Author(s): Pulkkinen, Jenni; Eklund, Kenneth; Koponen, Tuire; Heikkilä, Riikka; Georgiou, George; Salminen, Jonna; van Daal, Victor; Aro, Mikko

Title: Cognitive skills, self-beliefs and task interest in children with low reading and/or arithmetic fluency

Year: 2022

Version: Published version

Please cite the original version:

Pulkkinen, J., Eklund, K., Koponen, T., Heikkilä, R., Georgiou, G., Salminen, J., van Daal, V., & Aro, M. (2022). Cognitive skills, self-beliefs and task interest in children with low reading and/or arithmetic fluency. Learning and Individual Differences, 97, Article 102160. https://doi.org/10.1016/j.lindif.2022.102160

Learning and Individual Differences 97 (2022) 102160

Contents lists available at ScienceDirect

Learning and Individual Differences

journal homepage: www.elsevier.com/locate/lindif

Cognitive skills, self-beliefs and task interest in children with low reading and/or arithmetic fluency☆

Jenni Pulkkinen [a,*], Kenneth Eklund [b], Tuire Koponen [a], Riikka Heikkilä [a,c], George Georgiou [d], Jonna Salminen [a,1], Victor van Daal [e], Mikko Aro [a]

[a] Department of Education, University of Jyväskylä, Finland
[b] Faculty of Education and Psychology, University of Jyväskylä, Finland
[c] Niilo Mäki Institute, Finland
[d] Department of Educational Psychology, University of Alberta, Canada
[e] Faculty of Social and Behavioural Sciences, Programme group Developmental Psychology, University of Amsterdam, Netherlands

ARTICLE INFO

Keywords:
Arithmetic fluency
Reading fluency
Comorbidity
Cognitive processing
Self-concept/self-efficacy

ABSTRACT

This study examined the identifiability and early cognitive and motivational markers of low reading and arithmetic fluency. Comparisons of these characteristics between Finnish third graders (n = 197) with low fluency in reading, arithmetic, or both revealed, first, that the majority of third graders with low arithmetic fluency showed low arithmetic skills already at first-grade spring, whereas children with low reading fluency were identified from the second-grade fall onward. Second, all groups with low fluency showed low rapid automatized naming and counting skills across the primary school years, while in other cognitive skills these groups showed different patterns. Third, all groups with fluency problems demonstrated low self-efficacy and self-concept in the domain in which they had difficulties. The present findings enhance understanding about the emergence, stability and potential early cognitive and motivational markers of single and comorbid fluency problems in reading and arithmetic.

1. Introduction

Strengthening children's basic reading and arithmetic skills to reach a sufficient level of fluency is one of the main educational goals of primary school. In reading, effortless mastery of grapheme–phoneme correspondences and phonemic recoding form the basis of fluency (Hudson et al., 2008), which allows shifting of attention from decoding to meaning (Samuels, 2006). Fluent calculation skills require accurate and fast retrieval of arithmetic facts, such as solutions to simple additions and subtractions (Geary, 1993), that predict more complex arithmetic problem solving skills (Carr & Alexeev, 2011). Dysfluency is the most common and universal characteristic of difficulties in both domains, manifested by slow and laborious reading (Ziegler et al., 2003) and reliance on time-consuming calculation strategies (Geary, 1993). Research has shown that a considerable number of children face difficulties in achieving fluency in both academic areas (Koponen et al., 2018; Landerl & Moll, 2010). Prevalence rates of comorbid fluency difficulties vary between 22%–46% (Koponen et al., 2018; Landerl & Moll, 2010; Moll et al., 2014), and further, they are relatively persistent (Koponen et al., 2018).

Although previous studies have established the key cognitive predictors of reading (Child et al., 2018; Landerl & Wimmer, 2008) and arithmetic skills (Child et al., 2018), early cognitive predictors indicating particularly fluency problems in reading, arithmetic, or both have remained largely unexplored. To date, explicit focus on fluency problems, i.e., taking speed into account in addition to accuracy, has been rare in studies examining the role of cognitive skills in reading and arithmetic difficulties (see e.g., Landerl et al., 2009; Van Daal et al., 2013; Van Der Sluis et al., 2005; Wang et al., 2018). Additionally, motivational factors, such as task interest, self-efficacy beliefs, and academic self-concept, play central roles in the development of academic skills (Marsh & Martin, 2011; Talsma et al., 2018), but unfortunately, studies examining the characteristics of single and comorbid fluency problems have disregarded them. Moreover, most of the previous studies

☆ This study was financed by the Academy of Finland [Grant Number 277340].
* Corresponding author at: Department of Education, P.O. Box 35, FI-40014, University of Jyväskylä, Finland.
E-mail address: jenni.m.pulkkinen@jyu.fi (J. Pulkkinen).
[1] Jonna Salminen is now at the City of Jyväskylä.

https://doi.org/10.1016/j.lindif.2022.102160
Received 14 September 2021; Received in revised form 29 April 2022; Accepted 7 May 2022
Available online 1 June 2022
1041-6080/

have either used a cross-sectional design or identified children with single and comorbid difficulties using information only from one time point. In light of these limitations, this study aims to increase knowledge about the emergence, stability, and early cognitive and motivational markers of low reading and arithmetic fluency.

1.1. Stability of single and comorbid reading and arithmetic fluency difficulties

The stability of reading (Eklund et al., 2015; Georgiou, Inoue, Papadopoulos, & Parrila, 2021; Landerl & Wimmer, 2008) and arithmetic fluency (Korpipää et al., 2017; Zhang et al., 2020) seems to be relatively high across school years. For example, the correlation of reading fluency in the first two school years ($r = 0.67$, Torppa et al., 2007) and even from second to eighth grade ($r = 0.72$, Eklund et al., 2015) indicate high stability. Studies examining the stability of difficulties in reading fluency (Eklund et al., 2015; Koponen et al., 2018; Landerl & Wimmer, 2008; Torppa et al., 2007) allow us to draw similar conclusions. Similarly, in the area of arithmetic, strong associations have been found from first to fourth ($r = 0.61$, Zhang et al., 2020) and from first to seventh grade ($r = 0.51$, Korpipää et al., 2017), and evidence from studies focusing on children's arithmetic problems (Chong & Siegel, 2008; Koponen et al., 2018; Martin et al., 2013) suggest relatively high stability also in arithmetic fluency.

To date, the only longitudinal study examining the stability of single and comorbid fluency difficulties in elementary school children (Koponen et al., 2018) showed that 68% of children with comorbid problems in second grade had corresponding difficulties two years later, while the stability rates for single reading and arithmetic problems were 46% and 39%, respectively. Furthermore, the one-year stability of comorbid problems was rather high already from second grade onward, while single difficulties showed higher stability when they were identified in third grade compared to earlier grades. Unfortunately, Koponen et al. (2018) explored reading and arithmetic fluency using single tasks, and thus, studies exploring a comprehensive battery of measures among a population-based sample of children are imperative when examining the stability of low performance in reading and arithmetic.

1.2. Cognitive skills related to dysfluency in reading and arithmetic

The predictive contribution of phonological skills (Puolakanaho et al., 2008; Ziegler et al., 2010) and rapid automatized naming (RAN; Kirby et al., 2010; Landerl et al., 2019) to reading skills and reading difficulties (Landerl et al., 2009, 2013; Van Daal et al., 2013) is well documented, and thus they are referred to here as the core predictors of reading. However, findings considering the role of general cognitive skills, such as memory functions and processing speed, in reading difficulties are more mixed. For example, verbal short-term and working memory have been found as significant predictors of reading (Landerl et al., 2013), while visuospatial memory is typically examined in the context of mathematical skills (see e.g., Allen et al., 2019). Studies focusing particularly on reading fluency have not revealed clear differences in these memory processes between children with and without reading fluency problems (Landerl et al., 2009; Van Der Sluis et al., 2005).

Regarding arithmetic difficulties, the predictive role of verbal counting skills (Zhang et al., 2020) and the processing of numerical magnitudes (Landerl et al., 2009; Schwenk et al., 2017) are well documented in the literature. Adding to these numerical core predictors, low RAN performance can be a significant risk factor for arithmetic dysfluency (Donker et al., 2016; Koponen et al., 2017), although not all studies have confirmed this finding (Landerl et al., 2009). While counting skills are essential in establishing knowledge of arithmetic facts, RAN contribution could be linked to the automatization and retrieval process of these representations (Koponen, Aro, et al., 2007). In addition to retrieval, solving a calculation task often requires storing and processing information simultaneously. Thus, working memory contributes significantly to solving arithmetic tasks (Wu et al., 2017) and accordingly, restricted memory capacity may underlie arithmetic problems (Van Daal et al., 2013; Wang et al., 2018). Especially the role of visuospatial memory in mathematical learning has been emphasized in the literature (Allen et al., 2019), but whether weakness in memorizing visuospatial information would be an explicit marker of arithmetic fluency problems is still unclear.

Although reading and arithmetic are seen as distinct domains with specific cognitive predictors, they also share a substantial amount of variation (Koponen, Aunola, et al., 2007; Korpipää et al., 2017), which is predicted by both linguistic and number processing skills (Child et al., 2018; Cirino et al., 2018; Georgiou, Inoue, & Parrila, 2021; Korpipää et al., 2017). Of the core cognitive skills, RAN and verbal counting have consistently been found to predict this shared variance in reading and arithmetic fluency among elementary school children (Cirino et al., 2018; Koponen, Aunola, et al., 2007; Korpipää et al., 2017). Also, the shared variance has been predicted by a comparison of numerical magnitudes (Cirino et al., 2018) and phonological awareness, although the predictive role of phonology seems restricted to first (Cirino et al., 2018; Korpipää et al., 2017) and second grades (Child et al., 2018). Also, more general cognitive skills, such as memory functions (Child et al., 2018; Cirino et al., 2018; Korpipää et al., 2017), seem to be associated with the covariance of reading and arithmetic, although to a lesser extent and more indirectly as compared to the core predictors.

