# PASS Theory of Intelligence and Academic Achievement: A Meta-Analytic Review

by

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## Abstract

Although Planning, Attention, Simultaneous and Successive (PASS) processing theory of intelligence has been argued to offer an alternative look at intelligence and PASS processes – operationalized with the Cognitive Assessment System – have been used in several studies, it remains unclear how well the PASS processes relate to academic achievement. Thus, this study aimed to estimate the size of their relation by conducting a meta-analysis. To select the studies for the meta-analysis, I conducted an electronic database search (e.g., ERIC, PubMed, PsycINFO), an ancestral search, and also reviewed book chapters, dissertations, and interpretive and technical manuals. A total of 62 studies, involving 13,356 participants, met the inclusionary criteria. A random-effects model analysis of data from 62 studies with 93 independent samples revealed a moderate-to-strong relation between PASS processes and reading, $r = .409$, 95% CI = [ .363, .454]), and mathematics, $r = .461$, CI = [ .405, .517]. Moderator analyses further showed that (1) PASS processes were more strongly related with reading and mathematics in English than in other languages, (2) Simultaneous processing was more strongly related to mathematics accuracy and problem solving than mathematics fluency, (3) Simultaneous processing was more strongly related to problem solving than Attention, and (4) Planning was more strongly related to mathematics fluency than Simultaneous processing. Age, grade level, and sample characteristics did not moderate the PASS-reading/mathematics relation. Taken together, these findings suggest that PASS cognitive processes are significant correlates of academic achievement, but their relation may be affected by the language in which the study is conducted and the type of mathematics outcome.

## Preface

This dissertation is submitted for the degree of Master of Education in Special Education at the University of Alberta. The research reported herein was conducted under the supervision of Dr. George K. Georgiou, Department of Educational Psychology, University of Alberta. The literature review, data analysis, and discussion are the original work of Nithya Naveenkumar.

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# Chapter 1: Introduction

Reading and mathematics are certainly some of the most important skills children are asked to master in their early school life. Performance in these academic skills serves as a vital indicator of an individual's future education and occupational choices (e.g., Ek, Sovio, Remes, & Järvelin, 2005; Flashman, 2012; Lubinski, Benbow, & Kell, 2014; Rana & Mahmood, 2010). Consequently, knowing what influences performance in these two academic skills is of utmost importance not only because they determine an individual's future, but also because they can adversely affect society's future as well as a country's economic growth (e.g., Coulombe, Tremblay, & Marchant, 2004).

Intelligence has been found to be one of the factors affecting reading and mathematics performance (e.g., Barton, Dielman, & Cattell, 1972; Deary, Strand, Smith, & Fernandes, 2007; Mayes, Calhoun, Bixler, & Zimmerman, 2009; Soares, Lemos, Primi, & Almeida, 2015). In general, individuals with higher IQ outperform others with lower IQ in reading and mathematics. Meta-analyses have also been conducted to determine the size of the relation between intelligence and academic achievement (e.g., Peng, Wang, Wang, & Lin, 2019; Roth et al., 2015). Roth et al. (2015), for example, estimated the average correlation between IQ (operationalized with different IQ measures) and school grades to be .44.

Although several studies have established a close connection between IQ and academic achievement, some researchers have argued that traditional IQ tests (e.g., Wechsler Intelligence

Scale for Children) and academic achievement tests (measures include vocabulary, general information, arithmetic) often have very similar content (Naglieri, 2008; Naglieri & Borenstein, 2003). This leaves open the possibility that performance in these IQ measures is influenced by what a child already knows (or what s/he has learned at school) and not by how s/he thinks (which should be the target of intelligence testing) (e.g., Das, 2002; Gardner, 1993; Naglieri & Otero, 2018). Researchers have also claimed that the most popular psychometric batteries of IQ lack a theory base that relates intelligence measures to achievement (Das, Naglieri, & Kirby, 1994; Fagan, 2000; Sternberg, 1988).

To address these issues and to expand the scope of abilities measured, Das et al. (1994) proposed a neurocognitive theory of intelligence called PASS (for Planning, Attention, Simultaneous, and Successive processing). The PASS theory of intelligence provides a comprehensive way of conceptualizing and measuring human cognitive competencies through the Cognitive Assessment System (CAS; Naglieri & Das, 1997; CAS2; Naglieri, Das, & Goldstein, 2014). Researchers have found that all four PASS processes - measured by CAS - are correlated with academic performance (see Kroesbergen, Van Luit, Naglieri, Taddei, & Franchi, 2010; Naglieri, Rojahn, Matto, & Aquilino, 2005; Naglieri, Delauder, Goldstein, & Schwebech, 2006; Naglieri & Rojahn, 2004; Rosário, 2007). Although several studies have examined the relation of CAS measures with academic achievement, we are still lacking a quantitative synthesis of this line of research. Thus, the purpose of this meta-analysis was to estimate the size of the relation between PASS processes and academic achievement as well as the role of different moderators in their relation (e.g., the type of reading and mathematics outcome, the age of participants, the sample characteristics, and the language in which the study was conducted).

This thesis is expected to make two important contributions to the literature: First, it provides an integrative review of the existing research on the relation between PASS processes and academic achievement that cannot be provided by a single study. Second, given that PASS theory has been studied for more than 20 years, this is the first meta-analysis of correlational studies examining the association of PASS cognitive processes with reading/mathematics performance.

# Chapter 2: Literature review

## PASS Theory of Intelligence

Based on the neuropsychological work of Luria (1966, 1973), PASS theory of intelligence asserts that human cognition is organized into three functional units that support four cognitive processes (Planning, Attention, Simultaneous, and Successive) (e.g., Das et al., 1994; Naglieri & Das, 1990). According to Das et al. (1994), the first functional unit, Attention-Arousal is responsible for maintaining adequate level of arousal that facilitates focus of attention on a specific direction and on a particular stimulus. Difficulties in this first functional unit may result in difficulties with information coding (Simultaneous and Successive processing), as well as difficulties in controlling, organizing, and monitoring behavior (Planning).

The second functional unit is involved in the acquisition, storage and retrieval of information from the external environment through Simultaneous and Successive processes. Simultaneous processing involves integrating stimuli into groups or the recognition that a number of items share a common characteristic, for example, comprehending a sentence/paragraph. In turn, Successive processing is required for organizing separate items in a sequence, for example, remembering a sequence of words.

The third functional unit is responsible for selection and application of strategies, self-monitoring performance, evaluation and modification of approach if necessary. The abilities and behaviors involved in the Planning construct closely resembles executive functioning (EF) skills

(Das & Misra, 2005). All the three functional units are interrelated but have specific functions that are influenced by an individual's knowledge base.

**Operationalization of PASS Theory**

The PASS theory has been operationalized by Cognitive Assessment System (CAS; Naglieri & Das, 1997; Naglieri et al., 2014) that measures the PASS constructs in children from ages 5 through 17. The PASS constructs are comprised of four scales that are defined by three subtests in each scale. There are two forms of CAS battery – standard and basic. In the standard battery, each PASS scale consists of three subtests whereas the basic battery is composed of two subtests in each scale. All four PASS scales and the respective subtests are described below.

***Planning.*** Planning is assessed with three subtests: Matching Numbers, Planned Codes, and Planned Connections. Matching Numbers requires the examinee to rapidly underline two identical numbers in each row. Planned Codes requires an individual to fill out empty boxes, as quickly and accurately as possible based on the given key on the top of each page (i.e., A=XO, B=XX, C=OX, D=OO). In Planned Connections, the examinee is asked to connect a series of boxes with numbers or letters in a sequential order. Some of the items in this subtest include a sequence of numbers only, though others include both numbers and letters sequence to connect in an alternating manner (e.g., 1-A-2-B-3-C).

***Attention.*** Attention is assessed with three measures:  Expressive Attention, Number Detection, and Receptive Attention. In Expressive Attention, the examinee is asked to name stimuli on three pages within a specific time limit – i) to read colour names such as “Blue”, “Yellow”, “Green” and “Red” that are printed in black ink, ii) to name the colors of a series of rectangles, and iii) to name the colour of the ink in which the colour names are printed (e.g., Blue printed in red ink to be read as “Red”). Number Detection requires an individual to locate the target number as quickly as possible in the same font (i.e., the numbers 1, 2, and 3 printed in an open font) among the distractors in a varied font type. In Receptive Attention, an individual is asked to rapidly underline pairs of letters that are similar in appearance (e.g., TT or t t but not N t) and then identify pairs of letters that share a similar lexical perspective (e.g., t and T but not t and N).

***Simultaneous processing.*** Simultaneous processing is measured with three tasks: Nonverbal Matrices, Verbal-Spatial Relations. and Figure Memory. Nonverbal Matrices requires an individual to choose a missing piece from six possible answers that completes correctly a matrix. Verbal-Spatial Relations consists of six drawings (organized in a certain spatial manner) and a printed question (e.g., *Which picture shows a circle to the left of a cross under a triangle above a square?*). The examiner reads out the question and then asks the participant to select the correct response from six options. In Figure Memory, the examiner shows two- or three-dimensional geometric figures to the subject for 5 secs and then takes away the picture. Next, the examiner provides a response page and asks the subject to identify the original design that is enclosed in a larger complex geometric figure.

***Successive processing.*** Successive processing is assessed with three measures: Word Series, Sentence Questions, and Visual Digit Span. Word Series requires the subject to repeat a series of single-syllable, high frequency words (e.g., book, car, cow, dog) in the same order s/he had heard them by the examiner. In Sentence Questions, the examiner read out loud a series of sentences (i.e., “The blue is yellowing”) and then asks questions related to the sentences read (e.g., “Who is yellowing?”). Finally, in Visual Digit Span, the examiner shows a series of numbers from a stimulus book and then asks the subject to recall the numbers in the same order.

**PASS Processes and Reading**

To date several studies have shown that PASS processes are related to reading performance (see e.g., Das, Snart, & Mulcahy, 1982; Joseph, McCachran, & Naglieri, 2003; Kirby & Robinson, 1987; Naglieri, & Rojahn, 2004). For example, Naglieri and Rojahn (2004) studied the association between PASS processes and Broad Reading (Letter-Word Identification and Passage Comprehension) with the CAS standardization sample. The results indicated that the correlations between the four cognitive processes and Broad Reading ranged between .43 and .55 (the highest being between Simultaneous processing and Broad Reading).

Researchers have also proposed theoretical links between PASS processes and reading performance (see Das et al., 1994; Das & Misra, 2015; Naglieri & Otero, 2018; Papadopoulos, Parrila, & Kirby, 2015). Das et al. (1994), for example, proposed that Successive processing contributes to word reading through the effects of phonological recoding (sounding out) and

Simultaneous processing contributes to word reading through the effects of orthographic knowledge (the ability to form, store, and access orthographic representations). Planning and Attention have also been viewed as critical for reading comprehension. To succeed in reading comprehension, individuals need to develop a plan on how to approach a passage, actively revise their plan as they read a passage, and inhibit irrelevant information in order to develop a coherent text representation.

Findings of previous studies with typically–developing children (e.g., Das, Georgiou, & Janzen, 2008; Kendeou, Papadopoulos, & Spanoudis, 2015; Naglieri & Rojahn, 2004; Papadopoulos, 2001; Wang, Georgiou, & Das, 2012) have confirmed these predictions. For example, Papadopoulos (2001) found that the effect of Successive processing on reading accuracy (Word Identification and Word attack) in Greek–speaking Grade 1 children was mediated by phonological awareness. Likewise, these predictions were confirmed in the studies that involved children with reading difficulties (e.g., Das, Janzen, & Georgiou, 2007; Joseph et al., 2003; Wang, Georgiou, Das, & Li, 2012).

On the basis of these relations, Das (1999) also developed the PASS Reading Enhancement Program (PREP) that trains children on Simultaneous and Successive processing. Intervention studies showed that PREP training in children with reading difficulties led to a significant improvement in reading (Mahapatra, Das, Stack-Cutler, & Parrila, 2010; Papadopoulos, Charalambous, Kanari, & Loizou, 2004). Mahapatra et al. (2010), for example, examined the effects of PREP on word reading and comprehension in two groups of 14 fourth grade poor readers. The intervention group received PREP, while the control group received regular classroom instruction. Grade level comparisons showed that the intervention group showed a significant increase in word reading equal to 3.5 grades and in reading comprehension equal to 3.2 grades.

**PASS Processes and Mathematics**

Researchers have shown that PASS processes are also related to mathematics performance (e.g., Iseman & Naglieri, 2011; Kirby & Ashman, 1984; Kroesbergen et al., 2010; Naglieri & Rojahn, 2004). For example, Naglieri and Rojahn (2004) found that the correlations between the four cognitive processes and Broad Math (Calculation and Applied Problems) ranged between .45 and .58 (the highest being between Simultaneous processing and Broad Math).

Planning is important for mathematics because individuals must make decisions on how to solve a math problem and monitor their own performance. Attention is involved in selectively attending to the components of a problem and for suppressing irrelevant information. Simultaneous processing is relevant for tasks that consist of different interrelated elements that must be integrated into a whole, as in solving an equation with multiple operations (e.g., (3 + 5) X (4 + 4)/2 =?)) or in areas of mathematics that involve interpretation of spatial information (e.g., geometry). Finally, Successive processing is relevant when information has to be processed in a certain order, as in counting.

Findings of previous studies with typically–developing children (e.g., Georgiou, Manolitsis, & Tziraki, 2015; Naglieri & Das, 1987; Naglieri & Rojahn, 2004; Kroesbergen et al., 2010) as well as children with mathematics difficulties (e.g., Cai, Li, & Deng, 2013; Iglesias-Sarmiento & Deaño, 2011; Kroesbergen, Van Luit, & Naglieri, 2003) have confirmed these predictions. For example, Cai et al. (2013) found that children with Math Learning Difficulties (MLD; those who scored at the bottom 20% in a standardized math test and in three math class tests) demonstrated fairly lower scores on all four PASS processes than good math performers (those who scored at the top 20% in a standardized math test and in three math class tests).

