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PASS theory of intelligence and academic achievement: A meta-analytic review

George K. Georgiou[a,*], Kan Guo[b,**], Nithya Naveenkumar[a], Ana Paula Alves Vieira[c], J.P. Das[a]

[a] University of Alberta, Canada
[b] Beijing Normal University, China
[c] State University of Maringá, Brazil

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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 determine their association by conducting a meta-analysis. 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 = 0.409, 95% CI = [0.363, 0.454]), and mathematics, r = 0.461, CI = [0.405, 0.517]. Moderator analyses further showed that (1) PASS processes were more strongly related with reading and math in English than in other languages, (2) Simultaneous processing was more strongly related to math accuracy and problem solving than math fluency, (3) Simultaneous processing was more strongly related to problem solving than Attention, and (4) Planning was more strongly related to math fluency than Simultaneous processing. Age, grade level, and sample characteristics did not influence the size of the correlations. 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. They further support the use of intervention programs that stem from PASS theory for the enhancement of reading and mathematics skills.

1. Introduction

A plethora of studies has established that intelligence (operationalized with IQ tests) is related to school achievement (e.g., Barton, Dielman, & Cattell, 1972; Deary, Strand, Smith, & Fernandes, 2007; Mayes, Calhoun, Bixler, & Zimmerman, 2009; Naglieri & Bornstein, 2003; Soares, Lemos, Primi, & Almeida, 2015; see also Peng, Wang, Wang, & Lin, 2019; Roth et al., 2015, for meta-analyses). For example, Roth et al. (2015) estimated the average correlation between IQ (operationalized with different IQ measures) and school grades to be 0.44. In general, those with higher IQ outperform others with lower IQ in important school subjects such as reading and mathematics. Although this is well established, some researchers have argued that the most popular IQ batteries (e.g., WISC) include tests (e.g., Vocabulary, Arithmetic) that are very similar to achievement tests and thus assess more “knowing” than “thinking” (which should be the target of intelligence testing) (e.g., Das, 2002; Gardner, 1993; Naglieri & Otero, 2018).

To bypass this problem as well as to broaden the scope of abilities measured, Das, Naglieri, and Kirby (1994) proposed a neurocognitive theory of intelligence called PASS (for Planning, Attention, Simultaneous, and Successive processing) and a way of measuring it (Cognitive Assessment System [CAS]; Naglieri & Das, 1997). Although PASS theory is more than 20 years old and 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 reading/mathematics and if their relation is influenced by different factors (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).

* Correspondence to: G. K. Georgiou, Department of Educational Psychology, University of Alberta, 6-102 Educational North, Edmonton, AB T6G2G5, Canada.
** Correspondence to: K. Guo, School of Mathematical Sciences, Beijing Normal University, Beijing 100875, P.R. China.
E-mail addresses: georgiou@ualberta.ca (G.K. Georgiou), guokan@bnu.edu.cn (K. Guo).

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1.1. PASS theory of intelligence

The PASS theory of intelligence is rooted in Luria's (1966, 1973) work on cognition, according to which human cognition consists of three separate but interrelated brain systems that support four cognitive processes (planning, attention, simultaneous, and successive processing). The three brain systems are referred to as functional units. The first functional unit, Attention-Arousal, is responsible for two cognitive tasks which are (a) maintaining general alertness or orientation to the task and (b) controlling attention and resisting to distraction. The second functional unit is concerned with the storage and integration of information as well as with the grouping of information into simultaneous arrays or successive series. Simultaneous processing involves integrating stimuli into groups or the recognition that a number of items share a common characteristic. 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 the Planning system that is involved in decision-making, evaluation, programming, and regulation of present and future behavior. It is linked up with the execution of actions.

All processes are embedded within a knowledge base. The knowledge base is often divided into two categories – *tacit* or experiential and *formal* or instructed. Comprehension of a passage, for example, is dependent on ‘world knowledge’ or tacit knowledge arising from cultural and social background as well as experiences of the individual, on the one hand, and factual knowledge acquired through formal instruction.