Given the strong relationship between reading and arithmetic fluency and the cognitive skills predicting their covariance, the extent to which children with comorbid fluency problems might show weaknesses in these cognitive skills remains unclear. Although low performance in a variety of cognitive skills has been linked with comorbid reading and arithmetic difficulties (Cirino et al., 2015; Landerl et al., 2009; Willcutt et al., 2013), the role that these cognitive skills play in the background of single and comorbid fluency problems calls for further research. As the few studies focusing on fluency difficulties are largely limited to cross-sectional designs, longitudinal studies are needed in order to better understand the cognitive problems underlying persistently low reading and arithmetic fluency.

1.3. Motivational factors in children with reading and/or arithmetic difficulties

Evidence from recent studies reporting positive relations between children's self-beliefs and academic performance (Chen et al., 2018; Peura et al., 2019) and promising intervention effects for supporting children's self-efficacy beliefs (Aro et al., 2018; Koponen et al., 2021) highlights the importance of motivational factors for the development of academic skills. Certainly, academic performance is known to be associated with motivational factors, such as task-specific interest (Aunola et al., 2006), academic self-concept (Huang, 2011; Marsh & Martin, 2011), and self-efficacy (Talsma et al., 2018). Task interest reflects enjoyment experienced from engaging in a particular activity (Eccles et al., 1983), and positive emotional experiences presumably drive one to spend more time with the activity (Becker et al., 2010). Academic self-concept refers to subjective competence beliefs in a particular academic area in relation to others (Marsh, 1986; Möller et al., 2020), while self-efficacy beliefs are future-oriented judgments of one's capability to act and accomplish certain tasks (Bandura, 1997). Experiences of success and failure affect the confidence in mastering the activity (Bandura, 1997), which, in turn, influences the involvement, effort, and persistence allocated in the activity.

Regardless of the contribution of motivation to the development of academic skills, evidence on these associations in children with low reading and arithmetic skills is scarce. This evidence would be needed, since lack of interest or perceptions of poor competence emerging from early adverse experiences likely reduce the amount of skill use and practice, which may further impede skill development (Inoue et al., 2021). Research has shown that children with learning difficulties tend to have negative self-beliefs (Schuchardt et al., 2015; Zeleke, 2004) and low confidence in their abilities (Jungert & Andersson, 2013). Particularly, children, for whom reading and mathematics prove to be problematic at an early age, may be in heightened risk for developing negative perceptions of the skill or themselves as learners (Gibby-Leversuch et al., 2019). Children's ability to make realistic judgments on their capabilities develops with age (Harter, 2015), but knowledge on this development especially in children with low academic performance is still rather inconclusive.

The few studies that have investigated academic self-concept (Hanich & Jordan, 2004; Schuchardt et al., 2015) or self-efficacy beliefs (Jungert & Andersson, 2013) in children with single and comorbid difficulties in reading and math have focused on third to fifth graders, while research on younger children's self-beliefs and task interest remains absent. Further comparisons across early school years are needed as they provide novel information on whether these motivational issues manifest and develop differently in children with low performance only in reading or arithmetic, or in both domains.

1.4. The present study

The current study is part of a longitudinal research project (Reading and arithmetic dysfluency in children, 2014–2018) including five assessments of reading and arithmetic fluency, cognitive skills, and motivational factors from Grade 1 to Grade 3. The previous report of the follow-up (Koponen et al., 2020) examined the shared variance of reading and arithmetic skills in Grade 2 fall, and its cognitive predictors measured at Grade 1 with an unselected sample of children. The shared variance of reading and arithmetic fluency was strongly predicted by RAN and counting skills, while together with phonological awareness, symbolic number comparison and processing speed they almost fully explained the covariance of these academic skills.

The current study extends the understanding of reading and arithmetic fluency problems and their early identification in at least three important ways. First, groups with low fluency in reading, arithmetic, or both were identified on the basis of two Grade 3 assessment points (fall and spring), which presumably results in a more reliable identification of truly low performance than using a single assessment point. Second, we examined to what extent low reading and/or arithmetic fluency in Grade 3 could already be identifiable during the first primary school years. Third, our assessments included not only cognitive skills but also motivational factors. Examining the consistency of group differences in cognitive and motivational factors across the five assessment points allowed us to identify potential early markers indicating later single and comorbid fluency problems. Three research questions were asked in our study:

(1) To what extent third-grade children's fluency problems in reading, arithmetic or both would be identifiable in Grade 1 spring and during Grade 2?

Based on the findings of Koponen et al. (2018) suggesting that comorbid difficulties are fairly stable already from second grade onward, we expected that the level of identifiability in Grades 1 and 2 would be highest in children with both low reading, and arithmetic fluency.

(2) Do children with low fluency in reading, arithmetic, or both differ from each other or children without fluency problems in cognitive skills (RAN, phonological awareness, counting, number comparison, processing speed, verbal short-term memory, working memory, and visuospatial memory) during the two-year follow-up period?

In light of a strong relation between RAN and counting and their predictive association with reading and arithmetic covariation (Koponen et al., 2020; Korpipää et al., 2017), we expected that weaknesses in these skills would occur in all groups with low fluency. Moreover, low phonological awareness was expected to be specifically related to low reading fluency, and poor number comparison to low arithmetic fluency. Due to inconsistencies in earlier findings considering the role of more general cognitive skills (i.e., memory, processing speed) in reading and arithmetic fluency difficulties, we did not formulate any specific hypotheses about their relations with single fluency problems. In terms of the comorbid group, we expected to observe not only weaknesses in core linguistic and numerical predictors, but also low performance across general cognitive skills (Willcutt et al., 2013).

(3) How do domain-specific motivational factors (task interest, self-efficacy, and academic self-concept) differ between these four groups during the follow-up period?

Guided by the evidence on the domain-specificity of low self-beliefs (Schuchardt et al., 2015), we expected to observe low levels across the motivational factors in the domain(s) where fluency problems have been identified. As the grouping was based on children's performance scores in Grade 3, we expected to detect low domain-specific interest and self-beliefs in the three groups with low reading and/or arithmetic fluency at least by the beginning of third grade.

2. Method

2.1. Participants and procedure

In this study, the development of 197 children was followed semi-annually from Grade 1 spring to Grade 3 spring with altogether five assessment points. Table 1 presents the descriptive statistics on the children's age, gender, and their parents' educational levels. Research assistants trained in data collection conducted the assessments in schools during school hours. The participants were from six schools located in three municipalities in Central Finland. The children's caregivers were asked to provide written consent for their child to participate. The ethical statement for the project's research plan was received from the university's Ethical Committee.

Participants were divided into four groups based on their achievement scores in reading and arithmetic fluency composite scores at both the fall and spring of Grade 3. Children who scored below the cut-off score of −0.7 standard deviations below the mean (corresponding to the 25th percentile) in either reading (R_{low}, $n = 14$) or arithmetic fluency tasks (A_{low}, $n = 16$), or both (RA_{low}, $n = 25$) formed the three groups with low fluency. Children who did not meet these criteria were classified as not having low reading or arithmetic fluency (No $R_{low}A_{low}$, $n = 142$).

Despite the rather lenient cut-off score, it is noteworthy that our inclusion criterion was low performance in two consecutive assessment points in the reading and/or arithmetic composite scores. Overall, large amount of the children's scores fell below −1 SD (75% of scores of altogether 14 third grade assessment tasks among RA_{low} group; 56% of 8 reading tasks among R_{low}; 58% of 6 arithmetic tasks among A_{low}). Only one child in both A_{low} and R_{low} groups did not have any of the scores below −1 SD, their lowest scores being −0.98 and −0.99 SD.

2.2. Measures

A detailed description of the measures can be found in Supplemental materials (S1).

2.2.1. Academic outcomes

Reading fluency was assessed with four time-limited tasks: a group-administered Sentence reading task (Salmi et al., 2011) and individually administered Word list reading task (Häyrinen et al., 2013), the Pseudoword list reading task, and the Text reading task (Salmi et al.,

Table 1
Descriptive measures in groups with and without low reading and arithmetic fluency.

	No $R_{low}A_{low}$		R_{low}		A_{low}		RA_{low}	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age[a] (years)	7.78	0.28	7.85	0.25	7.76	0.31	7.77	0.30
IQ[b] (z-score)	0.19	0.95	−0.55	1.05	−0.14	1.05	−0.73	0.91
Highest parental education[c]	3.96	1.65	2.85	1.46	4.33	1.68	3.35	1.66
	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
Gender (%)	50.7	49.3	71.4	28.6	50.0	50.0	44.0	56.0

Note. Group sizes varied due to missing data in assessment points: No $R_{low}A_{low}$ = children without low reading or arithmetic fluency (n = 135–142); R_{low} = low reading fluency (n = 13–14); A_{low} = low arithmetic fluency (n = 15–16); RA_{low} = low reading and arithmetic fluency (n = 20–25).

[a] Children's age in Grade 1 spring.

[b] IQ was measured in Grade 2 fall.

[c] Parents' highest education was measured in the spring of 2017 when children were at 1st Grade.

2011). A mean of the standardized scores of these tasks was used as a reading fluency composite score at each assessment point. Cronbach's alpha reliability (α) for the composite score varied between 0.94 and 0.96 (from Grade 1 spring to Grade 3 spring). *Arithmetic fluency* was assessed with three time-limited group-administered tasks: the Addition fluency task (Koponen & Mononen, 2010a), the Subtraction fluency task (Koponen & Mononen, 2010b), and the Arithmetic fluency task (Aunola & Räsänen, 2007; from the second measurement point onward). A mean of the standardized scores from these tasks was used as an arithmetic fluency composite score (α = 0.89–0.95).

