Common factors in Dyslexia and Dyscalculia: Is Phonological Awareness the key?

Thijs van der Stam (3651002)
Universiteit Utrecht

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Werkveld Leerlingenzorg
Course code: 200500130
Docent: Mw. Dr. E. H. Kroesbergen
Tweede beoordelaar: Mw. J. E. van ’t Noordende, MSc
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Preface

Working on this master thesis I learned a lot concerning the learning disabilities dyslexia and dyscalculia. It helped me to get an insight in the comorbidity of these two disabilities and the possible problems this creates. Additionally, it showed me how difficult being a researcher within the field of social sciences can be.

With regard to my thesis, I would first like to thank my main mentor Evelyn Kroesbergen for her valuable insight into learning disabilities and how to research them; you really made my thesis process a lot of fun! I would also like to thank my other two data collectors for the dyscalculia group: Kim Verkooijen and Mirthe van der Leeuw. Together we eventually reached our goal. I would like to thank Esther Slot and Sietske van Viersen as well, for their management of the data collection and their support in hard times.

I would like to thank my closest friends and family for their support this past year. Finally and especially, I would like to show my love and gratitude to my dear husband Mark; you put up with me this past year. The hard times as well as the good, you proofread my thesis and were my rock when I was in doubt of my own abilities.

Abstract

Introduction – The effects of a weak phonological awareness (PA) concerning arithmetical fact retrieval are researched, in children with either dyslexia, dyscalculia or both, and compared to the effects of number sense (NS). We expect that the comorbidity of dyslexia and dyscalculia can be explained by PA. **Method** – 105 children from grade 4 to 6 have been tested on IQ, PA, numeracy and NS, and are divided in three groups: dyslexia, dyscalculia and comorbid. **Results** – Within the dyslexia group, numeracy correlates high with PA and medium with NS. PA explains 30.3% of variance in numeracy. Within the dyscalculia group, numeracy correlates high with NS, though is non-significant for PA. PA explains 1% in numeracy, whereas NS explains 31.2%. Within the comorbid group, numeracy correlates high with NS, though is non-significant for PA. PA explains 4.7% in numeracy, whereas NS explains 47.7%. **Conclusion –** No statistically significant effect for the influence PA might have on the arithmetical fact retrieval was found within the comorbid group. However, an effect was found for number sense as a possible overlap. The results are restricted by correlations of medium effect between IQ and PA within the dyscalculia and comorbid groups. Additionally, a gender effect for NS was found within the dyscalculia group. Moreover, our measurement of NS consists only of a number line representation. *Keywords:* Phonological awareness, number sense, dyslexia, dyscalculia, comorbidity.

Introduction

Phonology is one of the first portals to the acquisition of language during early language development (Stoel-Gammon & Sosa, 2007). Phonology is described by Fromkin, Rodman, and Neijt (1991) as the doctrine of sound patterns in natural languages affecting the way speech sounds are grouped. There are three types of phonological processes: visual word recognition, connection of phonemes to graphemes, and phonological awareness (Wagner & Torgessen, 1987). Phonological awareness is the ability to recognize and manipulate sublexical sound units like phonemes and alliteration (Caravolas, Hulme, & Snowling, 2001). Phonological awareness develops from the age of five; a child from that age uses his acquired basic knowledge of language and skills and expands them (Menn & Stoel-Gammon, 2009). Weak phonological skills are related to specific reading disability (dyslexia; Blachman, 2000). There is a growing consensus that problems in the acquirement of phonological awareness and alphabetic coding skills are the primary cause for dyslexia (Vellutino, Fletcher, Snowling, & Scanlon, 2004). Not all learning disabilities are as fully defined as dyslexia; dyscalculia is studied less extensively concerning its underlying factors, but it creates problems for a child's development just the same (Butterworth, Varma, & Laurillard, 2011). Dyslexia and dyscalculia are sometimes recognized as two separate learning disabilities each having their own underlying factors (Landerl, Fussenegger, Moll, & Willurger, 2009). However, a longitudinal study on the effects of poor phonological skills on mathematical skills shows that there is a link between phonological awareness and dyscalculia (Jordan, Wylie, & Mulhern, 2010). Krajewski and Schneider (2009) even found that phonological awareness uniquely predicted mathematical skills. The present study investigates the effects of a weak phonological awareness on arithmetical fact retrieval in children with either dyslexia, dyscalculia or both. The expectation is that children with comorbid dyslexia and dyscalculia will be affected in their arithmetical fact retrieval, resulting in low math problem solving abilities.