Intervention studies have also shown that cognitive strategy instruction (especially Planning) significantly improved children's math performance (Hald, 1999; Iseman & Naglieri, 2011; Naglieri & Gottling, 1997; Naglieri & Johnson, 2000). For example, Naglieri and Johnson (2000) found positive effects of Planning intervention in 19 children with learning disabilities and mild developmental disabilities (ages 12 and 14). The children with cognitive weaknesses in Planning showed substantial improvement in math accuracy (with a large effect size of 1.4), whereas the children with other cognitive weaknesses (Attention, Simultaneous, and Successive) and no cognitive weaknesses displayed comparably smaller effect sizes that ranged from -.2 to .5.

**The Present Study**

The purpose of this meta-analysis was to examine the strength of the relation between PASS processes and reading/mathematics performance. We aimed to answer the following five research questions:

(1) What is the size of the relation between PASS processes and reading/mathematics performance? Based on the findings of previous studies (e.g., Naglieri & Rojahn, 2004), we hypothesized that PASS processes would be strongly related to both reading and mathematics performance.

(2) Does the PASS–reading/mathematics relation vary as a function of the type of reading/mathematics outcome (e.g., reading accuracy vs. reading fluency vs. reading comprehension)? Because Planning and Attention are operationalized with measures that involve response times, we hypothesized that Planning and Attention would be more strongly related to reading/math fluency than reading/math accuracy. Furthermore, taking into consideration that Simultaneous processing requires comprehension of word relations and spatial orientation, we hypothesized that Simultaneous processing would be more strongly related to reading comprehension/problem solving than reading/math accuracy/fluency.

(3) Does the PASS–reading/mathematics relation vary as a function of age/grade level? Because the focus of reading/mathematics instruction changes across time (i.e.,

children focus more on decoding/calculations in early grades and on reading comprehension/problem solving in upper grades), the role of PASS processes should also change across time. Based on the findings of previous studies that showed that Successive processing predicts reading in early grades because of its connection to decoding (e.g., Papadopoulos, 2001), we hypothesized that Successive processing would be more strongly related to children in primary schools than in middle/high schools. Because the findings of previous studies that displayed Planning processing predicts reading in upper grades because of its connection to comprehension (e.g., Kendeou et al., 2015), we hypothesized that Planning would be more strongly related to children in middle/high schools and university students.

(4) Does the PASS–reading/mathematics relation vary as a function of language in which the studies were conducted? To our knowledge, only one study has directly compared the contribution of PASS processes to mathematics across languages (Italian vs. Dutch) and reported no significant differences across languages (Kroesbergen et al., 2010). Because of the dearth of studies that compared the PASS–reading/mathematics relation across languages, we did not formulate a specific hypothesis.

(5) Does the PASS–reading/mathematics relation vary as a function of sample characteristics (e.g., typically–developing children vs. children with learning disabilities vs. gifted children)? To our knowledge, only one study directly compared the relations of PASS processes in groups of different ability levels and reported

stronger correlations between Simultaneous and Successive processing with problem solving in the group of children with math disabilities than in the group of typically–developing children (Iglesias-Sarmiento, Deaño, Alfonso, & Conde, 2017). Because of the dearth of studies that compared the PASS–reading/mathematics relation with various ability groups, we did not formulate a specific hypothesis

# Method

## Data Collection

The inclusion, search, and coding procedures are detailed in Figure 1. To identify the studies for the meta-analysis, we first searched in electronic databases (i.e., ERIC, PubMed, Medline, PsycINFO, ProQuest Educational, Scopus, and Google Scholar) for publications between January 1997 (the year CAS was published) and March 2019. The following descriptors were used in our search*:* Set 1 *PASS theory*, PASS cognitive processes*, planning*, attention*, simultaneous processing*, successive processing*, cognitive assessment system*, CAS*,* combined with Set 2 - *reading ability*, reading achievement*, reading skills*, reading accuracy*, reading fluency*, reading comprehension*, character recognition*, oral reading*, decoding*, word recognition**, and/or Set 3 - *math ability*, math performance*, arithmetic*, math achievement*, calculation fluency*, problem solving*, math skills*, numeracy skills**. Within each set the OR command was used and between sets the AND command was used. Second, we searched for additional papers in e-books, interpretive and technical manuals (Naglieri & Das, 1997; Naglieri et al., 2014; Naglieri & Otero, 2017), and the reference lists of the studies identified through the initial database search. Finally, we contacted all authors who published studies on PASS processes and asked for any unpublished data.

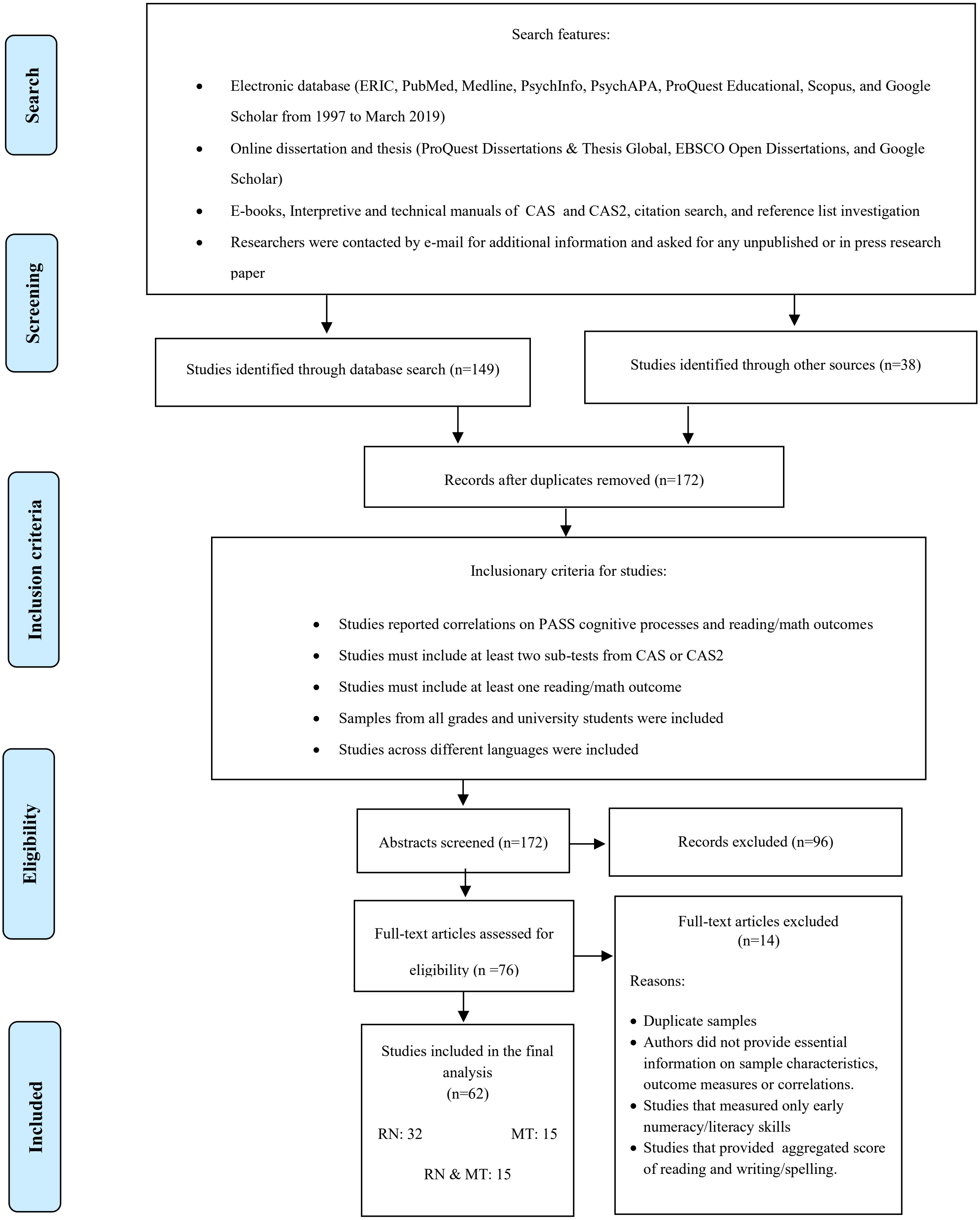


*Figure 1*. Flow diagram for the search and inclusion on studies. RN = Reading; MT = Mathematics

**Operational Criteria for Inclusion and Elimination of Studies**

For the target constructs included in this study, we first established operational criteria to determine the indicators of each construct. In regard to PASS processes, studies were considered if they had assessed one of the PASS processes (e.g., Planning) with at least two tasks from either edition of the CAS (Naglieri & Das, 1997; Naglieri et al., 2014) or more than one PASS process (e.g., Planning and Attention) with at least one task (e.g., Planned Codes to operationalize Planning and Expressive Attention to operationalize Attention)[1]. Studies that included only one measure of CAS (most often the Nonverbal Matrices as an indicator of nonverbal IQ) were excluded.

In regard to reading, we considered four types of outcomes (reading accuracy, reading fluency, reading comprehension, and Broad Reading). To be considered a measure of reading accuracy the task should require individuals to read aloud words or nonwords without any time limits. A task was considered a measure of reading fluency if it required individuals to read as many words, nonwords, or sentences as quickly and as accurately as possible within a specified time limit. Text reading speed was also considered a measure of reading fluency. To be considered a measure of reading comprehension, the task should require individuals to answer questions about a story they read or provide the missing word to complete accurately the meaning of a sentence. Finally, we included studies that reported correlations between PASS processes and Broad Reading (a cluster score derived from combining scores in reading accuracy, fluency, and comprehension).

In regard to mathematics, we considered four types of outcomes (math accuracy, math fluency, problem solving, and Broad Math). To be considered a measure of mathematics accuracy the task should require individuals to solve calculations under untimed conditions. To be considered a measure of mathematics fluency, the task should require individuals to solve as many arithmetic problems as possible within a given time limit. Problem solving tasks included either mathematical reasoning or applied math problems. Finally, we considered studies that reported correlations between PASS processes and Broad Math (a cluster score derived from combining scores in calculation, math fluency, and applied problems).

We further applied the following three exclusionary criteria:

1) To avoid including the same data from more than one study, we selected the study that was published earlier and excluded the later studies.
2) If a dissertation was also published as an article, we only considered the article.
3) The studies that examined the relation between PASS and academic achievement before 1997 were excluded.

After these criteria were applied, we identified 62 studies with 93 unique samples and the size of the samples ranged from 20 to 1691 participants. Of the 62 studies, one was published in Chinese and two in Portuguese.

**Coding Procedures**

To begin the coding process, we first created a coding spreadsheet and the following components of the selected studies were coded: a) mean age of the participants at the time of assessment, b) grade level, c) language in which the study was conducted, d) sample characteristics (e.g., reading: unselected, good readers, or poor readers; mathematics: unselected, good mathematicians, or poor mathematicians), e) type of reading outcome (accuracy/fluency/comprehension/Broad Reading), and f) type of math outcome (accuracy/fluency/problem solving/Broad Math).

Second, we coded all the effect sizes for each of the target constructs. Several studies reported more than one measure to examine the association between PASS processes and reading/math. To have one effect size per construct, we established a set of rules. For PASS processes, if more than one subtest (e.g., Matching Numbers, Planned Codes, Planned Connections) was used to measure a PASS process (i.e., Planning), an arithmetic mean of $r$ values was coded. For reading accuracy, reading fluency, and reading comprehension tasks, the multiple effect sizes for each construct (e.g., Word Identification and Word Attack as indicators of reading accuracy) were aggregated using an arithmetic mean. Similarly, for math accuracy, math fluency, and problem-solving tasks, when there was more than one effect size for each construct, the average *r* was coded. Third, for longitudinal studies, the data from the first measurement of reading and/or math ability was coded.

Finally, to ensure accuracy of coding, all 62 studies were coded individually by myself and a graduate student who received training in the coding procedures. The data were recorded into two coding spreadsheets (one for the reading studies and one for the math studies; see Appendix A and B) and the interrater agreement was calculated. The consensus rate varied between 95% and 98%. Differences in coding were due to inadequate information provided in some studies about their participants and measures. The discrepancy between the coders was resolved by revisiting the studies and after having a discussion between the two raters.

**Moderator Variables**

In each study, we coded five moderators that could explain the variation between studies. Studies that reported effect sizes from a pooled sample of poor and good readers/math performers were not coded.

**Age**. The participants' age was coded in three ways: a) If both the age range and mean age were reported and the age range was not larger than one year, the mean age was coded (e.g., the age 9.14 years was coded, when the age ranged between 9-10 years); b) If the age range alone was reported and it was not larger than one year, the median value was coded (e.g., when the age range was 9-10 years, 9.5 years was coded as age); and c) The mean age was coded, when the mean age was solely reported. The studies that reported the age range (i.e., larger than one year) without providing information on the mean age were excluded from the moderator analyses.

**Grade level**. Grade was coded as a moderator variable. The studies that had samples from different grades and reported the effect sizes separately for each grade were included in the moderator analyses. Studies were excluded if they assessed children from different grades and reported results from the pooled sample.

**Sample characteristics.** Reading performance was coded to differentiate the ability level of the samples. The studies that had unselected samples of children were coded as "unselected". The sample that consisted of gifted children, good comprehenders, and skilled readers were coded as "good readers". The participants described as reading below grade level, poor comprehenders, and less-skilled readers were coded as "poor readers". Two of the studies with a sample of children with Attention Deficit Hyperactive Disorder (ADHD), emotional or behavioral problems and one study with children with mild developmental disorders were eliminated from the moderator analyses.

Math performance was also coded to differentiate the ability level of the samples. The studies that had unselected samples of children were coded as "unselected". The samples that consisted of gifted children were coded as “good performers”. The participants described as having below grade level math performance were coded as “poor performers”. Three studies that included children with Math Learning Disabilities (MLD) in their sample and reported combined scores were excluded. Although, in one study, the correlations were reported separately for the participants with MLD, neither was included.

**Language.** The majority of the studies were conducted in English and we coded them as “English”. The studies in Greek, Portuguese, Dutch, Italian, and Spanish were coded as “other European languages”, and the studies in Chinese, Oriya, Arabic, and Malay were coded as “non-European languages”. Finally, four studies with English Language Learners were coded as “ELL”.