2.2.2. Core cognitive predictors of reading and arithmetic

Tasks of RAN, phonological awareness, counting, and number comparison were administered at all five measurement points. *RAN* was assessed with three tasks (objects, letters, and digits; see Denckla & Rudel, 1974). The composite score for RAN was the mean of the standardized scores of the three tasks (α = 0.83–0.84). *Phonological awareness* was measured with a phoneme and syllable deletion task (α = 0.88–0.89). *Counting* was assessed with two forward and two backward counting tasks with a time limit of 30 s. A mean of the standardized scores from these four tasks was used as a composite score (α = 0.80–0.83). *Number comparison* was measured with a computer-assisted task, in which a child was instructed to choose the larger of the two single-digit numbers varying between 2 and 9. The score was the number of correctly answered items.

2.2.3. General cognitive skills

General cognitive skills included three dimensions of memory processes and processing speed. Verbal short-term memory, working memory and visuospatial memory were assessed at all measurement points. *Verbal short-term memory* was assessed with the Forward digit span subtest (WISC–IV; Wechsler, 2010) and an analogous Word recall task created for this project. *Working memory* was assessed with Backward digit span (WISC-IV; Wechsler, 2010) and analogous Word recall tasks. The composite scores for these memory variables were based on the means of the standardized scores of the subtasks (α = 0.68–0.79 for verbal short-term memory and α = 0.57–0.70 for working memory). *Visuospatial memory* was assessed with a computerized version of the Corsi block task (Corsi, 1972). The score was the number of correct trials. *Processing speed* was assessed with the WISC–IV Symbol Search subtest (Wechsler, 2010) at all measurement points. Additionally, two tasks of identification of letters and numbers were used in Grade 2 fall and spring. All three subtasks had a time limit of 120 s. The composite score was the mean of the standardized scores of these tasks (Grade 2 fall and spring α = 0.83–0.84).

2.2.4. Motivational factors

Reading- and math-related task interest, self-efficacy, and academic self-concept were assessed at all measurement points. *Task interest* measuring children's enjoyment in reading and math activities was assessed with a computer-assisted questionnaire (α = 0.82–0.86 in reading and α = 0.88–0.92 in math). Reading and math *self-efficacy* were also assessed with a computerized questionnaire comprising questions related to everyday skills, beliefs of current knowledge, and the ability to learn reading/math (α = 0.79–0.86 in reading and α = 0.84–0.89 in math). *Academic self-concept* was assessed with an individually administered questionnaire addressing how good a child thinks he/she is in reading/math with and without comparison to other children, and experienced difficulty in reading/math (α = 0.63–0.91 in reading and α = 0.68–0.90 in math).

2.2.5. Background measures

General Intelligence was measured using the Verbal Similarities and Performance Matrix subtests of WISC-IV (Wechsler, 2010) in Grade 2 fall. The score used as a measure for IQ was the mean of the two tasks. *Parents' educational level* was asked when children were at Grade 1 with a parental questionnaire that was scored on a 7-point scale, the higher parental educational level being used as a measure of parental education.

2.3. Data analysis

Distributions of all standardized scores were normal or close to normal except for processing speed in Grade 1 spring and phonological awareness in Grade 3 spring. For processing speed, the distribution was corrected by moving three outliers to the left tail of the distribution. In phonological awareness, the distributions of raw score measures were left skewed at all measurement points, but after Box–Cox variable transformations (Osborne, 2010), they met the normality assumptions except for Grade 3 spring. There was also a ceiling effect from Grade 2 spring onward, which is common in a transparent orthography like Finnish (Ziegler et al., 2010). Thus, group comparisons of phonological awareness were not performed for the last assessment.

As a preliminary analysis, group differences in gender distribution were compared with cross-tabulation, and group differences in age, IQ, and parental educational level with ANOVA. Cross-tabulation was used to examine to what extent children's low reading and arithmetic fluency could already be identified in Grade 1 spring, Grade 2 fall, or Grade 2 spring. The low fluency levels in Grades 1 and 2 were classified using the same cut-off score as in Grade 3 ($z = -0.7$). Notably, children with RA_{low} were identified as having low reading fluency in Grades 1 and 2 since they scored below the cut-off score in reading fluency composite score. Similarly, all children scoring below the cut-off score in arithmetic fluency composite score were classified as having A_{low} difficulty. To test the accuracy of identification, Bootstrap-option in Frequency analysis was used to compare the 95% confidence intervals between identified and unidentified children separately in each of the three groups in the three measurement points.

Group differences in cognitive skills and motivational factors were analyzed with ANCOVA with IQ set as the covariate. In the case of a significant main effect of group ($p < .05$), Bonferroni corrected pairwise comparisons were used to define which groups differed significantly from each other. Means, standard deviations, and group comparisons are presented in supplemental materials (S4 and S5, cognitive skills and motivational factors, respectively). Due to the small sample sizes in R_{low}, A_{low}, and RA_{low} groups, ANCOVA results were interpreted in parallel with in pairs calculated effect sizes (*Cohen's d*, 0.20 = small; 0.50 = moderate; 0.80 = large; Cohen, 1992) using group means and standard deviations (i.e., without considering IQ as a covariate; see S6 in supplemental materials).

3. Results

Fig. 1 presents the reading and arithmetic fluency performance of the four groups at each of the five measurement points. To validate the performed grouping, two mixed design ANOVAs using time as the within-subject factor were carried out. They showed a statistically significant main effect of group in reading fluency ($F(3, 186) = 56.10$, $p < .001$) and arithmetic fluency ($F(3, 186) = 62.44$, $p < .001$) across the five measurement points from Grade 1 spring to Grade 3 spring. Pairwise comparisons ($p < .001$) revealed, as expected, that both R_{low} and RA_{low} had lower reading fluency than No $R_{low}A_{low}$ throughout the follow-up. Additionally, A_{low} outperformed RA_{low} at all assessment points and R_{low} from Grade 2 spring onward in reading fluency, while A_{low} scored lower than No $R_{low}A_{low}$ in reading fluency in Grade 2 (fall and spring) and Grade 3 spring. In arithmetic fluency, A_{low} and RA_{low} scored lower than No $R_{low}A_{low}$ at all measurement points. Also, R_{low} outperformed RA_{low} from Grade 2 spring onward and A_{low} in both Grade 3 assessments.

Group comparisons of background measures revealed a group difference in IQ ($F(3, 185) = 7.59$, $p < .001$); post hoc tests showing that No $R_{low}A_{low}$ outperformed RA_{low}. Therefore, IQ was used as a covariate in further comparisons. No differences were found in children's gender ($\chi2(3) = 2.84$, $p = .418$) or age ($F(3, 193) = 0.30$, $p = .824$). Even though there was a significant main effect of group on parents' educational level ($F(3, 179) = 2.90$, $p = .037$), post hoc tests did not reveal significant differences between any pairs of groups.

3.1. Earlier identifiability of single and comorbid fluency problems

This study aimed first to examine what proportion of children with low reading and/or arithmetic fluency in Grade 3 could already be identified at Grade 1 spring and during Grade 2. As indicated in Table 2,

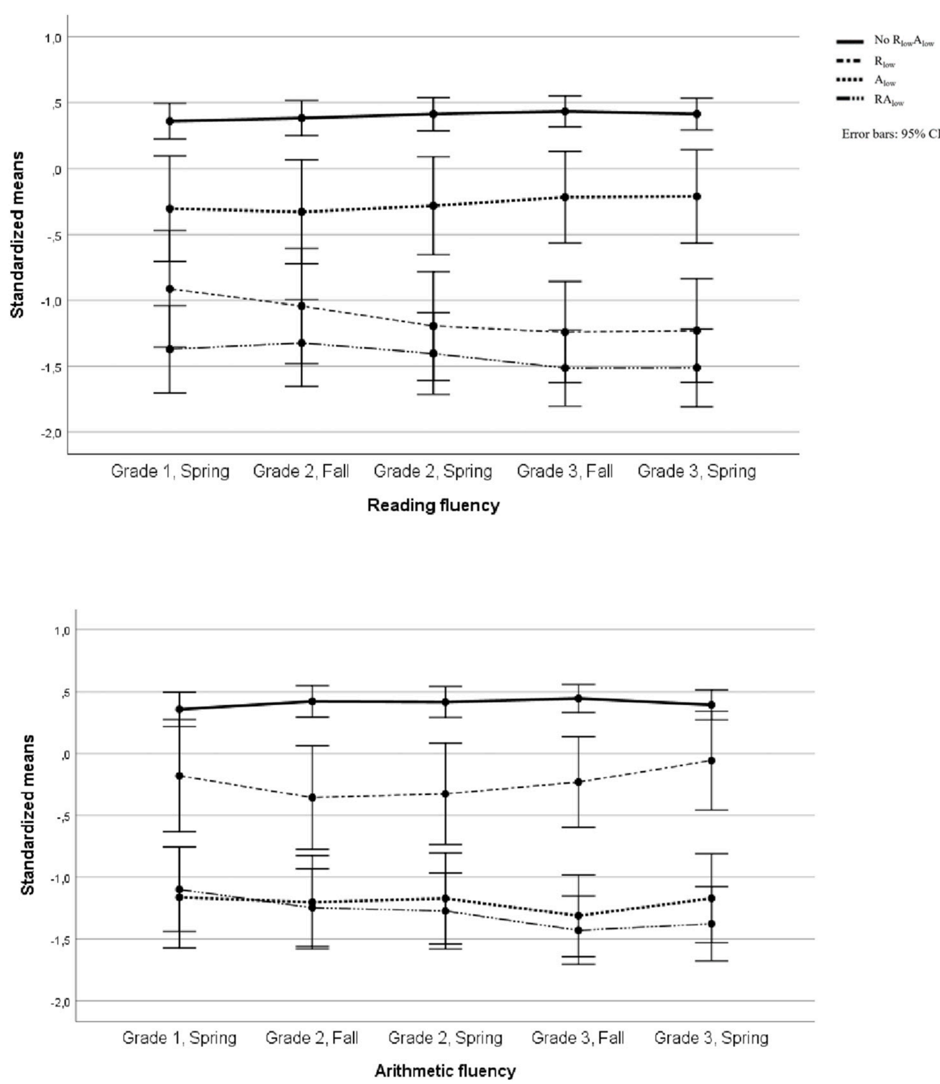

Fig. 1. Reading and arithmetic fluency development from Grade 1 to Grade 3 in the four groups.