Phonological awareness is considered a developmental process; starting with the awareness of syllables and alliteration, continuing with the development of the phonemic awareness (Goswami & Bryant, 1990; Hulme et al., 2002). The phonemic awareness is having the awareness to split words in separate phonemes (Ukrainetz, Nuspl, Wilkerson, & Rose Beddes, 2011). Moreover, Gombert (1992) suggests that phonological awareness consists of two types: epilinguistic and metalinguistic awareness. Whereas epilinguistic awareness refers to the sensitivity of the resemblance between phonemes, metalinguistic awareness focusses on the ability to use and think about language. There are different aspects influencing the phonological awareness development, including the phonemic awareness. There is no specific age for the phonemic awareness to start to develop (Goorhuis & Schaerlaekens, 2000). However, even before children start attending school, they begin to develop an awareness of phonological structures (Muter, Hulme, Snowling, & Stevenson, 2004).

An effect of a poor phonological awareness could be the development of dyslexia. Dyslexia has a prevalence of approximately 10-15% in school age children (Shaywitz, Escobar, Shaywitz, Fletcher, & Makuch, 1992). It is defined as a learning disability that primarily affects the skills involved in accurate and fluent word reading and spelling (Snowling & Hulme, 2012). Children who meet these criteria have to be of average intelligence and have received enough sociocultural opportunities (Demonet, Taylor, & Chaix, 2004). Although there is no definite answer to what the underlying causes for dyslexia are, a phonological deficit seems to be at the core (Blachman, 2000; Snowling, 2000; Snowling & Hulme, 2012; Vellutino et al., 2004). This phonological deficit can be separated in three specific factors, of which phonological awareness is one (Castles & Coltheart, 2004). The other two are rapid automatized naming (Warmington & Hulme, 2012) and phonological representations in the working memory (Noordenbos, Segers, Serniclaes, Mitterer, & Verhoeven, 2012). Not all research finds that a weak phonological awareness leads to dyslexia. For example, Blomert and Willems (2010) found no causal link between children at risk for developing dyslexia and a weak phonological awareness. Also, students with dyslexia could be affected by comorbid problems besides their reading difficulties. A study among Dutch students in higher education with dyslexia, compared with students without, showed that dyslexia affects verbal long-term memory, arithmetic and phonological processing (Callens, Tops, & Brysbaert, 2012).

Phonology might also affect another learning disability: dyscalculia. Whereas dyslexia affects mostly reading capabilities, dyscalculia influences the mathematical abilities. The prevalence of dyscalculia is 3-6% (Henik, Rubinsten, & Ashkenazi, 2011). Dyscalculia is defined as having problems with arithmetic, and visuospatial problems, as well as poor problem solving capabilities, despite average intelligence and instruction (Geary, 1993; Lagae, 2008). The retrieval of arithmetical facts also seems to be a problem for children with dyscalculia (Geary & Hoard, 2001). Geary (1993) categorizes the problems of dyscalculia in three subtypes: procedural, visuospatial and semantic memory. In hindsight, he explains that support has been found for the procedural type and the semantic memory type, but that the visuospatial type seems unfounded (Geary, 2010). It also seems that the problems of the procedural type and the difficulties in dealing with numbers appear to be a developmental delay and not a deficit (Geary, 2011). The underlying factors for dyscalculia have not yet been fully defined, but there are some indicators. Research has found that a poor number sense could be the origin of dyscalculia (Butterworth, 2010; Reigosa-Crespo et al., 2012). Geary and colleagues (2009) show in their research that a poor working memory could also be an underlying factor of dyscalculia. Students with dyscalculia could be affected by comorbid problems besides their mathematical difficulties. For instance, students with dyscalculia have been linked to math anxiety, which causes children to feel negative emotions when numbers are involved during their school work or later on in life (Rubinsten & Tannock, 2010). The problems that are involved with children with dyscalculia might also affect how they perceive advanced mathematics; especially visuospatial abilities correlate with future advanced mathematics (Wei, Yuan, Chen, & Zhou, 2012).