**Task type**. The reading outcome tasks were classified into accuracy, fluency, and comprehension. Likewise, math tasks were categorized into accuracy, fluency, and problem solving. Thirteen studies that reported correlations between PASS processes and Broad Reading, and 10 studies that provided correlations between PASS processes and Broad Math were excluded from the moderator analysis.

## Statistical Analysis

The metafor package for the R statistical program (Viechtbauer, 2010) was used for the analyses. The effect sizes for all the studies were displayed by the Pearson’s *r* correlation coefficient. When a correlation between PASS Full Scale and reading/mathematics outcome was available, it was used before the mean of *r* values of other subtests of PASS. For both reading and mathematics outcomes we estimated the overall weighted average effect using a random–effects model (Borenstein, Hedges, Higgins, & Rothstein, 2009) instead of a fixed–effects model, because it rests on the assumption that variation between studies can be systematic and not only due to random error. Whether or not the overall effect size differed from zero was tested with a *z* test. The 95% CI was also calculated for each overall effect size to provide more information about the correlation.

To examine whether variation in the *r* value between studies was significant, the *Q* test of homogeneity was used (Hedges & Olkin, 2014). A significant value on this test indicates a reliable variability between the effect sizes in the sample of studies. $I^2$ was used to determine the magnitude of the heterogeneity. $I^2$ is the proportion of total variation between effect sizes that is caused by real heterogeneity rather than chance. Values around 25% are typically considered 'low', values around 50% 'moderate', and values around 75% 'high' (Higgins et al., 2003).

Moderator variables were also explored as potential sources of additional variance in the effect sizes. Linear models were used to predict the study's outcome from the moderator variables, both for the continuous (i.e., age) and categorical (i.e., grade level, task type, sample characteristics, language) moderators. For a continuous moderator, a regression coefficient was estimated, and a *z* test was used to determine the significance. The degree of differences between the subsets of studies was tested with a *Q* test and by comparing the correlation magnitude with CIs between the study subsets.

**Publication Bias**

To test for publication bias, we first computed Rosenthal's Fail-Safe N and we also conducted the Rank Correlation and Egger's Regression tests. These tests examine the relationship between the size of the effects from each study and the associated standard error. Furthermore, funnel plots were created to assess whether the studies were distributed asymmetrically around the mean effect size, which may also indicate the presence of publication bias (Borenstein et al., 2009). In the funnel plot, the sample size is plotted on the *y* axis and the effect size on the *x* axis. In the absence of retrieval bias, this plot should form an inverted funnel. In the presence of bias, the funnel should be asymmetric. Finally, the "trim and fill" method for random-effects models (Duval & Tweedie, 2000) was used in order to examine the impact of possible missing studies. The "trim and fill" method imputes values to make the funnel plot symmetrical and calculate an estimated overall effect size on this basis.

# Results

## Study Features

Of the 62 studies that were included in our final analysis, 15 reported results on both reading and math outcomes, 32 reported results on only reading, and 15 on only math. There were 13,356 participants represented, with sample sizes ranging from 20 to 1,691. The mean age reported in the studies ranged from 4.91 to 22.26 years, and the grade level ranged from kindergarten to adults.

## Meta-Analytic Results

The random–effects model demonstrated that the overall mean correlations between PASS and both reading, and math outcomes were significant (see Table 1). For reading, the mean effect size across the 66 effects from 47 studies was $r = .409$ ($z = 17.666$, $p < .0001$, 95% CI = [ .363, .454]; see also Figure 2 for the forest plot), indicating a large effect size. The mean effect size for studies that reported correlations between PASS Full Scale and reading was even larger, $r = .605$ ($z = 21.236$, $p < .0001$, 95% CI = [ .549, .661]).

Table 1

*Overall Meta-Analytic Results*

| Outcomes | *k* | *n* | *r* | S.E. | *Z* value | *p* value | 95% CI | Heterogeneity | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | $I^2$ (%) | *Q* | *p* value |
| Reading[a] | 66 | 11230 | .409 | .023 | 17.666 | < .0001 | [ .363, .454] | 90.31 | 688.335 | < .0001 |
| | 20 | 5902 | .605 | .029 | 21.236 | < .0001 | [ .549, .661] | 90.73 | 102.267 | < .0001 |
| Math[a] | 48 | 8621 | .461 | .029 | 16.110 | < .0001 | [ .405, .517] | 93.09 | 452.096 | < .0001 |
| | 22 | 6063 | .615 | .022 | 28.041 | < .0001 | [ .572, .658] | 82.90 | 68.527 | < .0001 |

*Note*: [a]. The second row under reading or mathematics refers to the estimates obtained when the PASS Full Scale was used. *k* = number of correlations; *n* = total sample size; *r* = estimated correlation size (Pearson's *r*) in random-effects model; $I^2$ = the proportion of total variation caused by real heterogeneity; *Q* = Hedge's *Q* test of homogeneity

The overall effect size for math (estimated from 48 effects and 30 studies) was also large ($r = .461$; $z = 16.110$, $p < .0001$, 95% CI = [ .405, .517]; see also Figure 3 for the forest plot). Again, the mean effect size for studies that reported correlations between PASS Full Scale and mathematics was larger, $r = .615$ ($z = 28.041$, $p < .0001$, 95% CI = [ .572, .658]. The heterogeneity analysis further showed that the variation between studies was significant and large for both reading ($Q = 688.335$, $I^2 = 90.31\%$, $p < .0001$) and mathematics ($Q = 452.096$, $I^2 = 93.09\%$, $p < .0001$).

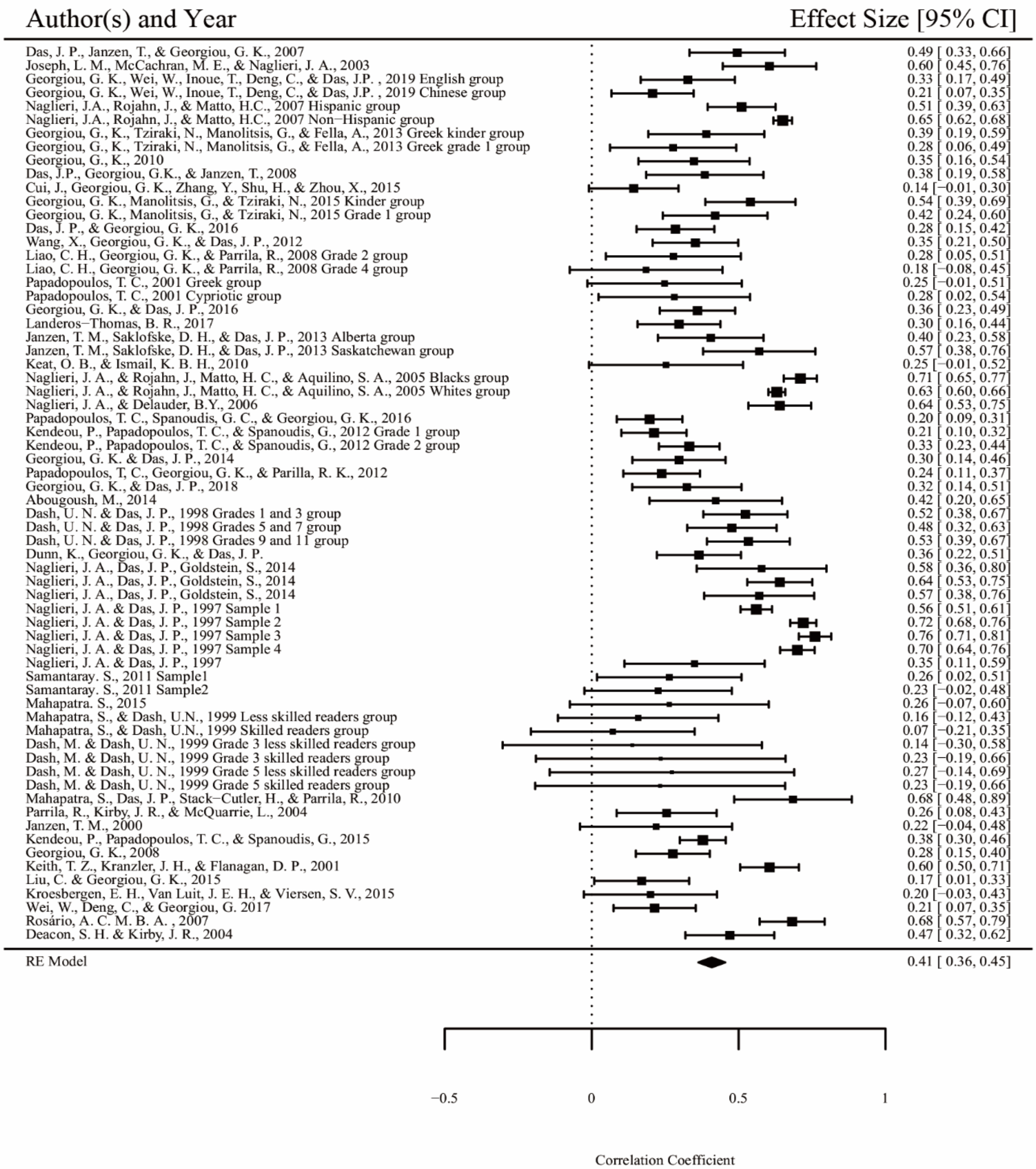


*Figure 2.* Forest plot: Strength of the correlations between PASS and reading

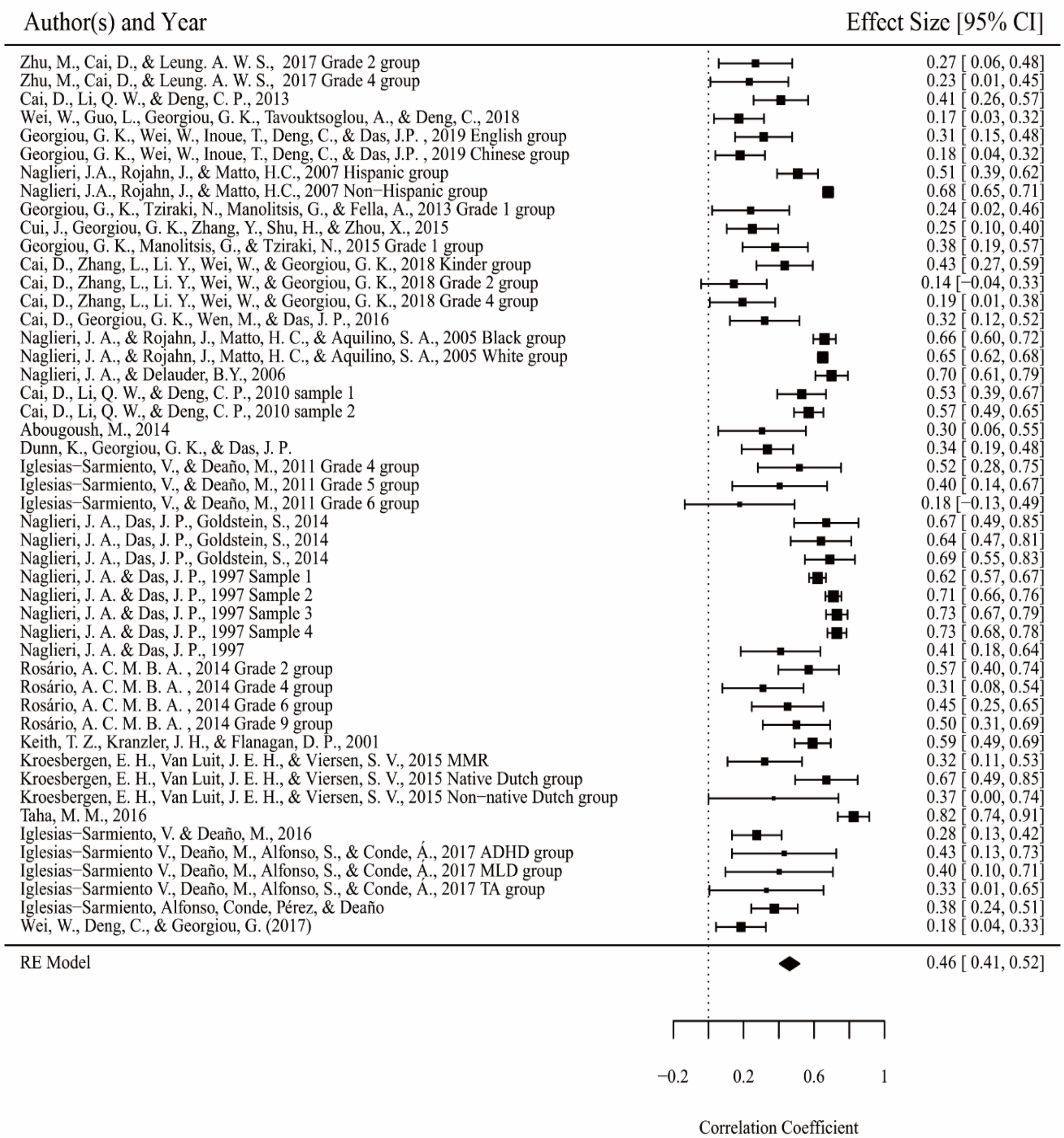


*Figure 3.* Forest plot: Strength of the correlations between PASS and math

**Results of the Moderator Analyses**

First, we examined if the type of reading/mathematics outcome moderates the PASS–reading/mathematics relations. The results are presented in Tables 2 and 3. When considering differences among PASS processes and outcome subtypes, the correlations were stable across PASS or outcome subtypes for reading. However, the correlations varied significantly for mathematics. First, Simultaneous processing produced significantly stronger correlations with math accuracy (.416 > .179, $z = 3.3523$, $p = .0008$) and problem solving (.478 > .179, $z = 4.2783$, $p < .0001$) than math fluency. Second, Planning correlated more strongly with math fluency than Simultaneous processing (.421 > .179, $z = 2.6455$, $p = .0082$). Finally, Simultaneous processing correlated more strongly with problem solving than Attention (.478 > .342, $z = 2.1169$, $p = .0343$).