1.2. PASS theory and academic achievement

One of the distinctive features of PASS theory is its close theoretical links to academic achievement (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) as well as children with reading difficulties (e.g., Das, Janzen, & Georgiou, 2007; Joseph, McCachran, & Naglieri, 2003; Wang, Georgiou, Das, & Li, 2012) have confirmed these predictions. For example, in a study with Greek–speaking adolescents, Kendeou et al. (2015) showed that all four processes were predictive of reading comprehension.

Researchers have also proposed specific links between PASS processes and mathematics (e.g., Iseman & Naglieri, 2011; Kirby & Ashman, 1984; Kroesbergen, Van Luit, Naglieri, Taddei, & Franchi, 2010). 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., $(3 + 5) \times (4 + 4)/2 = ?$)) 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. Again, previous studies with typically–developing children (e.g., Georgiou, Manolitsis, & Tziraki, 2015; Kroesbergen et al., 2010; Naglieri & Das, 1987; Naglieri & Rojahn, 2004) 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.

Although we have strong evidence to suggest that PASS processes relate to reading and mathematics (see Naglieri & Otero, 2018, for a review), several issues remain unclear. First, we do not know if all four processes are equally important for reading/mathematics or if their relation varies as a function of the type of reading/mathematics outcome (e.g., reading accuracy vs. reading fluency vs. reading comprehension). For example, because Planning and Attention are operationalized with measures that involve response time, one would expect them to be more strongly related to reading and mathematics fluency than accuracy. Second, we do not know if the relation of the PASS processes with reading/mathematics performance varies 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. For example, Successive processing may be more strongly related to reading in early grades because of its connection to decoding (e.g., Papadopoulos, 2001) and Planning may be more strongly related to reading in upper grades because of its connection to comprehension (e.g., Kendeou et al., 2015). Third, although a few studies have established that the factor structure of CAS is invariant across languages (e.g., Deng & Georgiou, 2015; Naglieri, Otero, DeLauder, & Matto, 2007; Naglieri, Taddei, & Williams, 2013), we still do not know if language moderates the PASS–reading/mathematics relations. The only study to directly compare the role of PASS processes across languages included only European languages (Italian vs. Dutch) and only mathematics outcomes (Kroesbergen et al., 2010). Kroesbergen et al. reported no significant differences across languages. Finally, it is unclear if sample characteristics (e.g., typically–developing children vs. children with learning disabilities vs. gifted children) play a role. 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). Their results need to be validated across multiple samples.

1.3. 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 two questions:

(1) What is the size of the relation between PASS processes and reading/mathematics performance?
(2) Does the relation between PASS processes and reading/mathematics performance vary as a function of (a) the type of reading/mathematics outcome; (b) the language in which the studies were conducted; (c) children's age/grade level, and (d) sample characteristics?

2. Method

2.1. Data collection

The inclusion, search, and coding procedures are detailed in Fig. 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*