It is possible to develop both dyslexia and dyscalculia. The prevalence of this comorbidity within the group of children with learning disability is higher than the prevalence of just one of these learning disability in the general population (Landerl & Moll, 2010). The prevalence of children with dyscalculia who also show reading problems range between 17 and 70 percent, whereas the prevalence of children with dyslexia who also show arithmetical problems range between 11 and 56 percent (Barbaresi, Katusic, Colligan,Weaver, & Jacobsen, 2005; Dirks, Spyer, Van Lieshout, & De Sonneville, 2008; Gross-Tsur, Manor, & Shalev, 1996; Lewis, Hitch, & Walker, 1994; Rubinsten, 2009). The effects are enlarged by both learning disabilities, as both disabilities have their own set of specific problems; children with comorbid dyslexia and dyscalculia have more problems in learning than children with just one of the two learning disabilities (Tressoldi, Rosati, & Lucangeli, 2007).

Researchers are not in agreement if there are truly two separate learning disabilities. Landerl, Fussenegger, Moll, and Willurger (2009) stress that dyslexia and dyscalculia are separate learning disabilities with each their own underlying cognitive factors. On the other hand Krajewski and Schneider (2009) show that the main factor for dyslexia, phonological awareness, also has an effect on the acquirement of mathematical abilities. A longitudinal study on the effects of poor phonological skills on the mathematical skills shows that there is a link between phonological awareness and dyscalculia (Jordan, Wylie, & Mulhern, 2010). Another study among adults with dyslexia about the effects of a poor phonological awareness shows that this target group had significant more problems with arithmetical fact retrieval, which is also a core problem in people with dyscalculia (De Smedt & Boets, 2010). These different findings show that more research is needed to better understand the overlap in dyslexia and dyscalculia.

The present study investigated the effects of a weak phonological awareness in children with either dyslexia, dyscalculia or both, concerning arithmetical fact retrieval. The following research questions, with accompanying hypotheses, have been formulated:

1. How is phonological awareness correlated with numeracy?
    a. Phonological awareness correlates high with numeracy for the comorbid dyslexia/dyscalculia group.
    b. Phonological awareness correlates medium with numeracy for the dyslexia group.
    c. Phonological awareness does not correlate with numeracy for the dyscalculia group.
2. How is number sense correlated with numeracy?
    a. Number sense correlates medium with numeracy for the comorbid dyslexia/dyscalculia group.
    b. Number sense does not correlate with numeracy for the dyslexia group.
    c. Number sense correlates high with numeracy for the dyscalculia group.
3. How much variance in numeracy is explained by phonological awareness compared to numbers sense?
    a. Within the comorbid dyslexia/dyscalculia group phonological awareness explains significantly more variance in numeracy than number sense.
    b. Within the dyslexia group phonological awareness explains significantly more variance in numeracy than number sense.
    c. Within the dyscalculia group number sense explains significantly more variance in numeracy than phonological awareness.

The expectation is that the comorbid dyslexia/dyscalculia group is affected by a low phonological awareness combined with a low arithmetical fact retrieval, resulting in complications concerning their math problem solving abilities. This could indicate that the comorbidity of dyslexia with dyscalculia lies in the semantic memory type as described by Geary (1993). Positive results in this area would give more insight in the comorbidity of dyslexia and dyscalculia. This would help to better understand these children with learning disabilities and how they could be supported best.

Method

The present study investigated the effects of a weak phonological awareness in children with either dyslexia, dyscalculia or both, concerning arithmetical fact retrieval. The expectation is that the comorbid dyslexia/dyscalculia group is affected by a low phonological awareness combined with a low arithmetical fact retrieval, resulting in complications concerning their math problem solving abilities.

Participants

For the current study, 105 children were selected from different primary schools across the Netherlands. The children are from grades 4 to 6 and achieved low scores on standardized tests regarding reading, spelling and/or mathematical skills. They were divided in three groups: children with dyslexia, children with dyscalculia and a comorbid dyslexia/dyscalculia group. The average age in years, the boy-girl distribution, and the average IQ are presented in Table 1 for each of the different groups.