Table 2

*Moderator Analyses for Reading: Categorical Moderator Variables (PASS and Outcome Subtype)*

| Moderator variable | Number of correlations (*k*) | Correlation (*r*) | *p* value | 95% CI | Difference in *r* (highest-lowest category) | Significance test of difference (*Q* test) | *p* value |
|---|---|---|---|---|---|---|---|
| Planning | | | | | .032 | .2849 | .8672 |
| Accuracy | 33 | .347 | < .0001 | [ .286, .409] | | | |
| Fluency | 11 | .315 | < .0001 | [ .214, .416] | | | |
| Comprehension | 26 | .330 | < .0001 | [ .261, .399] | | | |
| Attention | | | | | .032 | .5042 | .7772 |
| Accuracy | 25 | .292 | < .0001 | [ .223, .361] | | | |
| Fluency | 13 | .322 | < .0001 | [ .229, .415] | | | |
| Comprehension | 19 | .324 | < .0001 | [ .248, .400] | | | |
| Simultaneous | | | | | .105 | 2.4599 | .2923 |
| Accuracy | 34 | .355 | < .0001 | [ .295, .414] | | | |
| Fluency | 12 | .310 | < .0001 | [ .210, .409] | | | |
| Comprehension | 21 | .415 | < .0001 | [ .343, .487] | | | |
| Successive | | | | | .033 | .5938 | .7431 |
| Accuracy | 29 | .368 | < .0001 | [ .304, .433] | | | |
| Fluency | 15 | .353 | < .0001 | [ .267, .439] | | | |
| Comprehension | 20 | .386 | < .0001 | [ .311, .460] | | | |

*Note*: *k* = number of correlations; *r* = correlation size (Pearson's *r*) for subsets of studies belonging to different categories of the moderator variable.

Table 3

*Moderator Analyses for Math: Categorical Moderator Variables (PASS and Outcome Subtype)*

| Moderator variable | Number of correlations ($k$) | Correlation ($r$) | $p$ value | 95% CI | Difference in $r$ (highest-lowest category) | Significance test of difference ($Q$ test) | $p$ value |
|---|---|---|---|---|---|---|---|
| Planning | | | | | .061 | .6714 | .7148 |
| Accuracy | 13 | .409 | < .0001 | [ .313, .504] | | | |
| Fluency | 6 | .421 | < .0001 | [ .277, .564] | | | |
| Problem solving | 12 | .470 | < .0001 | [ .368, .571] | | | |
| Attention | | | | | .028 | .1532 | .9262 |
| Accuracy | 16 | .349 | < .0001 | [ .262, .436] | | | |
| Fluency | 10 | .321 | < .0001 | [ .206, .435] | | | |
| Problem solving | 16 | .342 | < .0001 | [ .253, .433] | | | |
| Simultaneous | | | | | .299 | 18.4090 | .0001 |
| Accuracy | 15 | .416 | < .0001 | [ .327, .505] | | | |
| Fluency | 12 | .179 | .0009 | [ .073, .285] | | | |
| Problem solving | 17 | .478 | < .0001 | [ .392, .564] | | | |
| Successive | | | | | .144 | 4.1787 | .1238 |
| Accuracy | 12 | .320 | < .0001 | [ .219, .422] | | | |
| Fluency | 8 | .250 | .0002 | [ .120, .379] | | | |
| Problem solving | 12 | .394 | < .0001 | [ .290, .498] | | | |

*Note*: $k$ = number of correlations; $r$ = correlation size (Pearson's $r$) for subsets of studies belonging to different categories of the moderator variable

Next, we examined the role of language, grade level, age, and sample characteristics in the PASS–reading/mathematics relation. As shown in Table 4, language was a significant moderator of the PASS–reading relation. Studies with English–speaking participants produced significantly larger correlations than studies in which the participants spoke other European or non-European languages ($p$s < .001). Grade level, reading level, and mean age ($\beta = .0007$, $p = .9003$, $k = 43$) did not reliably explain variation in the correlations. Language was also a significant moderator in the PASS–mathematics relation: studies with English–speaking participants produced significantly larger correlations than studies in other languages (see Table 5). The difference between other European and non-European languages was also significant. The correlations between PASS and mathematics were stable across different grade levels, math level range, and mean age ($\beta = .0136$, $p = .2452$, $k = 30$).

Table 4

*Moderator Analyses for Reading: Categorical Moderator Variables*

| Moderator variable | Number of correlations (*k*) | Correlation (*r*) | *p* value | 95% CI | Difference in *r* (highest-lowest category) | Significance test of difference (*Q* test) | *p* value |
|---|---|---|---|---|---|---|---|
| Language | | | | | .198 | 21.2367 | < .0001 |
| English | 31 | .503 | < .0001 | [ .447, .559] | | | |
| Other European | 12 | .316 | < .0001 | [ .224, .408] | | | |
| Non-European | 19 | .305 | < .0001 | [ .224, .386] | | | |
| ELL | 4 | .390 | < .0001 | [ .202, .579] | | | |
| Grade | | | | | .224 | 2.0580 | .5605 |
| Kindergarten | 4 | .309 | < .0001 | [ .153, .464] | | | |
| G1 to G6 | 42 | .365 | < .0001 | [ .314, .416] | | | |
| G7 to G12 | 1 | .533 | .0005 | [ .235, .831] | | | |
| Adults | 4 | .317 | < .0001 | [ .165, .468] | | | |
| Sample characteristics | | | | | .119 | 2.3237 | .3129 |
| Unselected | 50 | .416 | < .0001 | [ .366, .466] | | | |
| Poor readers | 5 | .326 | .0010 | [ .131, .520] | | | |
| Good readers | 6 | .297 | .0007 | [ .125, .470] | | | |

*Note*: *k* = number of correlations; *r* = correlation size (Pearson's *r*) for subsets of studies belonging to different categories of the moderator variable.

Table 5

*Moderator Analyses for Math: Categorical Moderator Variables*

| Moderator variable | Number of correlations (*k*) | Correlation (*r*) | *p* value | 95% CI | Difference in *r* (highest-lowest category) | Significance test of difference (*Q* test) | *p* value |
|---|---|---|---|---|---|---|---|
| Language | | | | | .250 | 22.0784 | < .0001 |
| English | 17 | .601 | < .0001 | [ .528, .675] | | | |
| Other European | 17 | .403 | < .0001 | [ .315, .490] | | | |
| Non-European | 14 | .351 | < .0001 | [ .265, .436] | | | |
| Grade | | | | | .176 | 2.3173 | .3139 |
| Kindergarten | 3 | .405 | < .0001 | [ .259, .552] | | | |
| G1 to G6 | 25 | .324 | < .0001 | [ .267, .381] | | | |
| G7 to G12 | 1 | .500 | .0005 | [ .219, .782] | | | |
| Sample characteristics | | | | | .106 | .7245 | .3947 |
| Unselected | 28 | .456 | < .0001 | [ .384, .528] | | | |
| Good performers | 3 | .350 | .0034 | [ .116, .584] | | | |

*Note*: *k* = number of correlations; *r* = correlation size (Pearson's *r*) for subsets of studies belonging to different categories of the moderator variable.

**Publication Bias**

The results of the Fail-Safe N analysis suggested that the estimated effect sizes were reasonably stable. More than 60,000 additional participants would be needed to achieve a null *p* value for each outcome ($N$ = 81,128 for reading, $N$ = 66,470 for math). The results of the Egger's Regression Test suggested the presence of publication bias in both the reading ($z$ = -5.3765, $p$ = < .0001) and the mathematics ($z$ = -4.9684, $p$ = < .0001) model (see Table 6). As suggested by the Rank Correlation Test, Kendall's tau for reading was not significant and tau for mathematics was significant (tau = -. 2287, $p$ = .0218). Subsequently, the "trim and fill" analyses were performed. The funnel plot indicated that studies were missing to the right of the mean (i.e., studies with effect sizes over the overall mean) (see Figures 4 and 5). Thus, the true effect size may be somewhat higher for reading (corrected effect size = .470) and mathematics (corrected effect size = .566) than what has been reported in the initial analyses.

Table 6

*Publication Bias Analyses*

| Outcomes | Fail-Safe N | Egger's Method | | Rank Correlation Test | | Trim and Fill Procedure | |
|---|---|---|---|---|---|---|---|
| | | *z* | *p* | Kendall's tau | *p* | Imputed | Corrected effect sizes |
| Reading | 81128 | -5.3765 | < .0001 | - .1170 | .1671 | 17 | .470 |
| Math | 66470 | -4.9684 | < .0001 | -. 2287 | .0218 | 16 | .566 |

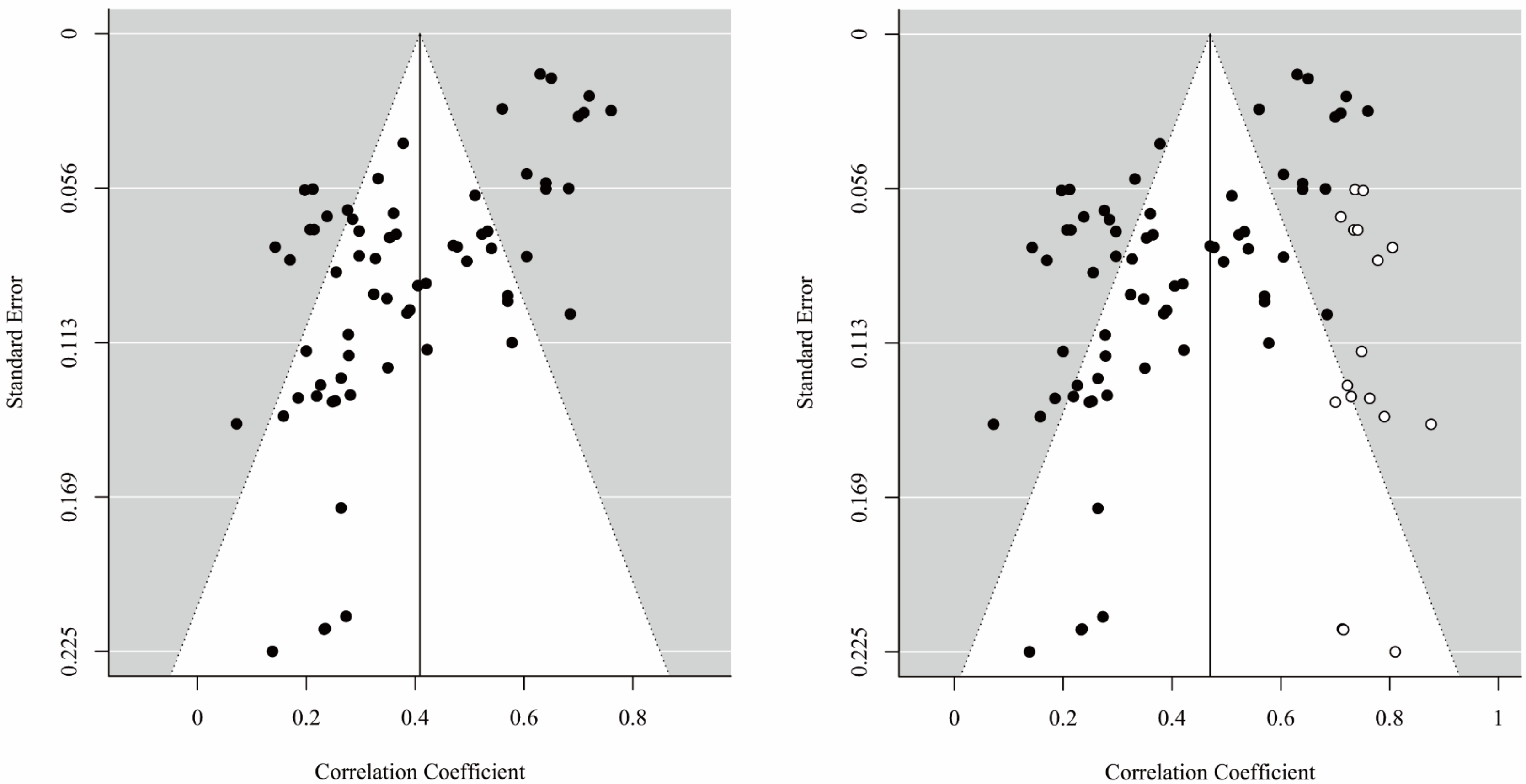


*Figure 4.* Funnel plots for reading (left) and funnel plots with imputed samples for reading (right).