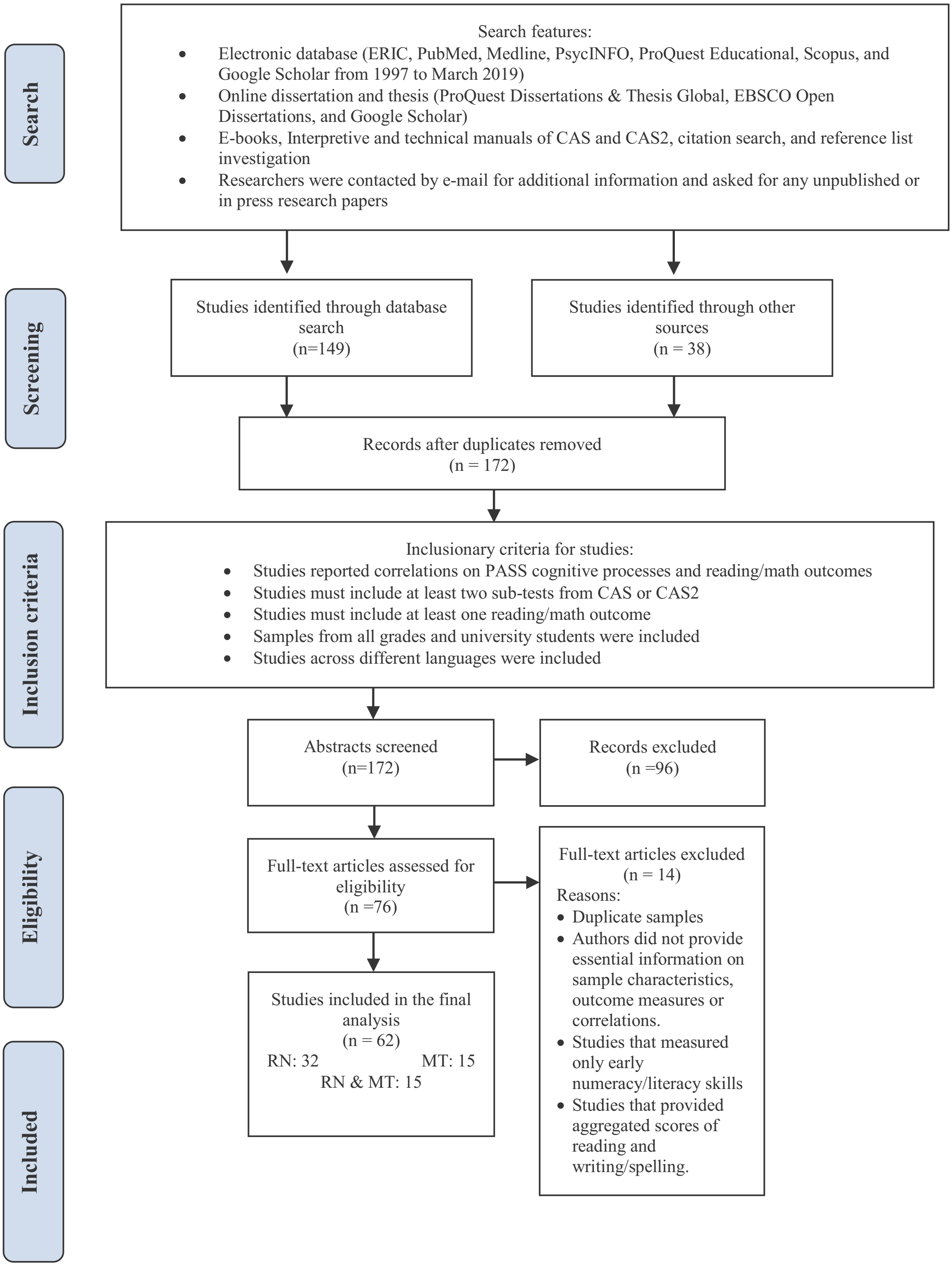

Fig. 1. Flow diagram for the search and inclusion on studies. RN = Reading; MT = Math.

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, Das, & Goldstein, 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/papers.

2.2. 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 et al., 2014; Naglieri & Das, 1997) 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. Across the 62 studies, one study was published in Chinese and two dissertations in Portuguese.

2.3. Coding procedures

To begin the coding process, first we 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, the data were coded individually by the third and fourth author 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 recorded. The consensus rate varied between 95% and 98%. Differences in coding were due to inadequate information provided in a few studies about describing the participants and measures. The discrepancy between the coders was resolved by revisiting the studies and a discussion between the two raters.

2.4. Moderator variables

In each study, we coded five important 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.