Table 1

Descriptive statistics for each of the groups

Group		Age in years		IQ	
		M	SD	M	SD
Dyslexia	Boys (N=17)	8.78	1.09	105.59	9.25
	Girls (N=11)	8.73	.98	104.36	16.60
	Total (N=28)	8.76	1.03	105.11	12.37
Dyscalculia	Boys (N=7)	9.43	.40	105.14	10.51
	Girls (N=24)	8.28	1.91	100.75	12.18
	Total (N=31)	8.54	1.75	101.74	11.80
Comorbid	Boys (N=25)	8.56	3.08	94.71	7.75
	Girls (N=21)	8.83	2.08	97.81	14.66
	Total (N=46)	8.68	2.65	96.16	11.47

The criteria for the dyslexia group are lowest 10% reading scores, or lowest 16% reading scores combined with lowest 10% spelling scores, in combination with low scores for phonological awareness and rapid naming. The criteria for the dyscalculia group are lowest 25% numeracy scores in combination with low number sense scores. The criteria for the comorbid dyslexia/dyscalculia group are either the criteria of the dyslexia group in combination with low numeracy scores or the criteria of the dyscalculia group in combination with low reading and/or spelling scores.

Instruments

A test battery of four tests was administered to measure the constructs within this study. For each construct it is indicated which tests have been used.

Phonological awareness. The Fonemische Analyse Test ([FAT], Van den Bos, Lutje Spelberg, & De Groot, 2010) is a test developed for Dutch children to measure their phonemic awareness. The test is administered individually and consists of two parts: a phoneme deletion task (12 items) and a phoneme substitution task (12 items). Both accuracy and processing time is recorded. Evers and colleagues (2009-2011) assessed the FAT on various types of validity. They found the principles of test construction and the quality of the instructions good, and the construct validity sufficient. The material, standards, reliability and criterion validity were considered inadequate. The updated version of the FAT, which is used in the current study, addresses these issues but has not yet been reassessed. We used the norm scores in the current study, which take both total amount of time and total amount of correct answers into account.

Number sense. In order to assess number sense, a number line is used which is based on a earlier version of Laski and Siegler (2007). A computer shows a line with on the left hand side the number 1 and on the right hand side the number 100. The child is asked to place different numbers on the line. The task consists of 22 sets which are used to calculate linear fit scores (Kolkman, Kroesbergen, & Leseman, 2013).

Intelligence. The Wechsler Intelligence Scale for Children, third edition, Dutch version ([WISC-III-NL], Wechsler, 2002) is a test developed for Dutch children to measure intelligence. Evers and colleagues (2009-2011) found the principles of test construction and the quality of the materials and instructions good, and construct validity, standards and reliability sufficient. The criterion validity was considered inadequate. The present study selected two verbal (Similarities and Vocabulary) and two performance subtests (Block Design and Object Assembly) from the thirteen subtest, in order to give an indication of a child's intelligence. The raw subtest scores are based on age-related comparative standards converted into standard scores from 1 to 19 (M = 10, SD = 3). There are standards for ages ranging from 6.0 years to 16.11 years with 4-monthly intervals.

Numeracy. The Tempo Test Rekenen ([TTR], De Vos, 1992) is a test developed to measure the numeracy of children attending primary as well as high school. The test is conducted by the child individually. The test consists of arithmetical problems of various kinds and degrees of difficulty. It contains five columns, each containing 40 problems: addition, subtraction, multiplication, division and mixed. The columns slowly increase in difficulty. In grade 3, only columns 1 and 2 are administrated. Grades 4 and higher try to finish all five columns. The TTR 1992 is an improved version of the TTR 1987. Evers and colleagues (2009-2011) found the principles of test construction and the quality of the materials good, and the quality of the instructions sufficient. The construct validity, standards, reliability and criterion validity are considered inadequate. The authors declared that the TTR is not supposed to be used for prediction purposes; criterion validity is not applicable.

Procedure

Firstly, the participants were tested individually by a researcher of Utrecht University. This took place in either a research room at the University of Utrecht, at the child's school or at the child's home. Secondly, records of the child's functioning at school were collected from the teachers with consent from the parents. Thirdly, the parents were asked to fill out some forms concerning the background of their children. The tests were conducted in the period from September 2012 to March in 2013. A complete dataset for all 105 children was obtained.

Data processing

Outliers were further analyzed and three participants have been removed from the dataset, because of extreme scores on multiple variables when compared to the average scores.