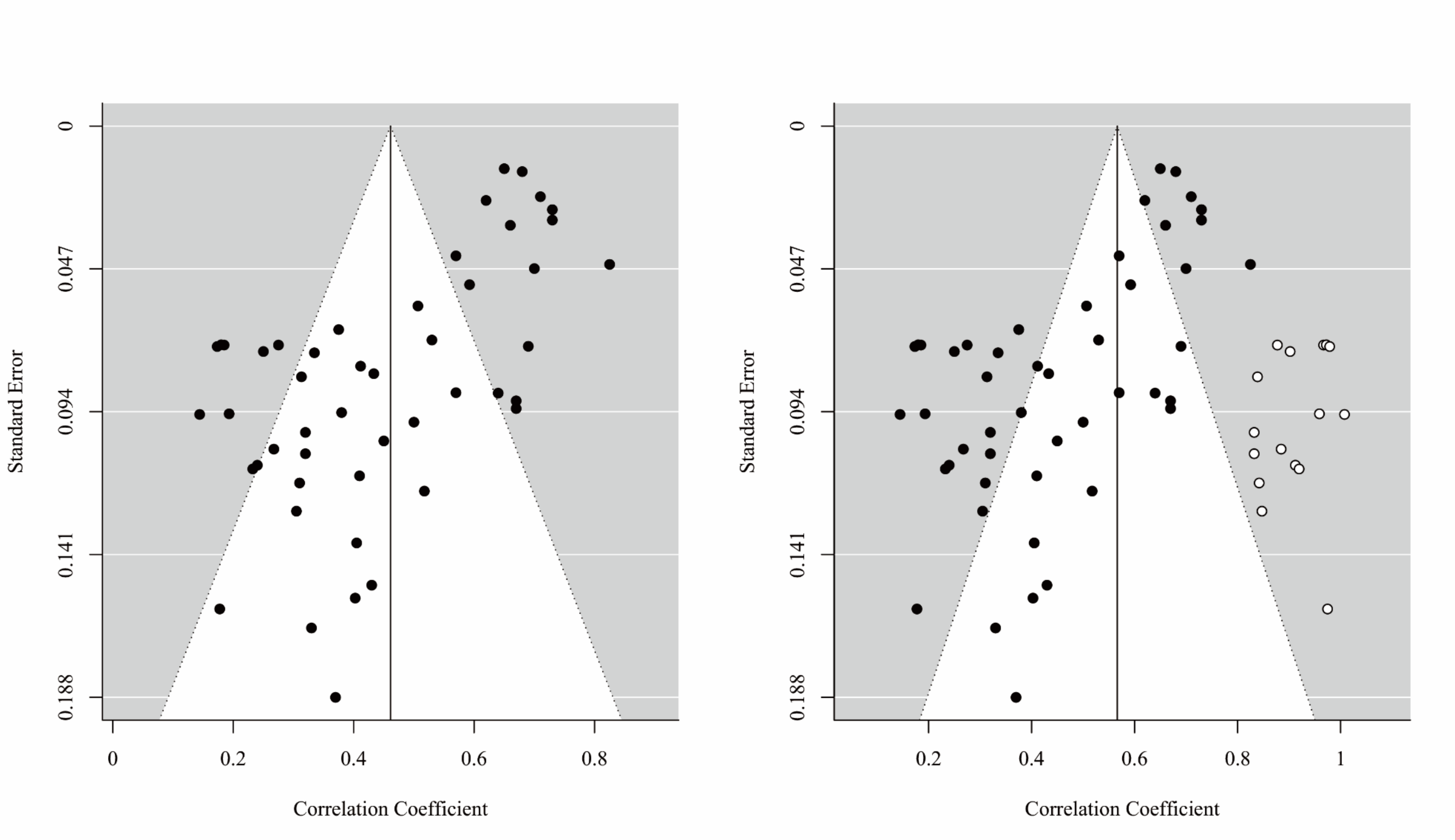


*Figure 5.* Funnel plots for math (left) and funnel plots with imputed samples for math (right)

## Discussion

The purpose of this meta-analysis was to estimate the size of the relation between PASS processes and reading/mathematics performance and if different factors (type of reading/mathematics outcome, age/grade level, language, and sample characteristics) moderate their relation. When any correlation by any PASS process was included in the statistical analysis, we found significant relations between the PASS processes and reading or mathematics (the average mean correlation was .409 and .461, respectively). These correlations are similar to those reported in previous meta-analyses on the relation between intelligence and academic achievement (e.g., Peng et al., 2019; Roth et al., 2015; Swanson, Trainin, Necoechea, & Hammill, 2003). They are also as strong as those reported in previous meta-analyses for key predictors of reading (e.g., phonological awareness, rapid naming; see Melby-Lervåg, Lyster, & Hulme, 2012; Ruan, Georgiou, Song, Li, & Shu, 2018; Swanson et al., 2003) and mathematics (e.g., approximate number system, working memory; see Chen & Li, 2014; Peng, Namkung, Barnes, & Sun, 2016; Schneider et al., 2017).

One could argue though that PASS theory is not adequately represented by these correlations as they were calculated by considering the correlations of individual PASS processes with reading/mathematics and not by considering the correlations generated by the combination of PASS processes (indexed by PASS Full Scale score). Indeed, when we repeated the analyses with the PASS Full Scale that takes into account the scores across all four sub-processes, the correlations were significantly larger (*r*= .605 for reading and *r* = .615 for mathematics; see Table 1). Although we do not directly compare these correlations to the ones generated by other IQ tests (obviously this is beyond the scope of this meta-analysis; however, see Naglieri et al., 2006; Naglieri & Otero, 2018), to our knowledge, none of the previous meta-analyses examining the relation between intelligence and academic achievement (e.g., Peng et al., 2019; Roth et al., 2015; Zaboski, Kranzler, & Gage, 2018) have produced equally strong correlations. This is remarkable if we consider that comparing PASS correlations with academic achievement to, for example, Wechsler or Woodcock ability tests to academic achievement puts PASS at a relative disadvantage because the measures included in CAS do not contain subtests with considerable knowledge requirements such as Vocabulary and Arithmetic, and even more subtle tasks in a scale like Fluid Reasoning, which also demands some knowledge.

However, we also found great heterogeneity in the correlations with reading and mathematics performance. Language explained some of this heterogeneity. Larger correlations with reading/mathematics performance were reported in English than in other languages. An explanation might be that CAS was originally developed in English and the adaptations that followed in other languages did not produce the desirable outcome. We acknowledge that language constraints may be partly responsible for that. For example, in Chinese, there is no present continuous tense and items like "The blue is yellowing the green" in the Sentence Repetition task do not have a direct translation. Unfortunately, many of the studies conducted in these other languages (particularly those conducted in India) failed to provide information on the psychometric properties of the CAS tasks (e.g., Dash & Das, 1998; Mahapatra & Dash, 1999; Samantaray, 2011) and, as a result, we do not know how well the CAS measures behaved. Notice also that these studies are associated with the highest standard error (see Figure 2).

Our results further showed significant differences in the relations of the four PASS processes with mathematics performance. In line with our expectation, Planning correlated more strongly with math fluency than Simultaneous processing and, in turn, Simultaneous processing correlated more strongly with problem solving than Attention. Math proficiency comprises computing and solving word problems (see Das & Misra, 2015, for a math proficiency model). Whereas computing is dependent on planning and executive functions, word problems that involve logical–grammatical relations rely more on Simultaneous processing. An alternative explanation may relate to the nature of the tasks. Because the Planning measures were all speeded, this may have inflated their relation with math fluency as opposed to Simultaneous processing tasks that did not have any speed requirements. Interestingly, no differences between the PASS processes and the reading outcomes were found. This reinforces the findings of previous studies in different languages (e.g., Kendeou et al., 2015; Naglieri & Rojahn, 2004) suggesting that all PASS processes are important in reading.

Age, grade level, and sample characteristics did not moderate the PASS–reading/math relations either. We interpret this to be evidence of domain general processes that are best described as cognitive universals. These are represented in the broad functional organization of the brain as proposed by Luria (1966, 1973). The present meta-analysis, based as it is on 62 empirical studies, supports the idea that PASS cognitive functions provide the foundation for the development of specific skills associated with reading and mathematics.

Some limitations of our study are worth mentioning. First, we acknowledge that some of the categories in the moderator analyses did not have many studies. For example, when examining the role of grade level in the PASS–reading relation, we only had one study in the 7-12 grade range, four studies in kindergarten, and four studies in adults. This may have inflated the standard error and reduced our chances to find significant differences. Second, we chose to examine the relations of PASS processes after the publication of CAS in 1997. We acknowledge that some studies with tasks that were subsequently included in CAS were published before 1997 (e.g., Das, Snart, & Mulcahy, 1982; Kirby & Das, 1977; Leong, Cheng, & Das, 1985). Third, our study showed no significant differences in the role of PASS processes in reading across the four groups we created in our meta-analysis. This finding is based on correlations obtained from studies conducted in different single languages and not from cross–linguistic studies that also control for other confounding variables (e.g., family's socioeconomic background). Indeed, our meta-analysis has shown that very little cross–linguistic research on PASS processes has been done (see Kroesbergen et al., 2010; Naglieri et al., 2007, for exceptions). Fourth, we acknowledge that we examined here the relations of the CAS measures with academic achievement, not the more broadly defined PASS processes. Clearly, the CAS was designed with PASS in mind, but the CAS tests are not the only measures of PASS processes. Fifth, we did not control for the role of instruction in the relations between PASS and reading/mathematics. Different forms of instruction may alter the cognitive processes brought to bear on particular tasks; for example, some education systems may employ arithmetic drills more than others, perhaps increasing calculation fluency and perhaps reducing the correlation with generic processing abilities. Finally, because the number of studies within each academic domain was relatively small, we could not further test for the effects of different interaction terms.

To conclude, the present meta-analysis adds to a growing body of research examining the role of intelligence in academic achievement (e.g., Peng et al., 2019; Roth et al., 2015) suggesting that there are significant benefits if we conceptualize intelligence as a constellation of cognitive processes that are linked to the functional organization of the brain. First, these cognitive processes (operationalized here with CAS) can produce correlations that are stronger than those derived from popular IQ batteries (e.g., WISC) that include tasks (e.g., Arithmetic, Vocabulary) whose content is often confounded by school learning. Second, these processes have direct implications for instruction and intervention programming. For example, cognitive strategy instruction based on PASS processes has been found to improve children's math calculation (Iseman & Naglieri, 2011) and PREP has been found to improve children's decoding (Papadopoulos et al., 2004) and reading comprehension (Mahapatra et al., 2010). However, this meta-analysis has also revealed areas in which more research is needed. This includes studies on PASS and academic achievement across languages as well as studies with specific student populations such as poor or good readers/mathematicians.

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Appendix A (*continued*)

**Appendix A**

**Studies on PASS and Reading outcomes**

| Study | Language | Reading ability level | Grade level | Subgroup | Mean age | Sample Size | Types of PASS processes | Reading accuracy | Reading fluency | Reading compreh ension | Broad Reading |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Abougoush, 2014 | English | Good | G1 to G6 | | | 52 | Pl | | | | 0.58 |
| | English | Good | G1 to G6 | | | 52 | Att | | | | 0.23 |
| | English | Good | G1 to G6 | | | 52 | Sim | | | | 0.43 |
| | English | Good | G1 to G6 | | | 52 | Suc | | | | 0.45 |
| Cui et al., 2015 | Non-Euro | Unselct | Kind | | 5.11 | 160 | Sim | 0.19 | | | |
| | Non-Euro | Unselct | Kind | | 5.11 | 160 | Suc | 0.10 | | | |
| Das & Georgiou, 2016 | English | Unselct | Adults | | 22.26 | | Pl | | 0.25 | | |
| Das et al., 2008 | English | Unselct | G1 to G6 | | 9.97 | 71 | Pl | 0.42 | | | |
| | English | Unselct | G1 to G6 | | 9.97 | 71 | Att | 0.08 | | | |
| | English | Unselct | G1 to G6 | | 9.97 | 71 | Sim | 0.25 | | | |
| | English | Unselct | G1 to G6 | | 9.97 | 71 | Suc | 0.26 | | | |
| Das et al., 2007 | English | Unselct | G1 to G6 | | 9.5 | 84 | Pl | 0.26 | | | |
| | English | Unselct | G1 to G6 | | 9.5 | 84 | Att | 0.26 | | | |
| | English | Unselct | G1 to G6 | | 9.5 | 84 | Sim | 0.28 | | | |
| | English | Unselct | G1 to G6 | | 9.5 | 84 | Suc | 0.45 | | | |
| Dash & Das, 1998 | Non-Euro | Unselct | G1 to G6 | Grade 1 and 3 | | 100 | Pl | 0.57 | | | |
| | Non-Euro | Unselct | G1 to G6 | Grade 1 and 3 | | 100 | Sim | 0.50 | | | |
| | Non-Euro | Unselct | G1 to G6 and G7 to G12 | Grade 5 and 7 | | 100 | Pl | 0.53 | | | |
| | Non-Euro | Unselct | G1 to G6 and G7 to G12 | Grade 5 and 7 | | 100 | Sim | 0.45 | | | |
| | Non-Euro | Unselct | G7 to G12 | Grade 9 and 11 | | 100 | Pl | 0.46 | | | |
| | Non-Euro | Unselct | G7 to G12 | Grade 9 and 11 | | 100 | Sim | 0.57 | | | |
| Dash & Dash, 1999 | Non-Euro | Poor | G1 to G6 | Grade 3 less skilled | | 20 | Pl | 0.15 | | 0.13 | |

(*Appendices continue*)

Appendix A (*continued*)

| Study | Language | Reading ability level | Grade level | Subgroup | Mean age | Sample Size | Types of PASS processes | Reading accuracy | Reading fluency | Reading compreh ension | Broad Reading |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Non-Euro | Good | G1 to G6 | Grade 3 skilled | | 20 | Pl | 0.32 | | 0.15 | |
| | Non-Euro | Poor | G1 to G6 | Grade 5 less skilled | | 20 | Pl | 0.21 | | 0.34 | |
| | Non-Euro | Good | G1 to G6 | Grade 5 skilled | | 20 | Pl | 0.18 | | 0.29 | |
| Deacon & Kirby, 2004 | English | Unselect | G1 to G6 | | 7.38 | 103 | Sim | 0.44 | | 0.50 | |
| Dunn et al., in press | English | Good | G1 to G6 | | 10.62 | 142 | Pl | | | | 0.40 |
| | English | Good | G1 to G6 | | 10.62 | 142 | Att | | | | 0.33 |
| | English | Good | G1 to G6 | | 10.62 | 142 | Sim | | | | 0.32 |
| | English | Good | G1 to G6 | | 10.62 | 142 | Suc | | | | 0.41 |
| Georgiou, 2008 | Other Euro | Unselct | G1 to G6 | | 9.77 | 208 | Att | | 0.26 | 0.32 | |
| | Other Euro | Unselct | G1 to G6 | | 9.77 | 208 | Suc | | 0.21 | 0.35 | |
| Georgiou, 2010 | English | Unselct | G1 to G6 | | 9.47 | 84 | Pl | 0.34 | | | |
| | English | Unselct | G1 to G6 | | 9.47 | 84 | Att | 0.32 | | | |
| | English | Unselct | G1 to G6 | | 9.47 | 84 | Sim | 0.31 | | | |
| | English | Unselct | G1 to G6 | | 9.47 | 84 | Suc | 0.42 | | | |
| Georgiou & Das, 2014 | English | Unselct | Adults | | 22.07 | 128 | Pl | | 0.22 | 0.25 | |
| | English | Unselct | Adults | | 22.07 | 128 | Att | | 0.27 | 0.22 | |
| | English | Unselct | Adults | | 22.07 | 128 | Sim | | 0.27 | 0.50 | |
| | English | Unselct | Adults | | 22.07 | 128 | Suc | | 0.37 | 0.40 | |
| Georgiou & Das, 2016 | English | Unselct | Adults | | 21.83 | 178 | Pl | | | 0.36 | |
| Georgiou & Das, 2018 | English | Unselct | Adults | | 21.82 | 90 | Pl | | 0.22 | 0.39 | |
| | English | Unselct | Adults | | 21.82 | 90 | Att | | 0.42 | 0.22 | |
| Georgiou et al., 2015 | Other Euro | Unselct | Kind | Kinder | 5.42 | 83 | Pl | 0.67 | | | |
| | Other Euro | Unselct | Kind | Kinder | 5.42 | 83 | Att | 0.50 | | | |
| | Other Euro | Unselct | Kind | Kinder | 5.42 | 83 | Sim | 0.46 | | | |
| | Other Euro | Unselct | Kind | Kinder | 5.42 | 83 | Suc | 0.53 | | | |
| | Other Euro | Unselct | G1 to G6 | Grade 1 | 6.83 | 83 | Pl | | 0.50 | | |
| | Other Euro | Unselct | G1 to G6 | Grade 1 | 6.83 | 83 | Att | | 0.40 | | |