2.4.1. 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 1 year, the mean age was coded (e.g., the age 9.14 years was coded, when the age ranged between 9 and 10 years); b) If the age range alone was reported and it was not larger than 1 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 1 year) without providing information on the mean age were excluded from the moderator analyses.

2.4.2. 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.

2.4.3. 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

[1] A description of the CAS measures can be found in Naglieri and Das (1997) and in Naglieri and Otero (2018).

(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.

2.4.4. 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".

2.4.5. 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.

2.5. 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, Thompson, Deeks, & Altman, 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.

2.6. 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.

3. Results

3.1. Study features

Of the 62 publications 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 publications ranged from 4.91 to 22.26 years, and the grade level ranged from kindergarten to adults.

3.2. 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 Fig. 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]).

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 Fig. 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 ($Q = 452.096$, $I^2 = 93.09\%$, $p < .0001$).

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: 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.

[a] The second row under reading or mathematics refers to the estimates obtained when the PASS Full Scale was used.

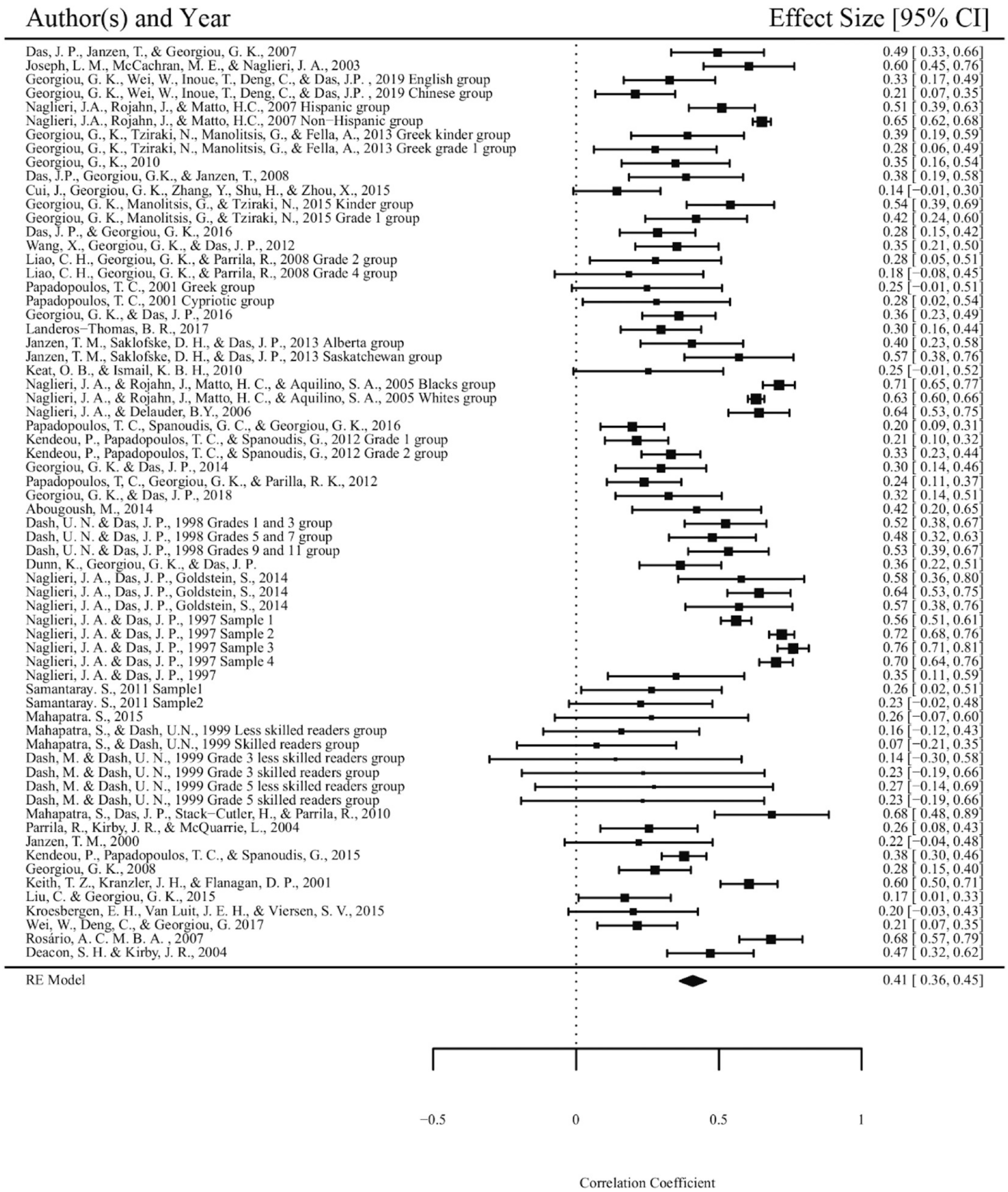

Figure 2. Forest plot: Strength of the correlations between PASS and reading.

3.3. 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, $z = 2.1169$, $p = .0343$).

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 ($ps < .001$). 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 ($\beta = .0136$, $p = .2452$, $k = 30$).