Analysis plan

The variables that were required for this study had already been determined. The descriptive statistics for each of the groups concerning phonological awareness, number sense, numeracy, months of lag in numeracy and IQ were collected and verified by means of a MANOVA for significant differences between the groups. Next, it has been checked whether the separate variables are normally distributed. It has also been checked if there are significant differences between boys and girls and if intelligence correlates with the separate variables. If so, the child's sex or intelligence was used as a covariate variable.

To answer the first research question, it has been calculated whether phonological awareness correlates with numeracy for each of the separate groups. For the second research question, it has been calculated if number sense correlates with numeracy for each of the separate groups. For the third research question a hierarchical multiple regression analysis has been performed to calculate in which ratio phonological awareness and number sense explain the variance in numeracy within the separate groups.

Ethic relevance

Utrecht University has approved this study and is authorized to administer the tests. Naturally, the researchers ensured that the cooperating schools, parents and their children were aware of the investigation. The researchers asked permission for cooperation with all parties and obtained it in writing from the parents. The privacy of all parties concerned has been ensured by anonymizing all data.

Results

For the statistical analyses, data from 102 participants have been used. Statistical outliers have been identified with boxplots and stem-and-leaf plots and three participants have been removed from the dataset. The number sense variable has been recalculated with a ^{10}log transformation in order to achieve normality; the more the score is below zero, the higher the number sense score. The numeracy lag variable has been created by subtracting the number of numeracy months from the actual number of months of received numeracy instruction.

In order to assess the data effectively, the variables were checked for normal distributions within the groups, as seen in Table 2 in the appendix. Normal distributions are checked with Shapiro-Wilk tests. All variables were found normally distributed for the total group. Normality is assumed for the three divided research groups on phonological awareness, number sense, numeracy, months of lag in numeracy and IQ.

The groups are visible in Table 3 with the average scores for phonological awareness, number sense, numeracy, months of lag in numeracy and IQ.

Table 3

Average scores for phonological awareness, number sense, numeracy and IQ for each of the groups

Group	Phonological awareness		Number sense		Numeracy		Numeracy lag		IQ	
	M	SD	M	SD	M	SD	M	SD	M	SD
Dyslexia	7.06	2.56	-1.24	.47	67.70	27.06	2.17	6.99	105.11	12.37
Dyscalculia	8.96	2.36	-.95	.47	47.52	18.86	12.17	6.43	101.74	11.80
Comorbid	6.52	2.26	-1.16	.44	52.03	16.33	14.50	5.52	96.79	11.08

A multivariate analysis of variance (MANOVA) was used to examine if the differences in average scores for phonological awareness, number sense, numeracy, months of lag in numeracy and IQ between the research groups are significant. Before conducting the MANOVA the data were examined to ensure that all of its underlying assumptions were met. Univariate normality could be assumed as mentioned earlier. Additionally, no multivariate outliers were found in the data, supporting assumption of multivariate normality. Correlations between the dependent variables were not excessive, indicating that multicollinearity was not of concern. Furthermore, the relationships that did exist between the dependent variables were roughly linear. Finally, Box's M was non-significant at $\alpha = .001$, indicating that homogeneity of variance-covariance matrices could be assumed. Findings showed that there was a significant effect of the grouping variable (dyslexia, dyscalculia or comorbid) on the combined dependent variables, F (10,76) = 8.213, $p < .001$, partial $\eta^2 = .351$. Analysis of the dependent variables individually showed no differences between the research groups for the variables number sense and IQ. However, the variable phonological awareness was statistically significant at a Bonferroni adjusted alpha level of .01, F (2,79) = 8.582, $p < .001$, partial $\eta^2 = .178$.The dyscalculia group scored significantly higher than the dyslexia and comorbid group. An independent samples *t* test showed no statistical significant difference between the dyslexia and comorbid group for phonological awareness, $t(67) = .917$, p = .363, two-tailed. The variable numeracy was also statistically significant at a Bonferroni adjusted alpha level of .01, F (2,79) = 6.779, $p = .002$, partial $\eta^2 = .146$. The dyslexia group scored significantly higher than the dyscalculia and comorbid groups. An independent samples *t* test showed no statistical significant difference between the dyscalculia and comorbid group for numeracy, $t(61) = -1.018$, p = .313, two-tailed. The variable numeracy lag was statistically significant as well at a Bonferroni adjusted alpha level of .01, F (2,79) = 28.028, $p < .001$, partial $\eta^2 = .415$. The dyslexia group had significantly lower numeracy lag than the dyscalculia and comorbid groups. An independent samples *t* test showed no statistical significant difference between the dyscalculia and comorbid group for numeracy lag, $t(61) = 1.546$, p = .127, two-tailed.