(*Appendices continue*)

Appendix A (*continued*)

| Study | Language | Reading ability level | Grade level | Subgroup | Mean age | Sample Size | Types of PASS processes | Reading accuracy | Reading fluency | Reading compreh ension | Broad Reading |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Other Euro | Unselct | G1 to G6 | Grade 1 | 6.83 | 83 | Sim | | 0.33 | | |
| | Other Euro | Unselct | G1 to G6 | Grade 1 | 6.83 | 83 | Suc | | 0.45 | | |
| Georgiou et al., 2013 | Other Euro | Unselct | Kind | Kinder | 5.38 | 72 | Att | 0.14 | | | |
| | Other Euro | Unselct | Kind | Kinder | 5.38 | 72 | Sim | 0.49 | | | |
| | Other Euro | Unselct | Kind | Kinder | 5.38 | 72 | Suc | 0.54 | | | |
| | Other Euro | Unselct | G1 to G6 | Grade 1 | 6.92 | 72 | Att | | 0.08 | | |
| | Other Euro | Unselct | G1 to G6 | Grade 1 | 6.92 | 72 | Sim | | 0.32 | | |
| | Other Euro | Unselct | G1 to G6 | Grade 1 | 6.92 | 72 | Suc | | 0.43 | | |
| Georgiou et al., 2019 | English | Unselct | G1 to G6 | English | 6.41 | 120 | Pl | 0.47 | | 0.45 | |
| | English | Unselct | G1 to G6 | English | 6.41 | 120 | Att | 0.27 | | 0.38 | |
| | English | Unselct | G1 to G6 | English | 6.41 | 120 | Sim | 0.19 | | 0.20 | |
| | Non-Euro | Unselct | G1 to G6 | Chinese | 7.15 | 181 | Pl | 0.21 | | 0.14 | |
| | Non-Euro | Unselct | G1 to G6 | Chinese | 7.15 | 181 | Att | 0.20 | | 0.34 | |
| | Non-Euro | Unselct | G1 to G6 | Chinese | 7.15 | 181 | Sim | 0.15 | | 0.20 | |
| Janzen, 2000 | English | Unselct | G1 to G6 | | 9 | 53 | Pl | 0.30 | | 0.15 | |
| | English | Unselct | G1 to G6 | | 9 | 53 | Att | 0.32 | | 0.44 | |
| | English | Unselct | G1 to G6 | | 9 | 53 | Sim | 0.13 | | -0.01 | |
| | English | Unselct | G1 to G6 | | 9 | 53 | Suc | 0.30 | | 0.29 | |
| Janzen et al., 2013 | English | Unselct | G1 to G6 | Alberta | 9.5 | 84 | Pl | 0.12 | | | |
| | English | Unselct | G1 to G6 | Alberta | 9.5 | 84 | Att | 0.19 | | | |
| | English | Unselct | G1 to G6 | Alberta | 9.5 | 84 | Sim | 0.14 | | | |
| | English | Unselct | G1 to G6 | Alberta | 9.5 | 84 | Suc | 0.38 | | | |
| | English | Unselct | G1 to G6 | Saskatchewan | 9.4 | 49 | Pl | 0.39 | | | |
| | English | Unselct | G1 to G6 | Saskatchewan | 9.4 | 49 | Att | 0.23 | | | |
| | English | Unselct | G1 to G6 | Saskatchewan | 9.4 | 49 | Sim | 0.15 | | | |
| | English | Unselct | G1 to G6 | Saskatchewan | 9.4 | 49 | Suc | 0.45 | | | |
| Joseph et al., 2003 | English | Poor | G1 to G6 | | 8.4 | 62 | Pl | 0.47 | | | |
| | English | Poor | G1 to G6 | | 8.4 | 62 | Att | 0.37 | | | |
| | English | Poor | G1 to G6 | | 8.4 | 62 | Sim | 0.51 | | | |

(*Appendices continue*)

Appendix A (*continued*)

| Study | Language | Reading ability level | Grade level | Subgroup | Mean age | Sample Size | Types of PASS processes | Reading accuracy | Reading fluency | Reading comprehension | Broad Reading |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | English | Poor | G1 to G6 | | 8.4 | 62 | Suc | 0.41 | | | |
| Keat & Ismail, 2010 | ELL | Poor | G1 to G6 | | | 50 | Pl | 0.35 | | -0.14 | 0.27 |
| | ELL | Poor | G1 to G6 | | | 50 | Att | 0.25 | | -0.30 | 0.16 |
| | ELL | Poor | G1 to G6 | | | 50 | Sim | 0.28 | | 0.12 | 0.32 |
| | ELL | Poor | G1 to G6 | | | 50 | Suc | 0.29 | | -0.10 | 0.26 |
| Keith et al., 2001 | English | Unselct | G1 to G6 | | 9.81 | 155 | Pl | | | 0.64 | |
| | English | Unselct | G1 to G6 | | 9.81 | 155 | Att | | | 0.50 | |
| | English | Unselct | G1 to G6 | | 9.81 | 155 | Sim | | | 0.75 | |
| | English | Unselct | G1 to G6 | | 9.81 | 155 | Suc | | | 0.53 | |
| Kendeou et al., 2012 | Other Euro | Unselct | G1 to G6 | Grade 1 | 6.6 | 286 | Sim | | 0.14 | | |
| | Other Euro | Unselct | G1 to G6 | Grade 1 | 6.6 | 286 | Suc | | 0.28 | | |
| | Other Euro | Unselct | G1 to G6 | Grade 2 | 7.7 | 286 | Sim | | | 0.30 | |
| | Other Euro | Unselct | G1 to G6 | Grade 2 | 7.7 | 286 | Suc | | | 0.37 | |
| Kendeou et al., 2015 | Other Euro | Unselct | | | | 462 | Pl | | | 0.52 | |
| | Other Euro | Unselct | | | | 462 | Att | | | 0.32 | |
| | Other Euro | Unselct | | | | 462 | Sim | | | 0.31 | |
| | Other Euro | Unselct | | | | 462 | Suc | | | 0.36 | |
| Kroesbergen et al., 2015 | Other Euro | | | | | 70 | Pl | | | | 0.09 |
| | Other Euro | | | | | 70 | Att | | | | 0.06 |
| | Other Euro | | | | | 70 | Sim | | | | 0.02 |
| | Other Euro | | | | | 70 | Suc | | | | 0.27 |
| Landeros-Thomas, 2017 | English | Unselct | G1 to G6 | | 9.8 | 162 | Pl | 0.09 | 0.23 | 0.30 | 0.23 |
| | English | Unselct | G1 to G6 | | 9.8 | 162 | Att | 0.12 | 0.20 | 0.22 | 0.28 |
| | English | Unselct | G1 to G6 | | 9.8 | 162 | Sim | 0.22 | 0.27 | 0.31 | 0.25 |
| | English | Unselct | G1 to G6 | | 9.8 | 162 | Suc | 0.54 | 0.55 | 0.58 | 0.61 |
| Liao et al., 2008 | Non-Euro | Unselct | G1 to G6 | Grade 2 | 8 | 63 | Sim | 0.36 | 0.26 | | |
| | Non-Euro | Unselct | G1 to G6 | Grade 2 | 8 | 63 | Suc | 0.19 | 0.25 | | |
| | Non-Euro | Unselct | G1 to G6 | Grade 4 | 10.01 | 54 | Sim | 0.29 | 0.14 | | |
| | Non-Euro | Unselct | G1 to G6 | Grade 4 | 10.01 | 54 | Suc | 0.11 | 0.16 | | |

(*Appendices continue*)

Appendix A (*continued*)

| Study | Language | Reading ability level | Grade level | Subgroup | Mean age | Sample Size | Types of PASS processes | Reading accuracy | Reading fluency | Reading compreh ension | Broad Reading |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Liu & Georgiou, 2015 | Non-Euro | Unselct | Kind | | 4.91 | 140 | Pl | 0.24 | | | |
| | Non-Euro | Unselct | Kind | | 4.91 | 140 | Att | 0.01 | | | |
| | Non-Euro | Unselct | Kind | | 4.91 | 140 | Sim | 0.21 | | | |
| | Non-Euro | Unselct | Kind | | 4.91 | 140 | Suc | 0.22 | | | |
| Mahapatra, 2015 | ELL | Poor and good | G1 to G6 | | | 30 | Pl | 0.21 | | 0.14 | |
| | ELL | Poor and good | G1 to G6 | | | 30 | Att | 0.24 | | 0.23 | |
| | ELL | Poor and good | G1 to G6 | | | 30 | Sim | 0.56 | | 0.70 | |
| | ELL | Poor and good | G1 to G6 | | | 30 | Suc | 0.01 | | 0.02 | |
| Mahapatra et al., 2010 | ELL | Poor and good | G1 to G6 | | 9.4 | 28 | Sim | 0.62 | | 0.75 | |
| Mahapatra & Dash, 1999 | Non-Euro | Poor | G1 to G6 | Less skilled | 10 | 50 | Pl | 0.11 | | 0.12 | |
| | Non-Euro | Poor | G1 to G6 | Less skilled | 10 | 50 | Sim | 0.09 | | 0.07 | |
| | Non-Euro | Poor | G1 to G6 | Less skilled | 10 | 50 | Suc | 0.46 | | 0.27 | |
| | Non-Euro | Good | G1 to G6 | Skilled | 10 | 50 | Pl | 0.08 | | 0.11 | |
| | Non-Euro | Good | G1 to G6 | Skilled | 10 | 50 | Sim | -0.06 | | 0.06 | |
| | Non-Euro | Good | G1 to G6 | Skilled | 10 | 50 | Suc | 0.10 | | 0.06 | |
| Naglieri & Das, 1997 | English | Unselct | | 5- 7 yrs | | 630 | Pl | 0.43 | | 0.37 | 0.41 |
| | English | Unselct | | 5- 7 yrs | | 630 | Att | 0.36 | | 0.33 | 0.41 |
| | English | Unselct | | 5- 7 yrs | | 630 | Sim | 0.41 | | 0.36 | 0.48 |
| | English | Unselct | | 5- 7 yrs | | 630 | Suc | 0.37 | | 0.36 | 0.36 |
| | English | Unselct | | 8- 10 yrs | | 454 | Pl | 0.37 | | 0.45 | 0.44 |
| | English | Unselct | | 8- 10 yrs | | 454 | Att | 0.39 | | 0.40 | 0.42 |
| | English | Unselct | | 8- 10 yrs | | 454 | Sim | 0.59 | | 0.65 | 0.67 |
| | English | Unselct | | 8- 10 yrs | | 454 | Suc | 0.54 | | 0.55 | 0.57 |
| | English | Unselct | | 11- 13 yrs | | 228 | Pl | 0.57 | | 0.53 | 0.63 |
| | English | Unselct | | 11- 13 yrs | | 228 | Att | 0.48 | | 0.48 | 0.55 |
| | English | Unselct | | 11- 13 yrs | | 228 | Sim | 0.64 | | 0.64 | 0.64 |

(*Appendices continue*)

Appendix A (*continued*)

| Study | Language | Reading ability level | Grade level | Subgroup | Mean age | Sample Size | Types of PASS processes | Reading accuracy | Reading fluency | Reading compreh ension | Broad Reading |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | English | Unselct | | 11- 13 yrs | | 228 | Suc | 0.57 | | 0.64 | 0.68 |
| | English | Unselct | | 14- 17 yrs | | 288 | Pl | 0.54 | | 0.52 | 0.46 |
| | English | Unselct | | 14- 17 yrs | | 288 | Att | 0.44 | | 0.40 | 0.49 |
| | English | Unselct | | 14- 17 yrs | | 288 | Sim | 0.52 | | 0.63 | 0.64 |
| | English | Unselct | | 14- 17 yrs | | 288 | Suc | 0.57 | | 0.62 | 0.59 |
| Naglieri & Das, 1997 | English | Unselct | | Gifted | 13.4 | 53 | Pl | | | 0.09 | |
| | English | Unselct | | Gifted | 13.4 | 53 | Att | | | 0.17 | |
| | English | Unselct | | Gifted | 13.4 | 53 | Sim | | | 0.36 | |
| | English | Unselct | | Gifted | 13.4 | 53 | Suc | | | 0.34 | |
| Naglieri et al., 2014 | English | | | Sample 1 | | 36 | Pl | | | | 0.51 |
| | English | | | Sample 1 | | 36 | Att | | | | 0.51 |
| | English | | | Sample 1 | | 36 | Sim | | | | 0.52 |
| | English | | | Sample 1 | | 36 | Suc | | | | 0.69 |
| Naglieri et al., 2014 | English | Unselct | | Sample 2 | | 110 | Pl | | 0.50 | | |
| | English | Unselct | | Sample 2 | | 110 | Att | | 0.53 | | |
| | English | Unselct | | Sample 2 | | 110 | Sim | | 0.49 | | |
| | English | Unselct | | Sample 2 | | 110 | Suc | | 0.44 | | |
| Naglieri et al., 2014 | English | Unselct | | Sample 3 | | 51 | Pl | | 0.34 | | |
| | English | Unselct | | Sample 3 | | 51 | Att | | 0.35 | | |
| | English | Unselct | | Sample 3 | | 51 | Sim | | 0.46 | | |
| | English | Unselct | | Sample 3 | | 51 | Suc | | 0.54 | | |
| Naglieri et al.,, 2006 | English | | | | | 119 | Pl | | | | 0.48 |
| | English | | | | | 119 | Att | | | | 0.36 |
| | English | | | | | 119 | Sim | | | | 0.51 |
| | English | | | | | 119 | Suc | | | | 0.50 |
| Naglieri et al., 2007 | English | Unselct | | Hispanics | 9.66 | 159 | FS | 0.51 | | 0.43 | 0.51 |
| | English | Unselct | | Non-Hispanics | 9.85 | 1274 | FS | 0.63 | | 0.63 | 0.65 |
| Naglieri et al., 2005 | English | Unselct | | Blacks | | 298 | FS | 0.70 | | 0.68 | 0.71 |