Table 2
Percentages of 3rd grade children with correspondingly low level of fluency in grades 1 and 2.

	Grade 1 spring			Grade 2 fall			Grade 2 spring		
	%	95% CI		%	95% CI		%	95% CI	
		LL	*UL*		*LL*	*UL*		*LL*	*UL*
R_{low}									
Correctly identified	46.2	23.1	69.2	78.6	64.3	92.1	85.7	71.4	92.9
Unidentified	53.8	38.5	69.2	21.4	7.1	35.7	14.3	0	35.7
A_{low}									
Correctly identified	75.0	62.5	87.5	87.5	75.0	100	87.5	75.0	100.0
Unidentified	25.0	12.5	43.8	12.5	0	31.3	12.5	0	25.0
RA_{low}									
Correctly identified	65.2	47.8	82.6	80.0	68.0	92.0	84.0	72.0	94.2
Unidentified	34.8	21.7	47.8	20.0	8.0	32.0	16.0	8.0	28.0

Note. R_{low} = low reading fluency; A_{low} = low arithmetic fluency; RA_{low} = low reading and arithmetic fluency; CI = confidence interval; *LL* = lower limit; *UL* = upper limit.

75% of children with low arithmetic skills and 65.2% with comorbid problems showed similarly low fluency already in Grade 1 spring. Yet, only 46.2% of children with low reading fluency in Grade 3 were identified as having correspondingly low reading skills in Grade 1 spring. The level of identifiability of reading and comorbid problems increased gradually during second grade, being around 85% in Grade 2 spring, while nearly 88% of children with low arithmetic skills were identifiable in both Grade 2 assessments. Bootstrap-option in Frequency analysis showed that in the A_{low} and RA_{low} groups, the 95% confidence intervals of the percentages of identified and unidentified children did not overlap with each other at any of the assessment points, whereas in R_{low}, they did in Grade 1 spring. These results suggest that A_{low} and RA_{low} groups were already identifiable at the end of first grade, while identification of R_{low} was not reliable until the beginning of second grade.

3.2. Group differences in cognitive skills

ANCOVA analysis (see S4) showed significant group differences in all cognitive skills throughout the follow-up except for verbal short-term memory, in which group differences were significant only from Grade 2 fall onward. The proportions of significant group differences and ranges of effect sizes are summarized in Table 3. Figures in Supplemental Materials (S2) present the development of cognitive skills in the four groups across the follow-up.

3.2.1. Group differences in RAN and phonological awareness

No $R_{low}A_{low}$ outperformed all three low-performing fluency groups in RAN. The difference between RA_{low} and No $R_{low}A_{low}$ persisted across the follow-up, effect sizes being large. Although the difference between R_{low} and No $R_{low}A_{low}$ in Grade 1 spring was not yet significant, effect sizes, however, were large already from Grade 1 spring onward. The A_{low} group was slower in RAN than No $R_{low}A_{low}$ until Grade 3 fall, and effect sizes were large or close to large throughout the follow-up.

Phonological awareness was consistently weaker in RA_{low} compared to No $R_{low}A_{low}$, effect sizes being large. A_{low} showed significantly lower scores than No $R_{low}A_{low}$ in Grade 2 spring and Grade 3 fall with moderate to large effect sizes across the follow-up. Even though there were no significant differences between R_{low} and other groups, effect sizes between R_{low} and No $R_{low}A_{low}$ varied from moderate to large from Grade 2 fall to Grade 3 fall.

To conclude, the three groups with low reading and/or arithmetic fluency had slower naming speed than the No $R_{low}A_{low}$ throughout the follow-up period. With respect to phonological awareness, only the RA_{low} performed consistently lower than the No $R_{low}A_{low}$.

3.2.2. Group differences in counting and number comparison

In counting, both RA_{low} and A_{low} groups performed weaker than No $R_{low}A_{low}$ throughout the follow-up. Effect sizes between RA_{low} and No $R_{low}A_{low}$ were large across the follow-up except for Grade 2 fall. Effect sizes between A_{low} and No $R_{low}A_{low}$ were also large. R_{low} scored significantly lower than No $R_{low}A_{low}$ only in Grade 2 spring, but the effect sizes were moderate to large across the follow-up period.

Number comparison was significantly lower in RA_{low} and A_{low} groups compared to No $R_{low}A_{low}$ across all grades, and the effect sizes were large. R_{low} scored significantly lower than No $R_{low}A_{low}$ only in

Table 3
Proportions of significant group differences and effect sizes in cognitive skills between the four groups.

	No $R_{low}A_{low}$ vs. R_{low}		No $R_{low}A_{low}$ vs. A_{low}		No $R_{low}A_{low}$ vs. RA_{low}		R_{low} vs. A_{low}		R_{low} vs. RA_{low}		A_{low} vs. RA_{low}	
	Pr	ES	Pr	ES	Pr	ES	Pr	ES	Pr	ES	Pr	ES
RAN	4/5	0.94–1.41	4/5	0.71–1.09	5/5	1.52–1.76	0/5	0.03–0.41	0/5	0.34–0.71	0/5	0.57–0.81
Phonological awareness[a]	0/4	0.45–0.85	2/4	0.68–0.93	4/4	1.28–1.35	0/4	0.13–0.32	0/4	0.51–0.86	0/4	0.40–0.73
Counting	1/5	0.68–0.98	5/5	0.76–0.99	5/5	1.26–1.51	0/5	0.02–0.31	0/5	0.47–1.06	0/5	0.38–0.82
Number comparison	1/5	0.40–1.20	5/5	1.00–1.31	5/5	0.85–1.56	0/5	0.15–0.66	0/5	0.28–0.97	0/5	0.14–0.53
Processing speed	0/5	0.28–0.55	5/5	0.81–1.35	5/5	1.04–1.51	2/5	0.39–0.99	3/5	0.64–1.09	0/5	0.14–0.34
Verbal short-term memory	0/5	0.09–0.30	0/5	0.35–0.65	3/5	0.75–1.01	0/5	0.12–0.74	1/5	0.51–0.90	0/5	0.11–0.59
Working memory	0/5	0.18–0.52	2/5	0.70–0.79	4/5	0.73–1.16	0/5	0.29–0.68	0/5	0.51–1.11	0/5	0.01–0.50
Visuospatial memory	0/5	0.04–0.86	4/5	0.69–1.07	1/5	0.46–0.83	1/5	0.17–1.12	0/5	0.04–0.57	0/5	0.16–0.61

Note. Proportions (Pr) represent the number of time points when the two contrasted groups differed significantly from each other. Effect sizes (ES) are presented from the smallest to the largest between the two contrasted groups. No $R_{low}A_{low}$ = children without low reading or arithmetic fluency; R_{low} = low reading fluency; A_{low} = low arithmetic fluency; RA_{low} = low reading and arithmetic fluency.

[a] Since the phonological awareness measure at Grade 3 spring did not meet the normality assumption and was no longer appropriate for statistical analyses, group comparisons were carried out only until the Grade 3 fall.

Grade 2 spring. The respective effect size was large, as it was also in Grade 1 spring.

To summarize, both groups with low arithmetic fluency showed consistently low levels in counting and number comparison, while moderate to large effect sizes in counting between R_{low} and No $R_{low}A_{low}$ indicated consistently lower counting also in the R_{low} group.

3.2.3. Group differences in general cognitive skills

In processing speed, pairwise comparisons revealed that both RA_{low} and A_{low} scored lower than No $R_{low}A_{low}$ across all grades with effect sizes being large. In addition, RA_{low} performed weaker than R_{low} from Grade 2 fall to Grade 3 fall, and A_{low} scored lower than R_{low} across Grade 2.

Also, in working memory, RA_{low} showed consistently lower scores than No $R_{low}A_{low}$ except for Grade 2 spring, effect sizes at these four assessment points being large. In addition, A_{low} scored lower than No $R_{low}A_{low}$ in Grade 2 fall and Grade 3 spring with moderate effect sizes. Even though pairwise comparisons did not show differences between RA_{low} and R_{low} in working memory, effect sizes between the groups were moderate or large. In verbal short-term memory, RA_{low} underperformed No $R_{low}A_{low}$ in Grade 2 and Grade 3 spring, though the effect sizes were large or close to large throughout the follow-up.

Visuospatial memory was significantly and consistently lower in A_{low} compared to No $R_{low}A_{low}$, except for Grade 2 fall. The effect sizes in the four assessment points were large. In Grade 2 fall, RA_{low} showed the lowest score being significantly different from No $R_{low}A_{low}$. Otherwise, effect sizes between RA_{low} and No $R_{low}A_{low}$ varied from small to moderate.

In conclusion, poor performance in processing speed and working memory were related to the two groups with low arithmetic fluency, while lowest scores in verbal short-term memory were observed in the RA_{low} group, and consistently low visuospatial memory, in turn, characterized the A_{low} group.