3.4. 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

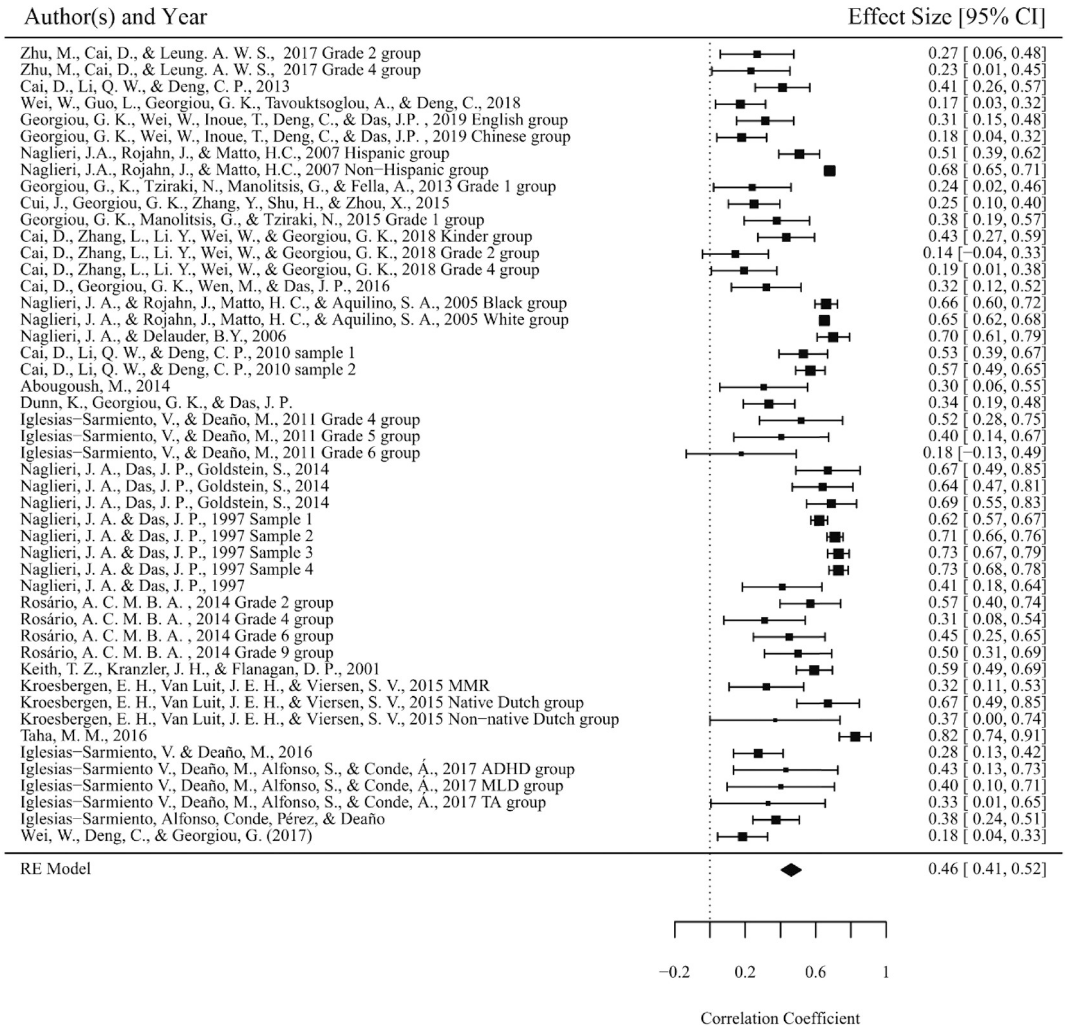

Figure 3. Forest plot: Strength of the correlations between PASS and math.

(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

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							
Accuracy	33	.347	<.0001	[.286, .409]	0.032	0.2849	.8672
Fluency	11	.315	<.0001	[.214, .416]			
Comprehension	26	.330	<.0001	[.261, .399]			
Attention							
Accuracy	25	.292	<.0001	[.223, .361]	0.032	0.5042	.7772
Fluency	13	.322	<.0001	[.229, .415]			
Comprehension	19	.324	<.0001	[.248, .400]			
Simultaneous							
Accuracy	34	.355	<.0001	[.295, .414]	0.105	2.4599	.2923
Fluency	12	.310	<.0001	[.210, .409]			
Comprehension	21	.415	<.0001	[.343, .487]			
Successive							
Accuracy	29	.368	<.0001	[.304, .433]	0.033	0.5938	.7431
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							
Accuracy	13	.409	<.0001	[.313, .504]	0.061	0.6714	.7148
Fluency	6	.421	<.0001	[.277, .564]			
Problem solving	12	.470	<.0001	[.368, .571]			
Attention							
Accuracy	16	.349	<.0001	[.262, .436]	0.028	0.1532	.9262
Fluency	10	.321	<.0001	[.206, .435]			
Problem solving	16	.342	<.0001	[.253, .433]			
Simultaneous							
Accuracy	15	.416	<.0001	[.327, .505]	0.299	18.4090	.0001
