and discussion; therefore, we have decided to focus our further analysis only on Function 1 which is presented in Table 5.

Results of this analysis found a similar pattern as those in the previous analyses. All of the coefficients were positive, indicating that as the error scores increase (decreasing number of phonological errors), scores on the canonical variate would also increase. Advanced Phonological Processing was the largest contributor, accounting for 63.20%, whereas basic errors explain 49.14%.

When we consider the KTEA-3 oral subtests, Listening Comprehension and Oral Expression were the primary contributors to the oral canonical variate. Secondary contributions were made by Associational Fluency, Object Naming Facility, and Letter Naming Facility.

An investigation of the stability of relationship across ages found that both age bands 6 to 11, $F(10, 2906) = 22.38$, $p < .0001$, and one for ages 12 to 19, $F(10, 2836) = 29.93$, $p < .0001$, were statistically significant. These results indicate that, for the overall model, the relationship between the phonological processing error scores and the KTEA-3 writing subtests is stable across the age categories.

Table 5 includes the results for canonical correlation coefficients for both age groups. Similar to the overall result, both the basic and advanced types of phonological processing errors have large standardized canonical function and structure coefficients. Advanced Phonological Processing errors are the largest contributor in both age groups. However, unlike in the previous analyses, Advanced Phonological Processing errors explain more of the variation in the canonical variate (64.96%) in the 12 to 19 age group than in the 6 to 11 age group (60.68%).

Moving to the KTEA-3 oral subtests, for both age groups Listening Comprehension and Oral Expression were the primary contributors to the oral canonical variate. Secondary contributions were made by Associational Fluency, Object Naming Facility, and Letter Naming Facility. All of the coefficients were positive, indicating that an increase in scores on the subtests would also increase scores on the canonical variate.

### *Descriptive Statistics and Correlation Matrix*

The correlations between error factor scores and the subtests/composites were all statistically significant. However, due to the slight correlation in the two error factor scores of phonological processing, we performed a final analysis of $z$-test scores for the two dependent correlations. The $p$ values from this test are presented are presented in Tables 6 and 7.

There are few statistically significant $z$-test results between error factor scores. For ages 6 to 11, there was a significant difference in correlations for the subtests/composites of Reading Vocabulary ($p = .022$), Letter Naming Facility ($p = .011$), and Reading Understanding Composite ($p = .031$). For ages 12 to 19, there were significant differences for Associational Fluency ($p = .025$). The total age sample compared correlations of both factors individually across age bands rather than comparing the correlations of the phonological processing factors. The only significant difference was Letter Naming Facility ($p = .020$) in the Basic Phonological Awareness factor. It appears that the relationship between error scores and the subtest/composite scores is both stable across the types of errors and stable across age ranges.

## Discussion

### *Examination of the Two Error Factors in Phonological Processing*

Many studies have used "phonological awareness," "phonological processing," or "phonemic awareness" interchangeably (Lund, Werfel, & Schuele, 2015). In the present study, "phonological processing" refers to the combined ability of memory (both short-term and working) and awareness of sound information.

Through analysis, we found two factors in phonological processing (or historically "phonological awareness"). These two factors are not completely independent because of slight correlations between them. The demarcation of the two may be difficulty level rather than separate error categories.

The first factor is Basic Phonological Awareness (BPA). BPA is the ability to identify and distinguish sounds, consisting of three subtests: blending, rhyming, and sound matching. Although BPA subtests also require storing sound inputs temporarily, the memory portion of the task seems less significant than it is in manipulating tasks.

The second factor is Advanced Phonological Processing (APP), which includes deleting and segmenting. Contrary to our anticipation, we found that segmenting errors are the most difficult and distinct in the KTEA-3. In particular, results from the younger group show a clearer distinction of segmenting errors from BPA. Deleting has long been considered a more difficult task than segmenting as deleting requires more working memory. Yopp (1988) compared the two different tasks under the same condition of phonemes. She categorized phoneme segmentation as "Simple

**Table 6.** Correlations Between Phonological Processing Errors and KTEA-3 Reading, Writing, and Oral Language Subtests.