3.3. Group differences in reading-related motivational factors

In reading self-efficacy, group differences were significant across the follow-up. Similarly, in reading self-concept, differences occurred throughout the study except for Grade 2 fall. In reading interest, differences were observed only in Grade 3 fall. The proportions of significant differences and ranges of effect sizes are summarized in Table 4, and figures in Supplemental Materials present the development of motivational factors in the four groups.

Pairwise comparisons revealed that RA_{low} had lower reading self-efficacy than No $R_{low}A_{low}$ throughout the follow-up, effect sizes being large. Moreover, RA_{low} showed lower scores than A_{low} during Grade 3 and R_{low} in Grade 3 fall. Self-efficacy of R_{low} in turn was lower than No $R_{low}A_{low}$ in Grade 2 fall, whereas the effect sizes varied from moderate to large. For reading self-concept, R_{low} and RA_{low} had significantly lower self-beliefs than No $R_{low}A_{low}$ and A_{low} in Grade 1 spring and Grade 3, including that RA_{low} differed significantly from these two groups also in Grade 2 spring. The effect sizes between the groups varied from moderate to large. Only significant group differences in reading interest were observed in Grade 3 fall, A_{low} showing higher interest in reading than R_{low} and RA_{low}.

Overall, the two groups with low reading fluency had low reading self-concept across the follow-up. Reading self-efficacy in turn was consistently low in RA_{low} group, while effect sizes indicated low reading self-efficacy also in R_{low} group. No systematic differences were observed for reading interest.

3.4. Group differences in math-related motivational factors

Group differences in math self-efficacy were significant across the measurement points and in math self-concept from Grade 2 fall onward. Differences in math interest were significant in Grade 1 spring and Grade 2 fall.

Compared to the No $R_{low}A_{low}$, A_{low} showed lower math self-efficacy throughout the study, while differences to RA_{low} were significant from Grade 2 fall onward. Effect sizes were large or close to large throughout the follow-up. In addition, A_{low} had lower math self-efficacy than R_{low} in Grade 2 spring, and RA_{low} scored lower than R_{low} in Grade 3 fall. In math self-concept, A_{low} had significantly lower self-beliefs than No $R_{low}A_{low}$ from Grade 2 fall onward, while RA_{low} had lower self-beliefs than No $R_{low}A_{low}$ only in Grade 3. In addition, in Grade 2 spring A_{low} had lower math self-concept compared to R_{low}, and the effect sizes were large or close to large already from Grade 2 fall onward. Although the differences between RA_{low} and R_{low} were not significant, the effect sizes were moderate or large in Grade 3. The only significant differences in math interest were found between A_{low} and No $R_{low}A_{low}$ in Grade 1 spring and A_{low} and R_{low} in Grade 2 fall.

To conclude, math self-efficacy was found to be consistently low in both groups with low arithmetic fluency. Math self-concept in turn was repeatedly low in A_{low} group, while in the RA_{low} group the level of math self-concept declined after the beginning of second grade being similarly low at third grade as in the A_{low} group. No systematic differences were found for math interest.

4. Discussion

4.1. Earlier identifiability of single and comorbid fluency problems

The stability of single and comorbid difficulties has usually been examined prospectively using a single assessment point for identifying low performing groups (e.g., Chong & Siegel, 2008; Eklund et al., 2015; Koponen et al., 2018). Here, a longitudinal approach with double-occurrence criteria was used to examine the extent to which third graders' low reading and arithmetic fluency could already be identified at earlier grades. Partially in line with our expectations, the results revealed that the majority of children with arithmetic and comorbid fluency problems at Grade 3 were already identifiable at Grade 1 spring, whereas children with low reading fluency were reliably identified from the beginning of second grade.

Table 4
Proportions of significant group differences and effect sizes in motivational factors between the four groups.

	No $R_{low}A_{low}$ vs. R_{low}		No $R_{low}A_{low}$ vs. A_{low}		No $R_{low}A_{low}$ vs. RA_{low}		R_{low} vs. A_{low}		R_{low} vs. RA_{low}		A_{low} vs. RA_{low}	
	Pr	ES	Pr	ES	Pr	ES	Pr	ES	Pr	ES	Pr	ES
Reading interest	0/5	0.11–0.72	0/5	0.00–0.46	0/5	0.37–0.74	1/5	0.11–1.10	0/5	0.02–0.35	1/5	0.24–1.12
Reading self-efficacy	1/5	0.63–1.02	0/5	0.07–0.74	5/5	0.89–1.82	0/5	0.07–0.87	1/5	0.14–1.01	2/5	0.16–1.07
Reading self-concept	3/5	0.66–1.64	0/5	0.00–0.70	4/5	0.61–1.52	3/5	0.85–1.98	0/5	0.05–0.17	4/5	0.82–1.41
Math interest	0/5	0.00–0.36	1/5	0.31–0.81	0/5	0.15–0.52	1/5	0.40–1.28	0/5	0.14–1.04	0/5	0.07–0.49
Math self-efficacy	0/5	0.01–0.43	5/5	0.79–1.06	4/5	0.60–1.42	1/5	0.37–1.07	1/5	0.41–1.42	0/5	0.00–0.49
Math self-concept	0/5	0.04–0.14	4/5	0.44–1.12	2/5	0.04–0.96	1/5	0.46–0.95	0/5	0.08–0.86	1/5	0.06–0.84

Note. Proportions (Pr) represent the number of time points when the two contrasted groups differed significantly from each other. Effect sizes (ES) are presented from the smallest to the largest between the two contrasted groups. No $R_{low}A_{low}$ = children without low reading or arithmetic fluency; R_{low} = low reading fluency; A_{low} = low arithmetic fluency; RA_{low} = low reading and arithmetic fluency.

One possible explanation for the finding that reading fluency problems were less reliably identifiable in first grade compared to low arithmetic fluency could be related to early reading instruction in Finnish, which strongly emphasizes rule-based serial phonemic assembly. Albeit most of the Finnish children learn accurate decoding during the first grade (Seymour et al., 2003), they tend to rely on a letter-by-letter reading strategy emphasizing accuracy instead of fluency. Indeed, long polysyllabic words, resulting from the complex agglutinative morphology of Finnish (Aro, 2017), do not support quick acquisition of reading fluency. The code-based approach in early reading instruction might mask early individual differences in reading fluency (see also Wimmer, 1993), which likely become more visible when instructional focus moves from code to meaning, and to learning by reading.

The finding that more than half of our children with low reading fluency remained unidentified at the end of the first grade suggests that the stability of individual differences starts to emerge later in reading as compared to arithmetic and comorbid difficulties. This view supports previous longitudinal studies that have reported divergent developmental trajectories in reading fluency (Eklund et al., 2015; Torppa et al., 2015), suggesting that fluency problems may emerge only after the early school years. The shift from code-based reading instruction toward increased amount of texts and reading comprehension likely challenges children whose reading skills are no longer sufficient to cope with the increased reading demands.

Overall, these findings underline the inter-individual variation, particularly in reading fluency development, highlighting the need to monitor skill development throughout and even after the early grades. In contrast, high level of early identifiability found for low arithmetic fluency suggests that first graders' low arithmetic skills already indicate persistent challenges in math development and thus justifies intensive and targeted support for basic calculation skills from early on.

4.2. Cognitive skills related to low reading and arithmetic fluency

Earlier studies on comorbid reading and arithmetic problems have suggested that deficits in RAN and phonological awareness are uniquely related to reading difficulties (Landerl et al., 2009; Van Daal et al., 2013), while arithmetic difficulties are characterized by problems in numerical skills (Landerl et al., 2009), and the cognitive deficits in children with comorbid reading and math problems seem to follow an additive pattern (Landerl et al., 2009; Van Der Sluis et al., 2005; Willcutt et al., 2013). Findings on general cognitive skills related to single difficulties have been more mixed, while there is consistent evidence that children with comorbid difficulties show weaknesses not only in the core predictors of reading and arithmetic but also in verbal memory (Landerl et al., 2009; Van Daal et al., 2013; Van Der Sluis et al., 2005;Wang et al., 2018; Willcutt et al., 2013) and processing speed tasks (Wang et al., 2018; Willcutt et al., 2013).

Findings from the present study suggest that cognitive profiles related to reading and arithmetic fluency problems are partially overlapping. All three groups with low fluency performed consistently low in RAN and counting, which was already observable at the end of the first school year. Indeed, RAN and counting have been shown to predict both reading and arithmetic fluency (Koponen et al., 2016) and their shared covariance (Georgiou, Inoue, & Parrila, 2021; Koponen et al., 2020; Korpipää et al., 2017). Current results further indicate that inefficient serial retrieval of verbal information could be a common risk factor for fluency problems in both domains. Also, Van Daal et al. (2013) reached a similar conclusion, as in their study, the overlap of reading and arithmetic problems was accounted for by tasks requiring rapid processing of verbal and numerical information.

Despite these similarities, however, the groups showed different weaknesses in the other cognitive skills during the follow-up, further providing useful information regarding the early identification of children at risk for persistent fluency problems. According to the present results, weak decoding skills together with below-average levels in naming speed and counting seem early markers of persistently low reading fluency. Although weak phonological awareness is considered as a central risk factor for reading difficulties, it did not come up as a clear indicator of problems in the R_{low} group. This finding could be related to the transparent orthography, where phonological skills predict especially the early phase of reading acquisition, i.e., accuracy rather than fluency (Georgiou et al., 2012; Landerl & Wimmer, 2008; Puolakanaho et al., 2008), but not later reading fluency (Landerl et al., 2019). However, the RA_{low} group had lower phonological awareness than R_{low}, while their reading fluency was at the same level. Thus, the missing relation cannot be fully explained with the predictive link of phonology to early reading skills. The difference could be related to the lower working memory capacity observed in the RA_{low} group, which may have influenced tasks that require manipulating a word by deleting a specific phoneme or syllable. However, the extent to which working memory could affect phonological awareness requires further evidence. Regarding absence of significant group differences in memory measures and processing speed between the R_{low} and No $R_{low}A_{low}$ groups, our results suggest that these skills may play a less prominent role in children with problems only in reading. However, for example working memory and processing speed might contribute differently to other components of reading, such as reading comprehension, which in turn has different cognitive demands (Cirino et al., 2018; Torppa et al., 2007).