Fluency	12	.179	.0009	[.073, .285]			
Problem solving	17	.478	<.0001	[.392, .564]			
Successive							
Accuracy	12	.320	<.0001	[.219, .422]	0.144	4.1787	.1238
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.

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							
English	31	.503	<.0001	[.447, .559]	0.198	21.2367	<.0001
Other European	12	.316	<.0001	[.224, .408]			
Non-European	19	.305	<.0001	[.224, .386]			
ELL	4	.390	<.0001	[.202, .579]			
Grade							
Kindergarten	4	.309	<.0001	[.153, .464]	0.224	2.0580	.5605
G1 to G6	42	.365	<.0001	[.314, .416]			
G7 to G12	1	.533	.0005	[.235, .831]			
Adults	4	.317	<.0001	[.165, .468]			
Sample characteristics							
Unselected	50	.416	<.0001	[.366, .466]	0.119	2.3237	.3129
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							
English	17	.601	<.0001	[.528, .675]	0.250	22.0784	<.0001
Other European	17	.403	<.0001	[.315, .490]			
Non-European	14	.351	<.0001	[.265, .436]			
Grade							
Kindergarten	3	.405	<.0001	[.259, .552]	0.176	2.3173	.3139
G1 to G6	25	.324	<.0001	[.267, .381]			
G7 to G12	1	.500	.0005	[.219, .782]			
Sample characteristics							
Unselected	28	.456	<.0001	[.384, .528]	0.106	0.7245	.3947
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.