Additionally, independent samples *t* tests were performed to check if there is an effect for gender within the separate groups for the variables phonological awareness, number sense, numeracy, numeracy lag and IQ. These results can be found in Table 4 in the appendix. All groups, except for one, do not show an effect for gender for each of the five variables. The exception is within the dyscalculia group; there seems to be an effect for gender for number sense. The *t* test was significant, $t(28) = -2.911$, p = .007, two-tailed, $d = 0.15$.

Furthermore, in order to make sure that intelligence does not account for the differences in variance for phonological awareness, number sense, numeracy and numeracy lag within each of the groups, bivariate correlations are performed. Pearson's *r* is used, as normality is assumed for each of the variables as explained earlier. These results can be found in Table 5 in the appendix. All groups, except for two, do not show a significant correlation with IQ for each of the four variables. The exceptions are within the dyscalculia group; the correlation between IQ and phonological awareness was positive and medium, $r(40) = .454$, $p < .05$, and within the comorbid dyslexia/dyscalculia group; the correlation between IQ and phonological awareness was positive and medium, $r(40) = .341$, $p < .05$.

In order to answer the first research question, we assessed the size and direction of the linear relationship between phonological awareness and numeracy. Pearson's *r* correlations were calculated for each of the groups as normality is assumed for each of the variables as explained earlier. For the dyslexia group, the correlation between these two variables was positive and large, $r(21) = .551$, $p < .01$. For the dyscalculia group, the correlation between these two variables was statistically non-significant, $r(26) = .101$, $p = .609$. For the comorbid dyslexia/dyscalculia group, the correlation between these two variables was also statistically non-significant, $r(30) = -.218$, $p = .231$.

In order to answer the second research question, we assessed the size and direction of the linear relationship between number sense and numeracy. Pearson's *r* correlations were calculated for each of the groups as normality is assumed for each of the variables as explained earlier. For the dyslexia group, the correlation between these two variables was positive and medium, $r(21) =.463$, $p < .05$. For the dyscalculia group, the correlation between these two variables was positive and strong, $r(26) =.567$, $p < .01$. For the comorbid dyslexia/dyscalculia group, the correlation between these two variables was also positive and strong, $r(32) =.713$, $p < .001$.

In order to answer the third research question, a hierarchical multiple regression analysis (MRA) was performed for each of the groups, to estimate the proportion of variance in numeracy that can be accounted for by phonological awareness and number sense. Prior to interpreting the results of the MRA, several assumptions were evaluated and met, including normality, linearity, and homoscedasticity of residuals. Within each of the groups Mahalanobis distance did not exceed the critical χ^2 for $df = 2$ (at $\alpha = .001$) of 13.82 for any cases in the data file, indicating that multivariate outliers were not of concern. Also, relatively high tolerances for both predictors in the regression model indicated that multicollinearity would not interfere with the ability to interpret the outcome of the MRA. Unstandardized (*B*) and standardized (β) regression coefficients, and squared semi-partial correlations (sr^2) for each predictor in the regression model are reported in Table 6 per group.

For the dyslexia group, on step 1 of the hierarchical MRA, phonological awareness accounted for a significant 30.3% of the variability in numeracy, $R^2 = .303$, adjusted $R^2 = .270$, $F(2, 20) = 9.142$, $p < .01$. This model has a large effect, Cohen's $f^2 = .435$. On step 2, number sense was added to the regression equation, but did not account for a statistically significant additional percentage of the variance in numeracy, $\Delta R^2 = .09$, $\Delta F(1, 20) = 2.969$, $p = .100$. For the dyscalculia group, on step 1 of the hierarchical MRA, phonological awareness accounted for a non-significant 1% of the variance in numeracy, $R^2 = .010$, $F(1, 25) = .243$, $p = .626$. On step 2, number sense was added to the regression equation, and accounted for an additional 31.2% of the variance in numeracy, $\Delta R^2 = .312$, $\Delta F(1, 24) = 11.023$, $p < .005$. In combination, the two predictor variables explained 32.1% of the variance in numeracy, R^2 = .321, adjusted R^2 = .265, $F(2, 24) = 5.682$, $p = .01$. This model has a large effect, Cohen's f^2 = .473. For the comorbid dyslexia/dyscalculia group, on step 1 of the hierarchical MRA, phonological awareness accounted for a non-significant 4.7% of the variance in numeracy, R^2 = .047, $F(1, 30) = 1.492$, $p = .231$. On step 2, number sense was added to the regression equation, and accounted for an additional 47.7% of the variance in numeracy, $\Delta R^2 = .477$, $\Delta F(1, 29) = 29.078$, $p < .001$. In combination, the two predictor variables explained 52.4% of the variance in numeracy, $R^2 = .524$, adjusted $R^2 = .492$, $F(2, 29) = 15.983$, $p < .001$. This model has a large effect, Cohen's $f^2 = 1.101$.

