Revista de Psicodidáctica, 2019, 24 (1), 62–70

psicodidáctica

Revista de Psicodidáctica

www.elsevier.es/psicod

Original

# Number Sense Abilities, Working Memory and RAN: A Longitudinal Approximation of Typical and Atypical Development in Chilean Children☆

Bárbara Guzmán[a], Cristina Rodríguez[a,b,*], Felipe Sepúlveda[a], and Roberto A. Ferreira[a]

[a] *Facultad de Educación, Universidad Católica de la Santísima Concepción, Campus San Andrés, 1850, Concepción, Chile*
[b] *Facultad de Psicología, Universidad de La Laguna, Campus Guajara, 38205 La Laguna, Tenerife, Spain*

ARTICLE INFO

*Article history:*
Received 17 April 2018
Accepted 14 November 2018
Available online 12 December 2018

*Keywords:*
Mathematics learning disabilities
Numbers sense
Domain-general cognitive abilities
RAN
Working memory

ABSTRACT

The present study examined the contribution of working memory and Rapid Automatized Naming (RAN) to growth trajectories in number processing, measured using Curriculum-based Measurement (CBM). Participants were two groups of first grade children; one group were at risk of developing mathematics disabilities (MLD-at-risk, $n = 32$), and the other included typically developing (non-MLD, $n = 32$) children. Of all the cognitive measures, backward digit span (BDS) tasks and RAN-Letter made significant contributions to differentiating group performance. RAN-Letter provided differentiation of groups, and BDS provided differentiation of the growth rates of both groups in number processing skills. These results highlight the relevance of RAN and BDS for the development of number processing skills in first grade, especially for MLD-at-risk children. BDS is therefore a very important task to be measured during the early stages of mathematics instruction, because it predicts deficits in development of number skills.

## Sentido numérico, memoria de trabajo y RAN: una aproximación longitudinal al desarrollo típico y atípico de niños chilenos

*Palabras clave:*
Dificultades específicas de aprendizaje en matemáticas
Sentido numérico
Habilidades cognitivas de dominio general
RAN
Memoria de trabajo

RESUMEN

En el presente estudio se investiga el efecto de la memoria de trabajo y la denominación automatizada rápida (RAN) en las trayectorias de crecimiento del procesamiento numérico, medido mediante Medidas Basadas en el Curriculum (CBM). Se evaluan dos grupos de niños de primer grado; un grupo en riesgo de desarrollar dificultades específicas de aprendizaje en matemáticas (MLD-en riesgo, $n = 32$), y otro compuesto por niños con desarrollo típico (sin-MLD, $n = 32$). De todas las medidas cognitivas administradas, se evidencia que la tarea de span verbal de dígitos inversos (BDS) y la subtarea de RAN-Letras contribuyen significativamente en la diferenciación del rendimiento de los grupos. RAN-Letras contribuye a la diferenciación de los grupos en el rendimiento de habilidades numéricas, mientras BDS contribuye de forma diferenciada a la ratio de crecimiento de los grupos en habilidades numéricas. Estos resultados visibilizan la relevancia de RAN y BDS para el desarrollo de habilidades de procesamiento numérico en primer grado, especialmente para niños en riesgo de MLD. Así, BDS emerge como una tarea importante a evaluar durante las primeras etapas de la instrucción matemática, debido su capacidad de predecir déficits en el desarrollo de habilidades numéricas.

PII of original article:S1136-1034(18)30092-3.

☆ Please cite this article as: Guzmán B, Rodríguez C, Sepúlveda F, Ferreira, RA. Sentido numérico, memoria de trabajo y RAN: una aproximación longitudinal al desarrollo típico y atípico de niños chilenos. Rev Psicodidáct. 2019;24:62–70. https://doi.org/10.1016/j.psicod.2018.11.002

* Corresponding author.
*E-mail addresses:* crodri@ull.es, m.rodriguez@ucsc.cl (C. Rodríguez).

## Introduction

At present, the identification of students with specific learning disabilities and, in particular, those with specific learning disabilities in mathematics (MLD), is undertaken from a preventive perspective (Clarke et al., 2016; Fuchs & Fuchs, 2006; Hinton, Flores, & Shippen, 2014). It is therefore no surprise that in the last few years, research worldwide has focused on the identification of early predictors of learning disabilities in order to act upon them as quickly as possible (e.g., Fuchs, Fuchs, & Compton, 2012; Kaufmann & Von Aster, 2012; Locuniak & Jordan, 2008; Tobia, Bonifacci, & Marzocchi, 2016). One of the most well-known and researched approaches for this purpose is the so-called Response to Intervention Model (RtI), which considers monitoring of children's response to treatment as the key to diagnosis. In all preventive models, early assessment is a determining factor for identification, and in the case of the RtI model, its application must be dynamic, involving the use of Curriculum-based Measurement (CBM). These measures have mostly been used to assess reading rather than mathematics, however recently a number of instrument for mathematics assessment have also been created (e.g., Clarke, Gersten, Dimino, & Rolfhus, 2012; Jiménez & de León, 2017; Lembke & Foegen, 2009). CBM measures have an advantage over other methods, since they allow the monitoring of skill development from an early stage, all the way through to diagnosis (Clarke & Shinn, 2004; Cummings & Petscher, 2015; Foegen, Jiban, & Deno, 2007). In most countries, diagnosis begins as early as kindergarten; however, in Chile, the official diagnosis of MLD is only made in the second grade, meaning that no evaluation is carried out during kindergarten or first grade. Hence, it is of interest to use CBM measures to monitor the progress of typically developing Chilean children and those at risk of developing MLD.