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

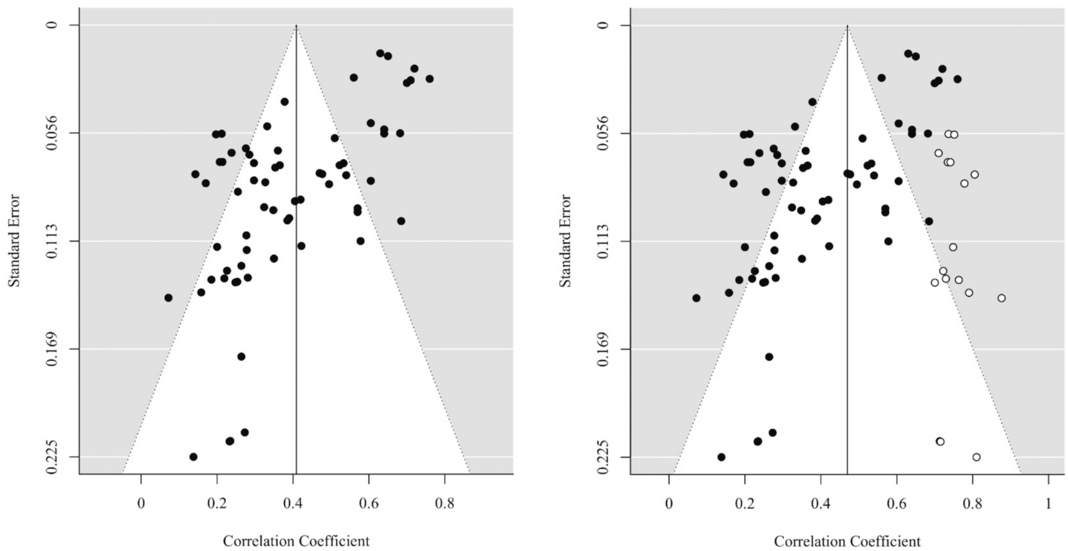

Figure 4. Funnel plots for reading (left) and funnel plots with imputed samples for reading (right).

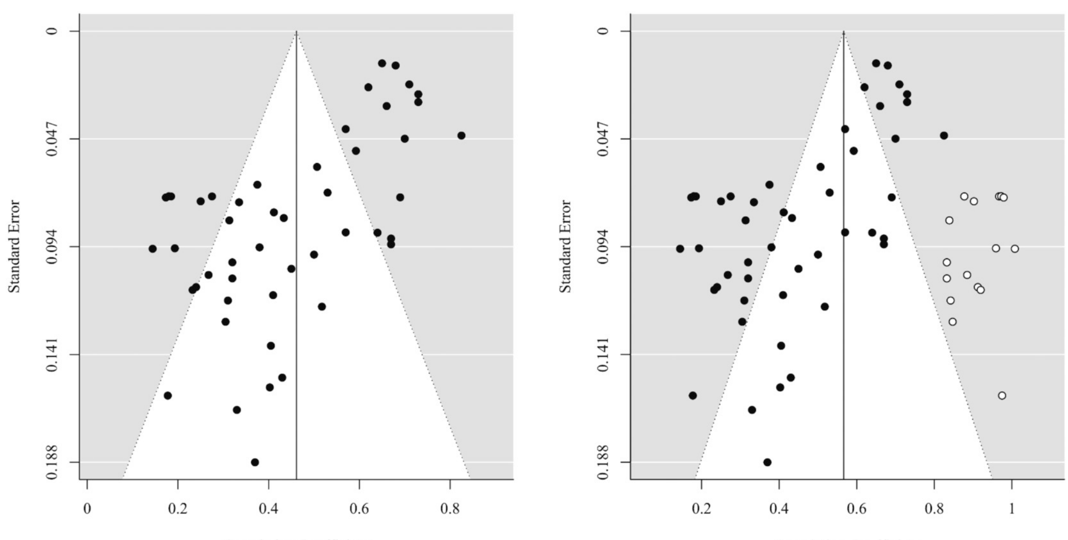

Figure 5. Funnel plots for math (left) and funnel plots with imputed samples for math (right).

with effect sizes over the overall mean) (see Figs. 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.