Well in line with our expectations and previous literature (Landerl et al., 2009; Schwenk et al., 2017), low performance in comparison of numerical magnitudes was clearly related to low arithmetic fluency. Together with below-age-level counting skills and RAN, these problems could indicate the need for closer monitoring of children's arithmetic development. In addition, low levels in processing speed and working memory, the latter requiring not only storing information but also executive control, characterized the groups with low arithmetic fluency. Weaknesses that children with low arithmetic skills show in working memory and processing speed could hinder efficient information processing needed in mental calculation tasks. For example, these arithmetic problems typically require rapid processing of information presented with visual symbols (written numbers and arithmetic operators), retrieval of arithmetic facts and holding them in mind while actively working toward the final answer (e.g., Imbo & Vandierendonck, 2007). The result that only the A_{low} group showed consistently low scores in visuospatial memory indicates a specific association between spatial and mathematical skills, which is well in accord with recently reported findings (see Allen et al., 2019, for a review). However, studies examining visuospatial memory in children with reading and/or arithmetic fluency problems have not reported very clear-cut results. Our results were in line with those of Van Der Sluis et al. (2005), who observed lowest visuospatial memory in children with low arithmetic skills only, while in contrast, Landerl et al. (2009) reported that memorizing visual information was weakest in the comorbid group. While previous literature has proposed that cognitive weaknesses related to comorbid problems would be an additive combination of those related to separate reading and math difficulties (Landerl et al., 2009; Willcutt et al., 2013), the current finding rather reflects a possibility for different subtypes of arithmetic problems with different cognitive characteristics.

Finally, the most concerning observations were related to the RA_{low} group showing consistently low levels in most of cognitive areas included in the present study, even though the effect of IQ was controlled for. Further, this group's weak verbal short-term memory indicates that even storing verbal information—without the requirement of its concurrent manipulation—is problematic when the difficulties co-occur. Due to the high stability of comorbid reading and arithmetic difficulties (Koponen et al., 2018), early emerging problems in academic skills and various areas of cognitive performance are strong signs indicating the need for early support and monitoring of the development of both reading and math skills.

4.3. Motivational factors related to low reading and arithmetic fluency

Academic self-beliefs are context- and domain-specific (Bandura, 1997; Marsh, 1986; Möller et al., 2020; Schöber et al., 2018; Susperreguy et al., 2018) already among elementary school children (Ehm et al., 2014), and children with learning difficulties tend to be at greater risk of having more negative academic self-beliefs than their peers without such difficulties (Hanich & Jordan, 2004; Zeleke, 2004). Present findings support these earlier findings and our expectations on domain-specific associations, showing that children with R_{low}, A_{low} and RA_{low} expressed low self-efficacy beliefs and academic self-concept consistently in the domain they showed low fluency. In other words, at this age single difficulties in either reading or arithmetic skills do not seem to reflect negatively on self-beliefs in the other skill. Similar pattern was observed with regard to task interest, although group differences reached significance only at a few assessment points.

Adding to domain-specificity, low self-efficacy and academic self-concept became apparent by the spring of second grade at the latest. While reading self-concept was similarly low in the R_{low} and RA_{low} groups across the follow-up, low math self-beliefs emerged differently in groups with low arithmetic fluency: RA_{low} showed clearly low mathematical self-concept only by Grade 3 fall, while it was consistently low in the A_{low} group already from the beginning of Grade 2. Since academic self-concept reflects competence perceptions in relation to others, as well as intra-individual comparisons between different academic subjects (Marsh, 1986; Möller et al., 2020), later appearing low math self-concept in the RA_{low} group could be explained through these comparison processes and subject-specific instructional differences. As reading is often instructed through tasks that involve reading aloud, children have likely received plenty of corrective feedback in reading activities that, together with social comparison, could make differences in reading skills observable for learners earlier than in math.

Although the RA_{low} group showed clearly low self-beliefs in both domains by third grade, the level of these self-beliefs was not substantially lower than in groups with single problems in reading or arithmetic. Thus, comorbidity does not necessarily induce more severe negative beliefs of oneself as a learner. In light of seemingly negative mathematical self-beliefs of the A_{low} group, future research should continue to investigate the interplay between mathematical self-beliefs and arithmetic development, especially when there is a risk for persistent problems.

4.4. Limitations

There are some limitations to consider when interpreting the results of this study. First, group sizes in the three groups with low fluency were rather small, which affects the statistical power of the analyses. To avoid Type II error (i.e., incorrectly rejecting a true group difference), we viewed the results of covariance analysis in parallel with in pairs calculated effect sizes. The level of observed power was repeatedly low in group comparisons related to verbal short-term memory and task interest (<0.80; see S4 and S5 in Supplemental materials) due to limited sample sizes. Therefore, the possibility of failing to detect existing differences cannot be ruled out, which is suggested by moderate or even large effect sizes found between the groups.

Second, group classification was based on a lenient cut-off criterion of -0.7 standard deviation below the mean that roughly corresponds to the 25th percentile. Therefore, children who met the criteria were described as having low reading and/or arithmetic fluency rather than deficits or disabilities. However, using the double-occurrence criterion increased the reliability of identification compared to using a single cut-off point only. As setting cut-offs is always somewhat arbitrary, and categorizing continuous variables has certain limitations, such as losing information and reducing power, future studies examining individual differences in reading and arithmetic development might advantage from applying dimensional approaches with continuous data. However, complex modelling was not feasible in the current study due to limited sample size and large number of examined factors of interest.

Third, performance in the phonological awareness measure was close to ceiling, which is typical and hard to avoid in a transparent orthography. This might have contributed to the finding that phonological awareness did not have a clear association with the R_{low} group. The predictive power of phonological skills on reading is smaller in languages with a transparent orthography than in those with a more irregular writing system (Landerl et al., 2019; Ziegler et al., 2010), and seems restricted to accuracy rather than fluency (Puolakanaho et al., 2008). Final limitation concerns interpretation of group differences in general cognitive skills while IQ has been controlled for. Probable overlap between IQ and tasks assessing memory and processing speed needs to be acknowledged since they assess partly similar information processing skills.

5. Conclusions

This study examined earlier identifiability of third graders' low reading and/or arithmetic fluency and early cognitive and motivational characteristics related to these fluency problems. The results suggest that low arithmetic fluency, with and without reading fluency problems, seem to be reliably identifiable by the end of the first grade, while low reading fluency becomes more apparent only from the beginning of the second school year. Consistent with the studies examining the covariance and predictors of reading and arithmetic fluency, low performance in RAN and counting appeared to be characteristic to all the three groups with fluency problems. Although the comorbid group had consistently low performance in a broader set of cognitive skills, it did not seem to be reflected on their reading- and math-related self-beliefs and interest, as they were not substantially lower than in children with either low reading or arithmetic fluency. However, all these three groups showed low domain-specific self-efficacy and self-concept already by the end of second grade, which underlines the importance of supporting their self-beliefs alongside academic skills. In light of the current findings, close attention should be paid especially to supporting children with comorbid problems, as they seem to have not only weaknesses in several cognitive skills, but also low self-beliefs in both reading and math.

Declaration of competing interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lindif.2022.102160.

References

Allen, K., Higgins, S., & Adams, J. (2019). The relationship between visuospatial working memory and mathematical performance in school-aged children: A systematic review. *Educational Psychology Review, 31*, 509–553. https://doi.org/10.1007/s10648-019-09470-8

Aro, M. (2017). Learning to read Finnish. In L. Verhoeven, & C. Perfetti (Eds.), *Learning to read across languages and writing systems* (pp. 416–436). Cambridge University Press.

Aro, T., Viholainen, H., Koponen, T., Peura, P., Räikkönen, E., Salmi, P., Sorvo, R., & Aro, M. (2018). Can reading fluency and self-efficacy of reading be enhanced with an intervention targeting the sources of self-efficacy? *Learning and Individual Differences, 67*, 53–66. https://doi.org/10.1016/j.lindif.2018.06.009

Aunola, K., & Räsänen, P. (2007). *The basic arithmetic test.* Jyväskylä, Finland: University of Jyväskylä.

Aunola, K., Leskinen, E., & Nurmi, J.-E. (2006). Developmental dynamics between mathematical performance, task motivation, and teachers' goals during the transition to primary school. *British Journal of Educational Psychology, 76*(1), 21–40. https://doi.org/10.1348/000709905X51608

Bandura, A. (1997). *Self-efficacy: The exercise of control.* Freeman.