Table 6

Unstandardized (B) and standardized (β) regression coefficients, and squared semi-partial correlations (sr^2) for each predictor variable each step of a hierarchical multiple regression predicting numeracy

Group	Variable	*B* [95% CI]	*β*	sr^2
Dyslexia	Step 1			
	Phonological awareness	5.699 [1.779, 9.618]**	.551	.304
	Step 2			
	Phonological awareness	4.633 [.659, 8.608]*	.448	.180
	Number sense	-19.537 [-43.187, 4.114]	-.317	.090
Dyscalculia	Step 1			
	Phonological awareness	.827 [-2.629, 4.283]	.098	.009
	Step 2			
	Phonological awareness	-.447 [-3.478, 2.584]	-.053	.003
	Number sense	-23.624 [-38.310, -8.938]**	-.578	.311
Comorbid	Step 1			
	Phonological awareness	-1.497 [-4.000, 1.006]	-.218	.048
	Step 2			
	Phonological awareness	-.264 [-2.125, 1.597]	-.038	.001
	Number sense	-24.009 [-33.116, -14.903]**	-.714	.477

CI = confidence interval

*$p < .05$ ** $p < .01$

When the same models are used to estimate the proportion of variance in numeracy lag, none are statistically significant.

Discussion

The present study investigated the effects of a weak phonological awareness in children with either dyslexia, dyscalculia or both, concerning arithmetical fact retrieval. Results will be discussed per research question.

Research question 1 assessed how phonological awareness correlates with numeracy. Results show that the correlation within the dyslexia group is as expected, positive and large. The results within the dyscalculia group were non-significant, as expected. The results within the comorbid dyslexia/dyscalculia group are unexpectedly non-significant though. This shows that phonological awareness does not account for the variance within the numeracy scores for the comorbid dyslexia/dyscalculia group. The link between phonological awareness and arithmetical fact retrieval is found in different studies (De Smedt & Boets, 2010; Jordan, Wylie, & Mulhern, 2010). However, within our research we could not reproduce these findings for the dyscalculia group or the comorbid dyslexia/dyscalculia group. The current research only has one moment of measurement, whereas Jordan, Wylie, and Mulhern (2010) performed a longitudinal study with a group of students with dyscalculia. De Smedt and Boets (2010) investigated adults with dyslexia and their growing problems with arithmetical fact retrieval. It is a possibility that this problem grows over the years, as our dyslexia group is on average much younger, and nonetheless already show a slight numeracy lag on average.

Research question 2 assessed how number sense correlates with numeracy. Results show that the correlation within the dyscalculia group is as expected, positive and large. The results within the comorbid dyslexia/dyscalculia group are unexpected, positive and large. This shows that number sense accounts for more variance within the numeracy scores for the comorbid dyslexia/dyscalculia group. A notable result, however, is that we found a significant correlation of medium effect between number sense and numeracy within our dyslexia group. A study to arithmetical fact retrieval in children with dyscalculia found that number sense predicted this part of mathematical skills (Mussolin, Meijas, & Noel, 2010). It could be that instead of phonological awareness predicting arithmetical fact retrieval for children with dyslexia and also within the comorbid group, number sense is the underlying factor. Nonetheless, researchers do not yet focus on this possible link.