| | Ages 6-11 | | | Ages 12-19 | | | Across ages | |
|---|---|---|---|---|---|---|---|---|
| | Basic Phonological Awareness ($n$ = 1,761) | Advanced Phonological Processing ($n$ = 1,548) | $p$ | Basic Phonological Awareness ($n$ = 1,489) | Advanced Phonological Processing ($n$ = 1,453) | $p$ | Basic Phonological Awareness $p$ | Advanced Phonological Processing $p$ |
| Basic Phonological Awareness | 1.000 | .141 | — | 1.000 | .120 | — | — | .566 |
| Advanced Phonological Processing | .141 | 1.000 | — | .120 | 1.000 | — | .551 | — |
| Reading Composite | | | | | | | | |
| Letter and Word Recognition | .350 | .300 | .103 | .317 | .325 | .807 | .294 | .448 |
| Reading Comprehension | .329 | .291 | .158 | .320 | .320 | .989 | .767 | .377 |
| Nonsense Word Decoding | .367 | .328 | .146 | .318 | .308 | .708 | .119 | .545 |
| Word Recognition Fluency | .249 | .202 | .088 | .245 | .241 | .898 | .899 | .259 |
| Decoding Fluency | .299 | .343 | .131 | .265 | .295 | .319 | .283 | .143 |
| Silent Reading Fluency | .272 | .225 | .109 | .229 | .251 | .480 | .202 | .458 |
| Reading Vocabulary | .343 | .278 | .022* | .315 | .332 | .577 | .366 | .105 |
| Writing Composite | | | | | | | | |
| Written Expression | .307 | .293 | .646 | .308 | .280 | .361 | .966 | .695 |
| Spelling | .317 | .315 | .933 | .311 | .310 | .980 | .849 | .893 |
| Writing Fluency | .160 | .124 | .227 | .152 | .134 | .552 | .824 | .787 |
| Oral Language Composite | | | | | | | | |
| Listening Comprehension | .242 | .269 | .388 | .280 | .312 | .312 | .243 | .193 |
| Oral Expression | .278 | .220 | .054 | .259 | .237 | .482 | .561 | .615 |
| Associational Fluency | .182 | .136 | .123 | .193 | .122 | .025* | .746 | .711 |
| Object Naming Facility | .176 | .121 | .085 | .152 | .156 | .898 | .494 | .316 |
| Letter Naming Facility | .204 | .123 | .011* | .125 | .122 | .937 | .020* | .989 |

*Note.* KTEA-3 = Kaufman Test of Educational Achievement–Third Edition.
*$p$ < .05, z-test.

**Table 7.** Correlations Between Phonological Processing Errors and KTEA-3 Reading, Writing, and Oral Language Subtest Composites.

| | Ages 6-11 | | | Ages 12-19 | | | Across ages | |
|---|---|---|---|---|---|---|---|---|
| | Basic Phonological Awareness ($n$ = 1,761) | Advanced Phonological Processing ($n$ = 1,548) | $p$ | Basic Phonological Awareness ($n$ = 1,489) | Advanced Phonological Processing ($n$ = 1,453) | $p$ | Basic Phonological Awareness $p$ | Advanced Phonological Processing $p$ |
| Basic Phonological Awareness | 1.000 | .141 | — | 1.000 | .120 | — | — | .566 |
| Advanced Phonological Processing | .141 | 1.000 | — | .120 | 1.000 | — | .551 | — |
| Reading Composite | .366 | .318 | .097 | .353 | .358 | .880 | .668 | .213 |
| Written Language Composite | .336 | .328 | .769 | .344 | .324 | .488 | .786 | .913 |
| Academic Skills Battery Composite | .353 | .339 | .590 | .341 | .367 | .336 | .694 | .370 |
| Sound-Symbol Composite | .482 | .494 | .619 | .482 | .506 | .345 | .987 | .664 |
| Decoding Composite | .378 | .333 | .055 | .343 | .340 | .882 | .253 | .832 |
| Reading Fluency Composite | .307 | .344 | .160 | .304 | .319 | .581 | .930 | .456 |
| Reading Understanding Composite | .358 | .298 | .031* | .341 | .349 | .777 | .588 | .119 |
| Oral Language Composite | .304 | .278 | .340 | .317 | .296 | .464 | .700 | .601 |
| Oral Fluency Composite | .229 | .172 | .051 | .220 | .176 | .143 | .801 | .893 |
| Comprehension Composite | .322 | .310 | .685 | .329 | .348 | .520 | .825 | .241 |
| Expression Composite | .336 | .297 | .155 | .327 | .301 | .359 | .777 | .897 |
| Orthographic Processing Composite | .324 | .288 | .193 | .307 | .295 | .672 | .585 | .851 |
| Academic Fluency Composite | .273 | .279 | .821 | .266 | .261 | .858 | .832 | .584 |

*Note.* KTEA-3 = Kaufman Test of Educational Achievement–Third Edition.
*$p$ < .05, z-test.