(*Appendices continue*)

Appendix A (*continued*)

| Study | Language | Reading ability level | Grade level | Subgroup | Mean age | Sample Size | Types of PASS processes | Reading accuracy | Reading fluency | Reading compreh ension | Broad Reading |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | English | Unselct | | Whites | | 1691 | FS | 0.60 | | 0.60 | 0.63 |
| Papadopoulos, 2001 | Other Euro | Unselct | G1 to G6 | Greek | 6.43 | 50 | Pl | 0.28 | | | |
| | Other Euro | Unselct | G1 to G6 | Greek | 6.43 | 50 | Att | 0.25 | | | |
| | Other Euro | Unselct | G1 to G6 | Greek | 6.43 | 50 | Sim | 0.31 | | | |
| | Other Euro | Unselct | G1 to G6 | Greek | 6.43 | 50 | Suc | 0.19 | | | |
| | Other Euro | Unselct | G1 to G6 | Cypriot | 6.3 | 50 | Pl | 0.16 | | | |
| | Other Euro | Unselct | G1 to G6 | Cypriot | 6.3 | 50 | Att | 0.19 | | | |
| | Other Euro | Unselct | G1 to G6 | Cypriot | 6.3 | 50 | Sim | 0.31 | | | |
| | Other Euro | Unselct | G1 to G6 | Cypriot | 6.3 | 50 | Suc | 0.38 | | | |
| Papadopoulos et al., 2012 | Other Euro | Unselct | G1 to G6 | | 9.77 | 202 | Att | | 0.26 | | |
| | Other Euro | Unselct | G1 to G6 | | 9.77 | 202 | Suc | | 0.21 | | |
| Papadopoulos et al., 2016 | Other Euro | Unselct | G1 to G6 | | 6.6 | 286 | Pl | | 0.24 | | |
| | Other Euro | Unselct | G1 to G6 | | 6.6 | 286 | Att | | 0.13 | | |
| | Other Euro | Unselct | G1 to G6 | | 6.6 | 286 | Suc | | 0.25 | | |
| Parrila et al., 2004 | Other Euro | Unselct | Kind and G1 to G6 | | | 117 | Suc | 0.25 | | 0.27 | |
| Rosário, 2007 | Other Euro | Unselct | G1 to G6 | | 9.11 | 91 | Pl | 0.61 | 0.57 | 0.69 | |
| | Other Euro | Unselct | G1 to G6 | | 9.11 | 91 | Att | 0.62 | 0.56 | 0.72 | |
| | Other Euro | Unselct | G1 to G6 | | 9.11 | 91 | Sim | 0.53 | 0.45 | 0.60 | |
| | Other Euro | Unselct | G1 to G6 | | 9.11 | 91 | Suc | 0.36 | 0.37 | 0.50 | |
| Samantaray, 2011 | ELL | Unselct | G1 to G6 | | 9.3 | 56 | Pl | -0.10 | 0.18 | -0.01 | |
| | ELL | Unselct | G1 to G6 | | 9.3 | 56 | Att | 0.43 | 0.32 | 0.31 | |
| | ELL | Unselct | G1 to G6 | | 9.3 | 56 | Sim | 0.30 | 0.22 | 0.33 | |
| | ELL | Unselct | G1 to G6 | | 9.3 | 56 | Suc | 0.42 | 0.40 | 0.37 | |
| | Non-Euro | Unselct | G1 to G6 | | 9.3 | 56 | Pl | 0.11 | | 0.13 | |
| | Non-Euro | Unselct | G1 to G6 | | 9.3 | 56 | Att | 0.19 | | 0.15 | |
| | Non-Euro | Unselct | G1 to G6 | | 9.3 | 56 | Sim | 0.24 | | 0.25 | |
| | Non-Euro | Unselct | G1 to G6 | | 9.3 | 56 | Suc | 0.36 | | 0.38 | |
| Wang et al., 2012 | Non-Euro | Unselct | G1 to G6 | | 10 | 140 | Pl | 0.16 | 0.18 | | |

(*Appendices continue*)

Appendix A (*continued*)

| Study | Language | Reading ability level | Grade level | Subgroup | Mean age | Sample Size | Types of PASS processes | Reading accuracy | Reading fluency | Reading compreh ension | Broad Reading |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Wei et al., 2017 | Non-Euro | Unselct | G1 to G6 | | 10 | 140 | Att | 0.38 | 0.39 | | |
| | Non-Euro | Unselct | G1 to G6 | | 10 | 140 | Sim | 0.48 | 0.33 | | |
| | Non-Euro | Unselct | G1 to G6 | | 10 | 140 | Suc | 0.48 | 0.42 | | |
| | Non-Euro | Unselct | G1 to G6 | | 7.17 | 180 | Pl | 0.31 | | 0.16 | |
| | Non-Euro | Unselct | G1 to G6 | | 7.17 | 180 | Att | 0.12 | | 0.15 | |
| | Non-Euro | Unselct | G1 to G6 | | 7.17 | 180 | Sim | 0.17 | | 0.28 | |
| | Non-Euro | Unselct | G1 to G6 | | 7.17 | 180 | Suc | 0.26 | | 0.26 | |

*Note.* Non-Euro = Non-European language; Other Euro= Other European language; ELL = English language learners; Unselct = Unselected; Kind = Kindergarten; Pl = Planning; Att = Attention; Sim = Simultaneous; Suc = Successive; FS = Full Scale.

(*Appendices continue*)

Appendix B (*continued*)

**Appendix B**

**Studies on PASS and Math Outcomes**

| Study | Language | Math performance level | Grade level | Subgroup | Mean age | Sample Size | Types of PASS processes | Math accuracy | Math fluency | Problem-solving | Broad Math |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Abougoush, 2014 | English | Good | G1 to G6 | | | 52 | Pl | | | | 0.37 |
| | English | Good | G1 to G6 | | | 52 | Att | | | | 0.13 |
| | English | Good | G1 to G6 | | | 52 | Sim | | | | 0.48 |
| | English | Good | G1 to G6 | | | 52 | Suc | | | | 0.24 |
| Cai et al., 2016 | Non-Euro | Unselct | G1 to G6 | | 7.89 | 80 | Pl | | 0.41 | 0.43 | |
| | Non-Euro | Unselct | G1 to G6 | | 7.89 | 80 | Sim | | 0.02 | 0.32 | |
| Cai et al., 2010 | Non-Euro | Unselct | Kind | Kinder | 5.8 | 105 | Pl | 0.40 | | | |
| | Non-Euro | Unselct | Kind | Kinder | 5.8 | 105 | Att | 0.42 | | | |
| | Non-Euro | Unselct | Kind | Kinder | 5.8 | 105 | Sim | 0.46 | | | |
| | Non-Euro | Unselct | Kind | Kinder | 5.8 | 105 | Suc | 0.45 | | | |
| | Non-Euro | Unselct | G1 to G6 and G7 to G12 | Grade 3,4,5,6,7,8 group | 11.6 | 250 | Pl | | | | 0.43 |
| | Non-Euro | Unselct | G1 to G6 and G7 to G12 | Grade 3,4,5,6,7,8 group | 11.6 | 250 | Att | | | | 0.41 |
| | Non-Euro | Unselct | G1 to G6 and G7 to G12 | Grade 3,4,5,6,7,8 group | 11.6 | 250 | Sim | | | | 0.51 |
| | Non-Euro | Unselct | G1 to G6 and G7 to G12 | Grade 3,4,5,6,7,8 group | 11.6 | 250 | Suc | | | | 0.39 |
| Cai et al., 2013 | Non-Euro | Good and MLD | G1 to G6 and G7 to G12 | | 11.97 | 111 | Pl | | | | 0.44 |
| | Non-Euro | Good and MLD | G1 to G6 and G7 to G12 | | 11.97 | 111 | Att | | | | 0.38 |
| | Non-Euro | Good and MLD | G1 to G6 and G7 to G12 | | 11.97 | 111 | Sim | | | | 0.46 |

(*Appendices continue*)

Appendix B (*continued*)

| Study | Language | Math performance level | Grade level | Subgroup | Mean age | Sample Size | Types of PASS processes | Math accuracy | Math fluency | Problem-solving | Broad Math |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Non-Euro | Good and MLD | G1 to G6 and G7 to G12 | | 11.97 | 111 | Suc | | | | 0.36 |
| Cai et al., 2018 | Non-Euro | Unselct | Kind | Kinder | 5.54 | 100 | Att | 0.37 | | 0.33 | |
| | Non-Euro | Unselct | Kind | Kinder | 5.54 | 100 | Sim | 0.63 | | 0.68 | |
| | Non-Euro | Unselct | Kind | Kinder | 5.54 | 100 | Suc | 0.22 | | 0.22 | |
| | Non-Euro | Unselct | G1 to G6 | Grade 2 | 7.68 | 107 | Att | 0.12 | 0.12 | 0.27 | |
| | Non-Euro | Unselct | G1 to G6 | Grade 2 | 7.68 | 107 | Sim | 0.10 | 0.01 | 0.26 | |
| | Non-Euro | Unselct | G1 to G6 | Grade 2 | 7.68 | 107 | Suc | -0.08 | 0.21 | 0.29 | |
| | Non-Euro | Unselct | G1 to G6 | Grade 4 | 9.65 | 104 | Att | 0.27 | 0.24 | 0.21 | |
| | Non-Euro | Unselct | G1 to G6 | Grade 4 | 9.65 | 104 | Sim | 0.26 | 0.05 | 0.38 | |
| | Non-Euro | Unselct | G1 to G6 | Grade 4 | 9.65 | 104 | Suc | 0.15 | 0.09 | 0.09 | |
| Cui et al., 2015 | Non-Euro | Unselct | Kind | | 5.11 | 160 | Sim | | 0.26 | | |
| | Non-Euro | Unselct | Kind | | 5.11 | 160 | Suc | | 0.24 | | |
| Dunn et al., 2019 | English | Good | G1 to G6 | | 10.62 | 142 | Pl | | | | 0.40 |
| | English | Good | G1 to G6 | | 10.62 | 142 | Att | | | | 0.30 |
| | English | Good | G1 to G6 | | 10.62 | 142 | Sim | | | | 0.42 |
| | English | Good | G1 to G6 | | 10.62 | 142 | Suc | | | | 0.22 |
| Georgiou et al., 2015 | Other Euro | Unselct | G1 to G6 | Grade 1 | 6.83 | 83 | Pl | | 0.46 | | |
| | Other Euro | Unselct | G1 to G6 | Grade 1 | 6.83 | 83 | Att | | 0.36 | | |
| | Other Euro | Unselct | G1 to G6 | Grade 1 | 6.83 | 83 | Sim | | 0.34 | | |
| | Other Euro | Unselct | G1 to G6 | Grade 1 | 6.83 | 83 | Suc | | 0.36 | | |
| Georgiou et al., 2013 | Other Euro | Unselct | G1 to G6 | Grade 1 | 6.92 | 72 | Att | | 0 | | |
| | Other Euro | Unselct | G1 to G6 | Grade 1 | 6.92 | 72 | Sim | | 0.40 | | |
| | Other Euro | Unselct | G1 to G6 | Grade 1 | 6.92 | 72 | Suc | | 0.32 | | |
| Georgiou et al., 2019 | English | Unselct | G1 to G6 | English | 6.41 | 120 | Pl | 0.33 | | 0.45 | |
| | English | Unselct | G1 to G6 | English | 6.41 | 120 | Att | 0.26 | | 0.31 | |
| | English | Unselct | G1 to G6 | English | 6.41 | 120 | Sim | 0.23 | | 0.30 | |
| | Non-Euro | Unselct | G1 to G6 | Chinese | 7.15 | 181 | Pl | 0.06 | | 0.22 | |
| | Non-Euro | Unselct | G1 to G6 | Chinese | 7.15 | 181 | Att | 0.05 | | 0.25 | |

(*Appendices continue*)