Becker, M., McElvany, N., & Kortenbruck, M. (2010). Intrinsic and extrinsic reading motivation as predictors of reading literacy: A longitudinal study. *Journal of Educational Psychology, 102*(4), 773–785. https://doi.org/10.1037/a0020084

Carr, M., & Alexeev, N. (2011). Fluency, accuracy, and gender predict developmental trajectories of arithmetic strategies. *Journal of Educational Psychology, 103*(3), 617–631. https://doi.org/10.1037/a0023864

Chen, L., Bae, S. R., Battista, C., Qin, S., Chen, T., Evans, T. M., & Menon, V. (2018). Positive attitude toward math supports early academic success: Behavioral evidence and neurocognitive mechanisms. *Psychological Science, 29*(3), 390–402. https://doi.org/10.1177/0956797617735528

Child, A. E., Cirino, P. T., Fletcher, J. M., Willcutt, E. G., & Fuchs, L. S. (2018). A cognitive dimensional approach to understanding shared and unique contributions to reading, math, and attention skills. *Journal of Learning Disabilities, 52*(1), 15–30. https://doi.org/10.1177/0022219418775115

Chong, S. L., & Siegel, L. S. (2008). Stability of computational deficits in math learning disability from second through fifth grades. *Developmental Neuropsychology, 33*(3), 300–317. https://doi.org/10.1080/87565640801982387

Cirino, P. T., Fuchs, L. S., Elias, J. T., Powell, S. R., & Schumacher, R. F. (2015). Cognitive and mathematical profiles for different forms of learning difficulties. *Journal of Learning Disabilities, 48*(2), 156–175. https://doi.org/10.1177/0022219413494239

Cirino, P. T., Child, A. E., & Macdonald, K. T. (2018). Longitudinal predictors of the overlap between reading and math skills. *Contemporary Educational Psychology, 54*, 99–111. https://doi.org/10.1016/j.cedpsych.2018.06.002

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112*(1), 155–159. https://doi.org/10.1037//0033-2909.112.1.155

Corsi, P. M. (1972). *Human memory and the medial temporal region of the brain.* Unpublished doctoral dissertation. Montreal, QC: McGill University.

Denckla, M. B., & Rudel, R. (1974). Rapid "automatized" naming of pictured objects, colors, letters and numbers by normal children. *Cortex, 10*(2), 186–202. https://doi.org/10.1016/S0010-9452(74)80009-2

Donker, M., Kroesbergen, E., Slot, E., Van Viersen, S., & De Bree, E. (2016). Alphanumeric and non-alphanumeric rapid automatized naming in children with reading and/or spelling difficulties and mathematical difficulties. *Learning and Individual Differences, 47*, 80–87. https://doi.org/10.1016/j.lindif.2015.12.011

Eccles, J. S., Adler, T. F., Futterman, R., Goff, S. B., Kaczala, C. M., Meece, J. L., et al. (1983). Expectancies, values, and academic behaviors. In J. T. Spence (Ed.), *Achievement and achievement motives* (pp. 75–146). San Francisco: Freeman.

Ehm, J., Lindberg, S., & Hasselhorn, M. (2014). Reading, writing, and math self-concept in elementary school children: Influence of dimensional comparison processes. *European Journal of Psychology of Education, 29*(2), 277–294. https://doi.org/10.1007/s10212-013-0198-x

Eklund, K., Torppa, M., Aro, M., Leppänen, P. H. T., & Lyytinen, H. (2015). Literacy skill development of children with familial risk for dyslexia through grades 2, 3, and 8. *Journal of Educational Psychology, 107*(1), 126–140. https://doi.org/10.1037/a0037121

Geary, D. C. (1993). Mathematical disabilities: Cognitive, neuropsychological, and genetic components. *Psychological Bulletin, 114*(2), 345–362. https://doi.org/10.1037/0033-2909.114.2.345

Georgiou, G. K., Torppa, M., Manolitsis, G., Lyytinen, H., & Parrila, R. (2012). Longitudinal predictors of reading and spelling across languages varying in orthographic consistency. *Reading and Writing, 25*(2), 321–346. https://doi.org/10.1007/s11145-010-9271-x

Georgiou, G., Inoue, T., Papadopoulos, T., & Parrila, R. (2021a). Examining the growth trajectories and cognitive predictors of reading in a consistent orthography: Evidence from a 10-year longitudinal study. *Applied PsychoLinguistics, 42*(5), 1287–1311. https://doi.org/10.1017/S0142716421000321

Georgiou, G., Inoue, T., & Parrila, R. (2021b). Do reading and arithmetic fluency share the same cognitive base? *Frontiers in Psychology, 12*, 3161. https://doi.org/10.3389/fpsyg.2021.709448

Gibby-Leversuch, R., Hartwell, B. K., & Wright, S. (2019). Dyslexia, literacy difficulties and the self-perceptions of children and young people: A systematic review. *Current Psychology*. https://doi.org/10.1007/s12144-019-00444-1

Hanich, L. B., & Jordan, N. C. (2004). Achievement-related beliefs of third-grade children with mathematics and reading difficulties. *The Journal of Educational Research, 97*(5), 227–233. https://doi.org/10.3200/JOER.97.5.227-234

Harter, S. (2015). *The construction of the self: Developmental and sociocultural foundations*. Guilford Publications.

Häyrinen, T., Serenius-Sirve, S., & Korkman, M. (2013). *Lukilasse 2. Lukemisen, kirjoittamisen ja laskemisen seulontatesti 1.-6. vuosiluokille [Lukilasse 2. Screening test for reading, writing, and counting in grades 1-6]. Hogrefe Psykologien Kustannus Oy*.

Huang, C. (2011). Self-concept and academic achievement: A meta-analysis of longitudinal relations. *Journal of School Psychology, 49*(5), 505–528. https://doi.org/10.1016/j.jsp.2011.07.001

Hudson, R. F., Pullen, P. C., Lane, H. B., & Torgesen, J. K. (2008). The complex nature of reading fluency: A multidimensional view. *Reading & Writing Quarterly, 25*(1), 4–32. https://doi.org/10.1080/10573560802491208

Imbo, I., & Vandierendonck, A. (2007). The development of strategy use in elementary school children: Working memory and individual differences. *Journal of Experimental Child Psychology, 96*(4), 284–309. https://doi.org/10.1016/j.jecp.2006.09.001

Inoue, T., Georgiou, G., Maekawa, H., & Parrila, R. (2021). Cultural influences on the relationship between self-concept, interest, task-focused behavior, and reading skills. *Journal of Cultural Cognitive Science, 5*, 311–323. https://doi.org/10.1007/s41809-020-00071-4

Jungert, T., & Andersson, U. (2013). Self-efficacy beliefs in mathematics, native language literacy and foreign language amongst boys and girls with and without mathematic difficulties. *Scandinavian Journal of Educational Research, 57*(1), 1–15. https://doi.org/10.1080/00313831.2011.621140

Kirby, J. R., Georgiou, G. K., Martinussen, R., & Parrila, R. (2010). Naming speed and reading: From prediction to instruction. *Reading Research Quarterly, 45*(3), 341–362. https://doi.org/10.1598/RRQ.45.3.4

Koponen, T., & Mononen, R. (2010). *The 2-minute addition fluency test*. Unpublished.

Koponen, T., & Mononen, R. (2010). *The 2-minute subtraction fluency test*. Unpublished.

Koponen, T., Aro, T., Räsänen, P., & Ahonen, T. (2007a). Language-based retrieval difficulties in arithmetic: A single case intervention study comparing two children with SLI. *Educational and Child Psychology, 24*(2), 98–107.

Koponen, T., Aunola, K., Ahonen, T., & Nurmi, J.-E. (2007b). Cognitive predictors of single-digit and procedural calculation skills and their covariation with reading skill. *Journal of Experimental Child Psychology, 97*(3), 220–241. https://doi.org/10.1016/j.jecp.2007.03.001

Koponen, T., Salmi, P., Torppa, M., Eklund, K., Aro, T., Aro, M., Poikkeus, A.-M., Lerkkanen, M.-K., & Nurmi, J.-E. (2016). Counting and rapid naming predict the fluency of arithmetic and reading skills. *Contemporary Educational Psychology, 44–45*, 83–94. https://doi.org/10.1016/j.cedpsych.2016.02.004

Koponen, T., Georgiou, G., Salmi, P., Leskinen, M., & Aro, M. (2017). A meta-analysis of the relation between RAN and mathematics. *Journal of Educational Psychology, 109*(7), 977–992. https://doi.org/10.1037/edu0000182

Koponen, T., Aro, M., Poikkeus, A.-M., Niemi, P., Lerkkanen, M.-K., Ahonen, T., & Nurmi, J.-E. (2018). Comorbid fluency difficulties in reading and math: Longitudinal stability across early grades. *Exceptional Children, 84*(3), 298–311. https://doi.org/10.1177/0014402918756269

Koponen, T., Eklund, K., Heikkilä, R., Salminen, J., Fuchs, L., Fuchs, D., & Aro, M. (2020). Cognitive correlates of the covariance in reading and arithmetic fluency: Importance of serial retrieval fluency. *Child Development, 91*(4), 1063–1080.