Phonemic Awareness" and phoneme deletion as "Compound Phonemic Awareness" among 6-year-old kindergarteners. Additionally, segmentation has generally not been considered a manipulation task. However, it is surprising that segmenting was more distinct than deleting because segmenting includes easier sound units, whereas deleting only includes phonemes in the KTEA-3. This may be due to the deliberate inhibition that segmenting requires from the examinee, as well as the need of a higher level of skillful attentiveness on the part of the examiner, something that may be difficult to standardize (J. Willis, personal communication, June 1, 2016).

### *Examination of Different Error Patterns in Different Age Levels*

Measurement of students' phonological processing ability on the KTEA-3 seems stable across ages. Our results support Wagner and colleagues' (1993) conclusions that phonological processing is an ability that can be measured in young children, and that these children's individual differences endure in a relatively stable way. Language-related skills do not show linear developmental growth (Farnia & Geva, 2013). Our study also supports the contention that phonological processing skills can develop quickly at the young age of about 6 (or Grade 1) alongside reading instruction or acquisition (Farrall, 2012; Kilpatrick, 2015; Perfetti et al., 1987), according to error pattern similarities between young students (age 6-11) and older students (age 12-19). These error pattern similarities indicate that segmentation and deletion tasks are generally more difficult for students across all ages. Also, segmentation and deletion predict students' reading, writing, and oral language skills better than does BPA across ages.

### *Examination of Correlations Between Phonological Processing Errors and Reading, Writing, and Oral Language Subtests Scores*

Do the two types of errors affect reading, writing, and oral language differently? The results do not support significantly different roles of the two errors on reading, writing, and oral language. However, the two error types might be independent in the subtests of Reading Vocabulary, Letter Naming Facility, and Reading Understanding Composite in 6 to 11 year olds, based on the $z$-test; Associational Fluency in 12 to 19 year olds; and Letter Naming Facility in the total group. Perhaps, skills related to fluency or complex cognitive processes need more of the memory skills that differentiate BPA and APP as predictors in those areas. For example, combined BPA and APP explained almost 22% variance of Reading Understanding Composite in the age 6 to 11 group (see the Table 7). When considering that reading comprehension is related to a multitude of skills, 22% is quite strong. This correlation is higher than Swanson et al.'s (2003) 19% and Engen and Høien's (2002) 15%, although we cannot fairly compare all the correlations due to differences in methods, tests, and groups.

Based on canonical correlation analysis, APP errors are more responsible for reading, writing, and oral language skills than BPA. Both APP and BPA were significantly related to

- All sub-reading skills (including processing speed-related skills, such as fluency and facility) in reading;
- Spelling and Written Expression (but not Writing Fluency in writing); and
- Listening Comprehension, Oral Expression, and Associational Fluency (but not Object Naming Facility and Letter Naming Facility in oral language).

### *Examination of Age Differences to Predict Reading, Writing, and Oral Language Subtests Based on Their Phonological Processing Performance*

In the literature, phonological processing has often been associated with beginning readers and code-related emerging skills (Lundberg et al., 1980). However, the results in the present study demonstrate that even older students' phonological processing performance can predict their reading, listening, and oral language. Interestingly, the APP errors of older students showed a stronger association with their oral language than the APP errors of younger students.

Additionally, the APP of the age 12 to 19 group correlated more with comprehension composite (reading and listening) and reading comprehension than the age 6 to 11 group. This result is not congruent with the prevailing idea that using phonological processing as a predictor may not be efficient as other variables may predict literacy better than phonological processing (Swanson et al., 2003). Although new technology develops fast enough to start grading writing more efficiently and accurately (J. C. Kaufman, 2015), measuring those skills still requires more time and effort than phonological processing.

## Implications

Phonological processing as a strong predictor of emerging literacy skills has been supported by a myriad of studies. Anthony and Francis (2005) highlighted the importance of accurate phonological assessment tools with "multiple levels of task complexity" and "multiple levels of linguistic complexity" for the practice. However, Kilpatrick (2012, 2015) noted that researchers have not determined which types of phonological tasks are most age-appropriate and useful for practitioners. He asserted that most school psychologists use segmentation rather than deletion due to its popularity. However, he suggests that deletion tasks can be even more useful to capture more globalized phonological skills beyond kindergarten. In the present study, APP errors explained more variance in all reading, writing, and oral language performance. Our study supports the importance of measuring segmentation as well as deletion to predict various language skills across ages 6 to 19 and give a more complete picture.

Although some might think that phonological processing and comprehension (both reading and listening) may not be strongly related, our study showed statistically meaningful correlations. Most of all, the issues related to reading comprehension level can be hidden until students become third graders (Cain & Oakhill, 2006; Hulme & Snowling, 2011) as approximately 10% of students with poor reading comprehension do not show difficulties in decoding and decoding fluency (Nation, Clarke, Marshall, & Durand, 2004) and 5% of students with poor reading comprehension showed typical intelligence and decoding skills (Cornoldi, de Beni, & Pazzaglia, 1996). However, phonological processing can be assessed in preschoolers as phonological tasks deal with speech sounds that do not necessarily require alphabetic knowledge (Pullen & Justice, 2003) nor much time.