Appendix B (*continued*)

| Study | Language | Math performance level | Grade level | Subgroup | Mean age | Sample Size | Types of PASS processes | Math accuracy | Math fluency | Problem-solving | Broad Math |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Non-Euro | Unselct | G1 to G6 | Chinese | 7.15 | 181 | Sim | 0.12 | | 0.38 | |
| Iglesias-Sarmiento et al., 2019 | Other Euro | MLD, good and poor | G1 to G6 | | 10.6 | 165 | Pl | 0.29 | | | |
| | Other Euro | MLD, good and poor | G1 to G6 | | 10.6 | 165 | Att | 0.22 | | | |
| | Other Euro | MLD, good and poor | G1 to G6 | | 10.6 | 165 | Sim | 0.57 | | | |
| | Other Euro | MLD, good and poor | G1 to G6 | | 10.6 | 165 | Suc | 0.42 | | | |
| Iglesias-Sarmiento & Deaño, 2011 | Other Euro | MLD, good and poor | G1 to G6 | Grade 4 | | 38 | Pl | | | | 0.29 |
| | Other Euro | MLD, good and poor | G1 to G6 | Grade 4 | | 38 | Att | | | | 0.55 |
| | Other Euro | MLD, good and poor | G1 to G6 | Grade 4 | | 38 | Sim | | | | 0.78 |
| | Other Euro | MLD, good and poor | G1 to G6 | Grade 4 | | 38 | Suc | | | | 0.45 |
| | Other Euro | MLD, good and poor | G1 to G6 | Grade 5 | | 38 | Pl | | | | 0.35 |
| | Other Euro | MLD, good and poor | G1 to G6 | Grade 5 | | 38 | Att | | | | 0.29 |
| | Other Euro | MLD, good and poor | G1 to G6 | Grade 5 | | 38 | Sim | | | | 0.49 |
| | Other Euro | MLD, good and poor | G1 to G6 | Grade 5 | | 38 | Suc | | | | 0.49 |
| | Other Euro | MLD, good and poor | G1 to G6 | Grade 6 | | 38 | Pl | | | | 0.01 |
| | Other Euro | MLD, good and poor | G1 to G6 | Grade 6 | | 38 | Att | | | | -0.21 |
| | Other Euro | MLD, good and poor | G1 to G6 | Grade 6 | | 38 | Sim | | | | 0.57 |
| | Other Euro | MLD, good and poor | G1 to G6 | Grade 6 | | 38 | Suc | | | | 0.34 |
| Iglesias-Sarmiento & Deaño, 2016 | Other Euro | MLD, good and poor | G1 to G6 | | | 165 | Pl | 0.18 | | | |

(*Appendices continue*)

Appendix B (*continued*)

| Study | Language | Math performance level | Grade level | Subgroup | Mean age | Sample Size | Types of PASS processes | Math accuracy | Math fluency | Problem-solving | Broad Math |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Other Euro | MLD, good and poor | G1 to G6 | | | 165 | Att | 0.23 | | | |
| | Other Euro | MLD, good and poor | G1 to G6 | | | 165 | Sim | 0.42 | | | |
| | Other Euro | MLD, good and poor | G1 to G6 | | | 165 | Suc | 0.27 | | | |
| Iglesias-Sarmiento et al., 2017 | Other Euro | ADHD | G1 to G6 | ADHD | 10.5 | 30 | Pl | | | 0.71 | |
| | Other Euro | ADHD | G1 to G6 | ADHD | 10.5 | 30 | Att | | | 0.69 | |
| | Other Euro | ADHD | G1 to G6 | ADHD | 10.5 | 30 | Sim | | | 0.13 | |
| | Other Euro | ADHD | G1 to G6 | ADHD | 10.5 | 30 | Suc | | | 0.19 | |
| | Other Euro | MLD | G1 to G6 | MLD | 10.6 | 30 | Pl | | | 0.32 | |
| | Other Euro | MLD | G1 to G6 | MLD | 10.6 | 30 | Att | | | 0.20 | |
| | Other Euro | MLD | G1 to G6 | MLD | 10.6 | 30 | Sim | | | 0.58 | |
| | Other Euro | MLD | G1 to G6 | MLD | 10.6 | 30 | Suc | | | 0.51 | |
| | Other Euro | Good | G1 to G6 | TA | 10.9 | 30 | Pl | | | 0.41 | |
| | Other Euro | Good | G1 to G6 | TA | 10.9 | 30 | Att | | | 0.28 | |
| | Other Euro | Good | G1 to G6 | TA | 10.9 | 30 | Sim | | | 0.37 | |
| | Other Euro | Good | G1 to G6 | TA | 10.9 | 30 | Suc | | | 0.26 | |
| Keith et al., 2001 | English | Unselct | G1 to G6 | | 9.81 | 155 | Pl | | | 0.68 | |
| | English | Unselct | G1 to G6 | | 9.81 | 155 | Att | | | 0.44 | |
| | English | Unselct | G1 to G6 | | 9.81 | 155 | Sim | | | 0.77 | |
| | English | Unselct | G1 to G6 | | 9.81 | 155 | Suc | | | 0.48 | |
| Kroesbergen et al., 2015 | Other Euro | | | | | 70 | Pl | | | | 0.23 |
| | Other Euro | | | | | 70 | Att | | | | 0.26 |
| | Other Euro | | | | | 70 | Sim | | | | 0.20 |
| | Other Euro | | | | | 70 | Suc | | | | 0.06 |
| Kroesbergen, et al., 2015 | Other Euro | | | Dutch | | 38 | Pl | | | | 0.64 |
| | Other Euro | | | Dutch | | 38 | Att | | | | 0.42 |
| | Other Euro | | | Dutch | | 38 | Sim | | | | 0.54 |

(*Appendices continue*)

Appendix B (*continued*)

| Study | Language | Math performance level | Grade level | Subgroup | Mean age | Sample Size | Types of PASS processes | Math accuracy | Math fluency | Problem-solving | Broad Math |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Other Euro | | | Dutch | | 38 | Suc | | | | 0.33 |
| | Other Euro | | | Non-native Dutch | | 22 | Pl | | | | 0.23 |
| | Other Euro | | | Non-native Dutch | | 22 | Att | | | | 0.14 |
| | Other Euro | | | Non-native Dutch | | 22 | Sim | | | | 0.43 |
| | Other Euro | | | Non-native Dutch | | 22 | Suc | | | | 0.21 |
| Naglieri & Das, 1997 | English | Unselct | | 5 -7 yrs | | 630 | Pl | 0.47 | | 0.44 | 0.53 |
| | English | Unselct | | 5 -7 yrs | | 630 | Att | 0.39 | | 0.47 | 0.47 |
| | English | Unselct | | 5 -7 yrs | | 630 | Sim | 0.33 | | 0.60 | 0.53 |
| | English | Unselct | | 5 -7 yrs | | 630 | Suc | 0.28 | | 0.48 | 0.44 |
| | English | Unselct | | 8 -10 yrs | | 454 | Pl | 0.53 | | 0.51 | 0.57 |
| | English | Unselct | | 8 -10 yrs | | 454 | Att | 0.40 | | 0.40 | 0.44 |
| | English | Unselct | | 8 -10 yrs | | 454 | Sim | 0.50 | | 0.62 | 0.61 |
| | English | Unselct | | 8 -10 yrs | | 454 | Suc | 0.42 | | 0.49 | 0.49 |
| | English | Unselct | | 11 -13 yrs | | 228 | Pl | 0.58 | | 0.61 | 0.60 |
| | English | Unselct | | 11 -13 yrs | | 228 | Att | 0.46 | | 0.49 | 0.48 |
| | English | Unselct | | 11 -13 yrs | | 228 | Sim | 0.58 | | 0.66 | 0.65 |
| | English | Unselct | | 11 -13 yrs | | 228 | Suc | 0.52 | | 0.57 | 0.58 |
| | English | Unselct | | 14 -17 yrs | | 288 | Pl | 0.59 | | 0.53 | 0.59 |
| | English | Unselct | | 14 -17 yrs | | 288 | Att | 0.46 | | 0.48 | 0.48 |
| | English | Unselct | | 14 -17 yrs | | 288 | Sim | 0.61 | | 0.67 | 0.68 |
| | English | Unselct | | 14 -17 yrs | | 288 | Suc | 0.52 | | 0.53 | 0.58 |
| Naglieri & Das, 1997 | English | Good | | | 13.4 | 53 | Pl | 0.35 | | | |
| | English | Good | | | 13.4 | 53 | Att | 0.28 | | | |
| | English | Good | | | 13.4 | 53 | Sim | 0.43 | | | |
| | English | Good | | | 13.4 | 53 | Suc | 0.13 | | | |
| Naglieri et al., 2014 | English | | | Sample 1 | | 36 | Pl | | | | 0.63 |

(*Appendices continue*)

Appendix B (*continued*)

| Study | Language | Math performance level | Grade level | Subgroup | Mean age | Sample Size | Types of PASS processes | Math accuracy | Math fluency | Problem-solving | Broad Math |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | English | | | Sample 1 | | 36 | Att | | | | 0.40 |
| | English | | | Sample 1 | | 36 | Sim | | | | 0.61 |
| | English | | | Sample 1 | | 36 | Suc | | | | 0.66 |
| Naglieri et al., 2014 | English | | | Sample 2 | | 46 | Pl | | 0.64 | | |
| | English | | | Sample 2 | | 46 | Att | | 0.51 | | |
| | English | | | Sample 2 | | 46 | Sim | | 0.49 | | |
| | English | | | Sample 2 | | 46 | Suc | | 0.26 | | |
| Naglieri et al., 2014 | English | | | Sample 3 | | 53 | Pl | 0.51 | | | |
| | English | | | Sample 3 | | 53 | Att | 0.49 | | | |
| | English | | | Sample 3 | | 53 | Sim | 0.65 | | | |
| | English | | | Sample 3 | | 53 | Suc | 0.37 | | | |
| Naglieri et al., 2006 | English | | | | | 119 | Pl | | 0.50 | | 0.51 |
| | English | | | | | 119 | Att | | 0.39 | | 0.39 |
| | English | | | | | 119 | Sim | | 0.58 | | 0.63 |
| | English | | | | | 119 | Suc | | 0.45 | | 0.51 |
| Naglieri et al., 2007 | English | Unselct | | Hispanic | 9.66 | 158 | FS | 0.40 | | 0.62 | |
| | English | Unselct | | Non-Hispanics | 9.85 | 1284 | FS | 0.69 | | 0.65 | |
| Naglieri et al., 2005 | English | Unselct | | Blacks | | 298 | FS | 0.69 | | 0.60 | 0.66 |
| | English | Unselct | | Whites | | 1691 | FS | 0.65 | | 0.64 | 0.65 |
| Rosário, 2014 | Other Euro | Unselct | G1 to G6 | Grade 2 | 7.25 | 60 | Pl | | | | 0.34 |
| | Other Euro | Unselct | G1 to G6 | Grade 2 | 7.25 | 60 | Att | | | | 0.43 |
| | Other Euro | Unselct | G1 to G6 | Grade 2 | 7.25 | 60 | Sim | | | | 0.53 |
| | Other Euro | Unselct | G1 to G6 | Grade 2 | 7.25 | 60 | Suc | | | | 0.39 |
| | Other Euro | Unselct | G1 to G6 | Grade 4 | 9.14 | 60 | Pl | | | | -0.04 |
| | Other Euro | Unselct | G1 to G6 | Grade 4 | 9.14 | 60 | Att | | | | 0.27 |
| | Other Euro | Unselct | G1 to G6 | Grade 4 | 9.14 | 60 | Sim | | | | 0.47 |
| | Other Euro | Unselct | G1 to G6 | Grade 4 | 9.14 | 60 | Suc | | | | 0.15 |
| | Other Euro | Unselct | G1 to G6 | Grade 6 | 11.09 | 60 | Pl | | | | 0.22 |

(*Appendices continue*)

Appendix B (*continued*)

| Study | Language | Math performance level | Grade level | Subgroup | Mean age | Sample Size | Types of PASS processes | Math accuracy | Math fluency | Problem-solving | Broad Math |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Other Euro | Unselct | G1 to G6 | Grade 6 | 11.09 | 60 | Att | | | | 0.26 |
| | Other Euro | Unselct | G1 to G6 | Grade 6 | 11.09 | 60 | Sim | | | | 0.44 |
| | Other Euro | Unselct | G1 to G6 | Grade 6 | 11.09 | 60 | Suc | | | | 0.32 |
| | Other Euro | Unselct | G7 to G12 | Grade 9 | 14.27 | 60 | Pl | | | | 0.44 |
| | Other Euro | Unselct | G7 to G12 | Grade 9 | 14.27 | 60 | Att | | | | 0.36 |
| | Other Euro | Unselct | G7 to G12 | Grade 9 | 14.27 | 60 | Sim | | | | 0.52 |
| | Other Euro | Unselct | G7 to G12 | Grade 9 | 14.27 | 60 | Suc | | | | 0.31 |
| Taha, 2016 | Non-Euro | | | | 13.52 | 50 | Pl | 0.81 | | | |
| | Non-Euro | | | | 13.52 | 50 | Att | 0.84 | | | |
| Wei et al., 2017 | Non-Euro | | G1 to G6 | | 7.17 | 180 | Pl | | 0.39 | 0.21 | |
| | Non-Euro | | G1 to G6 | | 7.17 | 180 | Att | | 0.12 | 0.03 | |
| | Non-Euro | | G1 to G6 | | 7.17 | 180 | Sim | | 0.03 | 0.39 | |
| | Non-Euro | | G1 to G6 | | 7.17 | 180 | Suc | | 0.07 | 0.24 | |
| Wei et al., 2018 | Non-Euro | Unselct | G1 to G6 | | 8.16 | 179 | Pl | 0.09 | 0.14 | | |
| | Non-Euro | Unselct | G1 to G6 | | 8.16 | 179 | Att | 0.19 | 0.33 | | |
| | Non-Euro | Unselct | G1 to G6 | | 8.16 | 179 | Sim | 0.23 | 0.06 | | |
| Zhu et al., 2017 | Non-Euro | Unselct | G1 to G6 | Grade 2 | 7.72 | 77 | Att | | 0.50 | 0.30 | |
| | Non-Euro | Unselct | G1 to G6 | Grade 2 | 7.72 | 77 | Sim | | 0.01 | 0.26 | |
| | Non-Euro | Unselct | G1 to G6 | Grade 4 | 9.69 | 71 | Att | | 0.39 | 0.16 | |
| | Non-Euro | Unselct | G1 to G6 | Grade 4 | 9.69 | 71 | Sim | | 0.08 | 0.30 | |

*Note.* Non-Euro = Non-European language; Other Euro= Other European language; Unselct = Unselected; Kind = Kindergarten; ADHD = Attention Deficit Hyperactive Disorder; MLD = Math Learning Disabilities; TA = Typical Achievers; Pl = Planning; Att = Attention; Sim = Simultaneous; Suc = Successive; FS = Full Scale.