Koponen, T., Aro, T., Peura, P., Leskinen, M., Viholainen, H., & Aro, M. (2021). Benefits of integrating an explicit self-efficacy intervention with calculation strategy training for low-performing elementary students. *Frontiers in Psychology, 12*, Article 714379. https://doi.org/10.3389/fpsyg.2021.714379

Korpipää, H., Koponen, T., Aro, M., Tolvanen, A., Aunola, K., Poikkeus, A.-M., Lerkkanen, M.-K., & Nurmi, J.-E. (2017). Covariation between reading and arithmetic skills from grade 1 to grade 7. *Contemporary Educational Psychology, 51*, 131–140. https://doi.org/10.1016/j.cedpsych.2017.06.005

Landerl, K., & Moll, K. (2010). Comorbidity of learning disorders: Prevalence and familial transmission. *Journal of Child Psychology and Psychiatry, 51*(3), 287–294. https://doi.org/10.1111/j.1469-7610.2009.02164.x

Landerl, K., & Wimmer, H. (2008). Development of word reading fluency and spelling in a consistent orthography: An 8-year follow-up. *Journal of Educational Psychology, 100*(1), 150–161. https://doi.org/10.1037/0022-0663.100.1.150

Landerl, K., Fussenegger, B., Moll, K., & Willburger, E. (2009). Dyslexia and dyscalculia: Two learning disorders with different cognitive profiles. *Journal of Experimental Child Psychology, 103*(3), 309–324. https://doi.org/10.1016/j.jecp.2009.03.006

Landerl, K., Ramus, F., Moll, K., Lyytinen, H., Leppänen, P. H. T., Lohvansuu, K., O'Donovan, M., Williams, J., Bartling, J., Bruder, J., Kunze, S., Neuhoff, N., Tóth, D., Honbolygó, F., Csépe, V., Bogliotti, C., Iannuzzi, S., Chaix, Y., Démonet, J., & Schulte-Körne, G. (2013). Predictors of developmental dyslexia in European orthographies with varying complexity. *Journal of Child Psychology and Psychiatry, 54*(6), 686–694. https://doi.org/10.1111/jcpp.12029

Landerl, K., Freudenthaler, H. H., Heene, M., De Jong, P. F., Desrochers, A., Manolitsis, G., Parrila, R., & Georgiou, G. K. (2019). Phonological awareness and rapid automatized naming as longitudinal predictors of reading in five alphabetic orthographies with varying degrees of consistency. *Scientific Studies of Reading, 23*(3), 220–234. https://doi.org/10.1080/10888438.2018.1510936

Marsh, H. W. (1986). Verbal and math self-concepts: An internal/external frame of reference model. *American Educational Research Journal, 23*(1), 129–149. https://doi.org/10.3102/00028312023001129

Marsh, H. W., & Martin, A. J. (2011). Academic self-concept and academic achievement: Relations and causal ordering. *British Journal of Educational Psychology, 81*(1), 59–77. https://doi.org/10.1348/000709910X503501

Martin, R. B., Cirino, P. T., Barnes, M. A., Ewing-Cobbs, L., Fuchs, L. S., Stuebing, K. K., & Fletcher, J. M. (2013). Prediction and stability of mathematics skill and difficulty. *Journal of Learning Disabilities, 46*(5), 428–443. https://doi.org/10.1177/0022219411436214

Moll, K., Kunze, S., Neuhoff, N., Bruder, J., & Schulte-Körne, G. (2014). Specific learning disorder: Prevalence and gender differences. *PLoS ONE, 9*(7), Article e103537. https://doi.org/10.1371/journal.pone.0103537

Möller, J., Zitzmann, S., Helm, F., Machts, N., & Wolff, F. (2020). A meta-analysis of relations between achievement and self-concept. *Review of Educational Research, 90*(3), 376–419. https://doi.org/10.3102/0034654320919354

Osborne, J. (2010). Improving your data transformations: Applying the box-cox transformation. *Practical Assessment, Research, and Evaluation, 15*(1). https://doi.org/10.7275/qbpc-gk17

Peura, P., Aro, T., Viholainen, H., Räikkönen, E., Usher, E. L., Sorvo, R., & Aro, M. (2019). Reading self-efficacy and reading fluency development among primary school children: Does specificity of self-efficacy matter? *Learning and Individual Differences, 73*, 67–78. https://doi.org/10.1016/j.lindif.2019.05.007

Puolakanaho, A., Ahonen, T., Aro, M., Eklund, K., Leppänen, P. H. T., Poikkeus, A.-M., Tolvanen, A., Torppa, M., & Lyytinen, H. (2008). Developmental links of very early phonological and language skills to second grade reading outcomes: Strong to accuracy but only minor to fluency. *Journal of Learning Disabilities, 41*(4), 353–370. https://doi.org/10.1177/0022219407311747

Salmi, P., Eklund, K., Järvisalo, E., & Aro, M. (2011). *Luki-mat - oppimisen arviointi: Lukemisen ja kirjoittamisen tuen tarpeen tunnistamisen välineet 2. Luokalle [A screening tool of reading and spelling for 2nd Grade]*. Jyväskylä, Finland: Niilo Mäki Institute.

Samuels, S. J. (2006). Reading fluency: Its past, present, and future. In T. Rasinski, C. Blachowicz, & K. Lems (Eds.), *Fluency instruction: Research-based best practices* (pp. 7–20). Guilford.

Schöber, C., Schütte, K., Köller, O., McElvany, N., & Gebauer, M. M. (2018). Reciprocal effects between self-efficacy and achievement in mathematics and reading. *Learning and Individual Differences, 63*, 1–11. https://doi.org/10.1016/j.lindif.2018.01.008

Schuchardt, K., Brandenburg, J., Fischbach, A., Büttner, G., Grube, D., Mähler, C., & Hasselhorn, M. (2015). Die entwicklung des akademischen selbstkonzeptes bei grundschulkindern mit lernschwierigkeiten. *Zeitschrift für Erziehungswissenschaft, 18*, 513–526. https://doi.org/10.1007/s11618-015-0649-z

Schwenk, C., Sasanguie, D., Kuhn, J., Kempe, S., Doebler, P., & Holling, H. (2017). (Non-)symbolic magnitude processing in children with mathematical difficulties: A meta-analysis. *Research in Developmental Disabilities, 64*, 152–167. https://doi.org/10.1016/j.ridd.2017.03.003

Seymour, P. H. K., Aro, M., & Erskine, J. M. (2003). Foundation literacy acquisition in European orthographies. *British Journal of Psychology, 94*(2), 143–174. https://doi.org/10.1348/000712603321661859

Susperreguy, M. I., Davis-Kean, P., Duckworth, K., & Chen, M. (2018). Self-concept predicts academic achievement across levels of the achievement distribution: Domain specificity for math and reading. *Child Development, 89*(6), 2196–2214. https://doi.org/10.1111/cdev.12924

Talsma, K., Schüz, B., Schwarzer, R., & Norris, K. (2018). I believe, therefore I achieve (and vice versa): A meta-analytic cross-lagged panel analysis of self-efficacy and academic performance. *Learning and Individual Differences, 61*, 136–150. https://doi.org/10.1016/j.lindif.2017.11.015

Torppa, M., Tolvanen, A., Poikkeus, A.-M., Eklund, K., Lerkkanen, M.-K., Leskinen, E., & Lyytinen, H. (2007). Reading development subtypes and their early characteristics. *Annals of Dyslexia, 57*(1), 3–32. https://doi.org/10.1007/s11881-007-0003-0

Torppa, M., Eklund, K., Van Bergen, E., & Lyytinen, H. (2015). Late-emerging and resolving dyslexia: A follow-up study from age 3 to 14. *Journal of Abnormal Child Psychology, 43*(7), 1389–1401. https://doi.org/10.1007/s10802-015-0003-1

Van Daal, V., Van der Leij, A., & Adèr, H. (2013). Specificity and overlap in skills underpinning reading and arithmetical fluency. *Reading and Writing, 26*(6), 1009–1030. https://doi.org/10.1007/s11145-012-9404-5

Van Der Sluis, S., Van Der Leij, A., & De Jong, P. F. (2005). Working memory in dutch children with reading- and arithmetic-related LD. *Journal of Learning Disabilities, 38*(3), 207–221. https://doi.org/10.1177/00222194050380030301

Wang, X., Georgiou, G. K., Li, Q., & Tavouktsoglou, A. (2018). Do chinese children with math difficulties have a deficit in executive functioning? *Frontiers in Psychology, 9*. https://doi.org/10.3389/fpsyg.2018.00906

Wechsler, D. (2010). *WISC–IV—Wechsler intelligence scale for Children–IV*. Helsinki, Finland: NCS Pearson Ltd., Psykologien Kustannus.

Willcutt, E. G., Petrill, S. A., Wu, S., Boada, R., DeFries, J. C., Olson, R. K., & Pennington, B. F. (2013). Comorbidity between reading disability and math disability: Concurrent psychopathology, functional impairment, and neuropsychological functioning. *Journal of Learning Disabilities, 46*(6), 500–516. https://doi.org/10.1177/0022219413477476

Wimmer, H. (1993). Characteristics of developmental dyslexia in a regular writing system. *Applied PsychoLinguistics, 14*(1), 1–33. https://doi.org/10.1017/S0142716400010122

Wu, S. S., Chen, L., Battista, C., Smith Watts, A. K., Willcutt, E. G., & Menon, V. (2017). Distinct influences of affective and cognitive factors on children's non-verbal and verbal mathematical abilities. *Cognition, 166*, 118–129. https://doi.org/10.1016/j.cognition.2017.05.016

Zeleke, S. (2004). Self-concepts of students with learning disabilities and their normally achieving peers: A review. *European Journal of Special Needs Education, 19*(2), 145–170. https://doi.org/10.1080/08856250410001678469

Zhang, X., Räsänen, P., Koponen, T., Aunola, K., Lerkkanen, M.-K., & Nurmi, J.-E. (2020). Early cognitive precursors of children's mathematics learning disability and persistent low achievement: A 5-year longitudinal study. *Child Development, 91*(1), 7–27. https://doi.org/10.1111/cdev.13123

Ziegler, J. C., Perry, C., Ma-Wyatt, A., Ladner, D., & Schulte-Körne, G. (2003). Developmental dyslexia in different languages: Language-specific or universal? *Journal of Experimental Child Psychology, 86*(3), 169–193. https://doi.org/10.1016/S0022-0965(03)00139-5

Ziegler, J. C., Bertrand, D., Tóth, D., Csépe, V., Reis, A., Faísca, L., Saine, N., Lyytinen, H., Vaessen, A., & Blomert, L. (2010). Orthographic depth and its impact on universal predictors of reading: A cross-language investigation. *Psychological Science, 21*(4), 551–559. https://doi.org/10.1177/0956797610363406