Research question 3 assessed how much variance in numeracy is explained by phonological awareness compared to numbers sense. As expected, within the dyslexia group phonological awareness statistically accounts for more variance within numeracy than number sense. Also, within the dyscalculia group number sense statistically accounts for more variance within numeracy than phonological awareness. It was unexpected, though, that within the comorbid dyslexia/dyscalculia group results show that the variance within the numeracy results cannot be explained significantly by phonological awareness alone. The MRA with the variables phonological awareness and number sense shows that, within the comorbid dyslexia/dyscalculia group, number sense accounts for a statistically significant 47.7% variance, whereas the proportion that could be explained by phonological awareness is only 4.7% and statistically non-significant.

Other results are in line with earlier research on the overlap of dyslexia and dyscalculia. We found that the comorbid dyslexia/dyscalculia group is affected more by both learning disabilities as well; they scored on average lower for phonological awareness and have a greater numeracy lag, as depicted in Table 3. This is in line with a study on the effects of comorbid dyslexia and dyscalculia, which found that these children have more problems than children with just one learning disability (Tressoldi, Rosati, & Lucangeli, 2007). Moreover, our research found that dyslexia and dyscalculia are two separate problems, as also stated by Landerl, Fussenegger, Moll, and Willurger (2009). Even though our dyslexia group shows on average a numeracy lag, its variance is accounted for more by phonological awareness than number sense. Additionally, the average scores on phonological awareness and number sense differ, as displayed in Table 3 and checked with a MANOVA.

The current results are restricted by the fact that within the comorbid dyslexia/dyscalculia group, as well as the dyscalculia group, we found a correlation of medium effect between intelligence and phonological awareness. This could interfere with the results of the correlation between phonological awareness and numeracy as well as the performed MRA. Additionally, we found a gender effect for number sense within the dyscalculia group. This could be due to the gender distribution of the dyscalculia group, as it contains only a small number of boys (N=7). Moreover, our measurement of number sense consists only of a number line representation, where other researchers use various methods for this measurement (Butterworth, 2010; Kolkman, Kroesbergen, & Leseman, 2013; Mussolin, Meijas, & Noel, 2010).

In conclusion, we hoped to create more insight in the overlap between dyslexia and dyscalculia and theorized that the comorbid dyslexia/dyscalculia group would be affected by a low phonological awareness combined with a low arithmetical fact retrieval, resulting in complications concerning their math problem solving abilities. This would indicate that the comorbidity of dyslexia with dyscalculia lies in the semantic memory type as described by Geary (1993). However, we found no statistically significant effect for the influence phonological awareness might have on the arithmetical fact retrieval within a group of students with comorbid dyslexia/dyscalculia. We did find effects for number sense as a possible overlap, but more research is needed to verify this, as the current study does not contain the predictive capabilities for it.

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Appendix

Table 2

Normal distributions for phonological awareness, number sense, numeracy, months of lag in numeracy and IQ

	Shapiro-Wilk (W)				
	Phonological awareness	Number sense	Numeracy	Numeracy lag	IQ
Total	.978	.973	.980	.985	.983

* $p < .05$

Table 4

Independent samples t *tests for gender effect*

Group		Levene's test (sig)	*t*	df	Sig[A]
Dyslexia	Phonological awareness	.773	-.739	26	.467
	IQ	.082	.251	26	.804
	Numeracy	.833	.595	21	.558
	Numeracy lag	.262	.265	21	.793
	Number sense	.874	-.533	26	.606
Dyscalculia	Phonological awareness	.636	.089	27	.929
	IQ	.766	.863	29	.395
	Numeracy	.005	1.334	23.120	.195
	Numeracy lag	.532	-1.212	27	.236
	Number sense	.084	-2.911	27	.007
Comorbid	Phonological awareness	.599	-.591	42	.557
	IQ	.016	-.869	29.458	.392
	Numeracy	.559	1.359	32	.184
	Numeracy lag	.236	1.134	35	.265
	Number sense	.320	-1.200	41	.237

[A]2-tailed

Table 5

Correlations between IQ and phonological awareness, numeracy, numeracy lag and number sense for each of the groups

Group		Pearson's *r*	df
Dyslexia	Phonological awareness	.363	26
	Numeracy	.122	26
	Numeracy lag	-.072	21
	Number sense	-.352	26
Dyscalculia	Phonological awareness	.454*	27
	Numeracy	-.142	27
	Numeracy lag	.063	27
	Number sense	-.352	29
Comorbid	Phonological awareness	.341*	39
	Numeracy	-.001	31
	Numeracy lag	.118	31
	Number sense	.136	40

*p < .05