4. 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 taken into account, 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 math (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. 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, DeLauder, Goldstein, & Schwebech, 2006; Naglieri & Otero, 2018), to our knowledge, none of the previous meta-analyses examining the relationship 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. Language explained some of this heterogeneity. Larger correlations with reading/mathematics 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 Fig. 2). However, even if the CAS measures in these languages functioned properly, it is possible that their reading/mathematics outcomes did not. For example, a careful look at the descriptive statistics in Mahapatra's (2015) study shows that in the group of good comprehenders there was restriction of range ($M = 37.73$; $SD = 1.16$), which, in turn, may explain the low correlation reported between planning and passage comprehension in that group ($r = .140$).

Our results further showed significant differences in the relations of the four PASS processes with mathematics. 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, Rojahn, & Matto, 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 PASS Reading Enhancement Program (PREP) has been found to improve children's decoding (Papadopoulos, Charalambous, Kanari, & Loizou, 2004) and reading comprehension (Mahapatra, Das, Stack-Cutler, & Parrila, 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.

Acknowledgments

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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 comprehension	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, Georgiou, Zhang, Shu, and Zhou (2015)	Non-Euro	Unselct	Kind		5.11	160	Sim	0.19			
	Non-Euro	Unselct	Kind		5.11	160	Suc	0.10			
Das and 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 and 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 and Dash (1999)	Non-Euro	Poor	G1 to G6	Grade 3 less skilled		20	Pl	0.15		0.13	
	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 and Kirby (2004)	English	Unselect	G1 to G6		7.38	103	Sim	0.44		0.50	
Dunn, Georgiou, and Das (2020)	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 and 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 and Das (2016)	English	Unselct	Adults		21.83	178	Pl			0.36	
Georgiou and 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		
	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, Tziraki, Manolitsis, and Fella (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			
		Unselct	G1 to G6	Grade 1	6.92	72	Att		0.08		

	Other Euro										
	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, Wei, Inoue, Deng, and Das (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, Saklofske, and Das (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			
	English	Poor	G1 to G6		8.4	62	Suc	0.41			
Keat and 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, Kranzler, and Flanagan (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, Papadopoulos, and Spanoudis (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, Van Luit, and Viersen (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, Georgiou, and Parrila (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		
Liu and 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 and 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 and 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
	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 and 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, Rojahn, and Matto (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, Rojahn, Matto, and Aquilino (2005)	English	Unselct		Blacks		298	FS	0.70		0.68	0.71
	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, Georgiou, and Parrila (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, Spanoudis, and Georgiou (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, Kirby, and McQuarrie (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, Georgiou, and Das (2012)	Non-Euro	Unselct	G1 to G6	10	140	Pl	0.16	0.18	
	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	
Wei, Deng, and Georgiou (2017)	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.

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, Georgiou, Wen, and Das (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, Li, and Deng (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
	Non-Euro	Good and MLD	G1 to G6 and G7 to G12		11.97	111	Suc				0.36
Cai, Zhang, Li, Wei, and Georgiou (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. (2020)	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		
		Unselct	G1 to G6	Grade 1	6.83	83	Sim		0.34		

	Other Euro										
	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	
	Non-Euro	Unselct	G1 to G6	Chinese	7.15	181	Sim	0.12		0.38	
Iglesias-Sarmiento, Alfonso, Conde, Pérez, and Deaño (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 and 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 and Deaño (2016)	Other Euro	MLD, good and poor	G1 to G6			165	Pl	0.18			
	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
	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 and 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 and 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
	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, Rojahn, and Matto (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
	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, Guo, Georgiou, Tavouktsoglou, and Deng (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, Cai, and Leung (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	

Notes 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.

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