Error analysis is especially important to poor readers because some students achieve a very high score on easy tasks, but a poor score on difficult tasks (Kilpatrick, 2012). Inversely, some poor readers can show difficulty in basic tasks, such as blending, but better scores in advanced tasks, such as deleting. These poor readers did not master essential blending skills but they could perform better in advanced phonological tasks using their spelling knowledge. Yet, their overall cut-off single scores, without distinguishing the levels of difficulty, do not tell practitioners that they only mastered Basic Phonological Awareness skills or they masked their difficulties in basic skills. Not all students need accurate levels of educational tests, but those students with oral language and literacy acquisition difficulties need more differentiated phonological processing tests. Especially, the RTI model can fail to diagnose specific issues for interventions, and Cunningham et al. (2015) pinpointed the importance of mastering both easy and difficult phonological processing skills in literacy. Torgesen et al. (2001) showed that phoneme-level interventions with the poor readers in the bottom 2% (or 98 percentile) could result in effective remediation.

In the current study, even students as young as age 6 demonstrated ability to manipulate phonemes in deleting tasks. In addition, phonological performance of older students through age 19 predicted their reading, writing, and oral language. This indicates that we should look beyond

BPA to also consider APP. In summary, practitioners can use APP tasks to predict reading, writing, and oral language for students in a wide range of grades, including young students.

## Limitations and Future Studies

Due to the great number of participants, we did not identify students' performance or different error types based on each individual age or grade; instead, age and grade bands were used. However, we found no significant differences across ages and grades. Most participants aged 4 and 5 were eliminated from our analyses due to missing data.

Phonological processing is a latent ability similar in that regard to intelligence. There are always gaps between hypothetically pure phonological processing skills and phonological test scores. For example, illiterate young children with limited alphabet exposure may not be able to understand instructions to perform difficult phonological tasks. Reversely, the ceiling effect could have failed to assess older students' high phonological performance to differentiate complex skills. Additionally, other literacy skills (Kilpatrick, 2015; Perfetti et al., 1987), such as spelling, can mediate phonological processing. In other words, students can spell in their head to manipulate phonemes so scores may overestimate actual phonological skills. J. Willis (personal communication, March 26, 2016) recommended the inclusion of tasks that are more difficult for older students beyond phoneme deletion or segmentation. The examples are substituting sounds or reversing phonemes (e.g., "enough" backwards is "funny" and "knife" is "fine").

One issue with these advanced tasks is that they call for heavy working memory, so the validity of phonological "awareness" tests can be poor. However, phonological "processing" can include phonological working memory, which justifies complex phonological tasks. Therefore, we argue that the term "phonological awareness" should be "phonological processing" from segmenting to all manipulating phonemes in future research. Some phonological tests are so easy that some students without achieving Advanced Phonological Processing may not be recognized due to the name of "awareness." When phonological processing is timed, students using "mental spelling" strategies may be identified (Kilpatrick, 2015). Yet, under the name of "awareness," it seems difficult to time phonological processing because the results would be conflated with fluency rather than the automaticity that is necessary for successful reading.

Although it is scientifically meaningful to research phonological awareness and phonological working memory separately in theoretical frames, researchers should focus more on difficulty levels of globalized tasks for practical efficiency. It is important for researchers to develop research-based tools to support practitioners, such as classroom teachers who must be knowledgeable about such matters for their role in identifying and responding to students' needs in the prevailing RTI framework (Farrall, 2012).

In regard to future studies, we found some students across ages demonstrated discrepancy between the two types of phonological categories: Basic Phonological Awareness and Advanced Phonological Processing. It would be meaningful to research at what age this discrepancy begins to diminish, and if this can explain the variance of phonological processing, cognitive, linguistic abilities, or SES after first grade.

In the present study, participants were controlled for SES, ethnicity, and region. However, academic performance, including literacy, is influenced by many social background variables. In the United States, there is converging evidence to support that students from poor families (Buckingham, Beaman, & Wheldall, 2014) or high poverty (Plucker, Giancola, Healey, Arndt, & Wang, 2015) are less likely to read well enough to obtain future opportunities (National Reading Panel, 2000). According to Noble, Farah, and McCandliss (2006), however, no single study had researched the relationship between SES and phonological awareness before them. Thus, it would be meaningful to see different patterns of errors in phonological processing depending on different backgrounds.

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