An increasing number of authors have raised the importance of assessing not only numerical abilities for the diagnosis of MLD, but also the cognitive abilities that support them (Cowan & Powell, 2014; Mazzocco & Rasanen, 2013; Rodríguez & Jiménez, 2016; Träff, Olsson, Östergren, & Skagerlund, 2017). This perspective emerged as a result of the debate between researchers supporting models of numerical disabilities that assume a deficit in specific domains of quantity representation (Butterworth, Varma, & Laurillard, 2011; Geary, 2013; Piazza et al., 2010), and those in favour of general purpose models, that assume MLD is a by-product of deficits in working memory (WM), verbal reasoning, and visual-spatial abilities (Geary, Hoard, Byrd-craven, Nugent, & Numtee, 2007; Raghubar, Barnes, & Hecht, 2010). More recently, this heated debate has evolved towards a more eclectic perspective, where both models are recognised as effective in assessing children at risk of developing MLD. For example, Träff (2013) found that general cognitive abilities and basic number abilities are necessary to explain the development of more complex numerical skills (e.g., fact retrieval, arithmetic fact retrieval, and word problem solving). These findings were also observed in the case of atypical numerical development or dyscalculia, supporting theories of multiple deficits (Träff et al., 2017).

Some studies have analysed the contribution of general and specific domain skills to mathematics achievement from a longitudinal perspective (Chu, vanMarle, & Geary, 2016; Geary, 2011; Kolkman, Kroesbergen, & Leseman, 2014; Xenidou-Dervou et al., 2018). For instance, in a 5-year study (K-5), Geary (2011) found a significant contribution of both general and specific domain skills to the growth rates of mathematics achievement. These findings differ from those of a study conducted by Xenidou-Dervou et al. (2018), in which kindergarten children were monitored over two years. The results showed that general domain skills were significant predictors of mathematics achievement at the starting point (mid-Grade 1). However, they did not affect the growth rates of mathematics achievement over time. Similarly, in a three-year longitudinal study carried out by Chu et al. (2016), domain-general skills did not predict growth in mathematical performance in kindergarten. The interpretation for these findings is that at initial stages of mathematical learning, working memory demands are not high enough to influence performance in simple numerical tasks.

### *The relationship between working memory, RAN and number processing*

Unlike numerical cognition, the relationship between cognitive abilities and reading development has been the focus of substantial research for decades (Chu et al., 2016), leading to some consolidated findings. This research has systematically confirmed the contribution of working memory (WM) and rapid automatized naming (RAN) in the development of reading, and consequently in reading learning disabilities (RLD) (e.g., Landerl & Wimmer, 2008; Rodríguez, Van den Boer, Jiménez, & de Jong, 2015). In recent years, findings pointing to the influence of phonological awareness, working memory and RAN in mathematical skills have gathered widespread support (e.g., Clarke & Shinn, 2004; Raghubar et al., 2010; Simmons & Singleton, 2008; Träff, 2013). There are also several studies that have shown that participants with MLD have a deficit in working memory skills, and that this deficit predicts subsequent lower performance in numerical abilities (Aragón, Navarro, Aguilar, & Cerda, 2015; Toll, Van der Ven, Kroesbergen, & Van Luit, 2011; Passolunghi & Siegel, 2004).

In a longitudinal study conducted by Toll and Van Luit (2013), children aged between four and five years were classified based on their WM performance (limited vs. average) in order to study early arithmetic performance in both groups. The results evidenced deficits in most arithmetic domains of the children with limited performance, which is consistent with other work demonstrating that children with MLD show a deficit in WM (e.g., Geary et al., 2007; Presentación, Mercader, Siegenthaler, Fernández, & Miranda, 2015; Raghubar et al., 2010). Although there is a strong consensus regarding the role of WM in numerical processing, there are divergent results in terms of the working memory components (phonological loop, visual-sketchpad, and central executive control) and the mathematical skills involved, as well as the developmental stage the children under study are going through (see Peng, Namkung, Barnes, & Sun, 2016, for review). For instance, in first grade, the phonological loop is the best predictor of performance in mathematics tasks that require verbal processing (Rasmussen & Bisanz, 2005). However, much later, at seven and eight years of age, the central executive becomes the leading predictor, followed by the phonological loop, in explaining mathematics performance (Henry & MacLean, 2003; Meyer, Salimpoor, Wu, Geary, & Menon, 2010). This suggests that both the phonological loop and the central executive are key components in the performance of mathematics tasks that require verbal processing at initial stages of mathematical learning.

Over the past decade, there has been a growing interest in assessing RAN as a cognitive predictor of arithmetic knowledge. This has been followed by attempts to understand its relationship with MLD, in the same way that RAN is related to RLD (e.g., Cirino, Fuchs, Elias, Powell, & Schumacher, 2015; Georgiou, Tziraki, Manolitsis, & Fella, 2013; Mazzocco & Grimm, 2013). The findings are heterogeneous and differ depending on the stimuli used in each study. For instance, Donker, Kroesbergen, Slot, Van Viersen, and De Bree (2016) studied the performance of alphanumeric RAN (digits and letters) and non-alphanumeric RAN (colours and objects) tasks in children with reading and writing disabilities, children with MLD, and children with comorbid disorders. The results indicated that children with reading and writing disabilities had a deficit in alphanumeric RAN, children with MLD had low performance in non-alphanumeric RAN, and the comorbid group had a deficit in both RAN measures. In contrast to the above results, in a longitudinal study, Mazzocco and Grimm (2013) found that the results of alphanumeric RAN were related to the performance of children with MLD. Among the studies that have looked at the role of alphanumeric tasks, some suggest MLD children show a deficit in digit naming but not in letter naming. For instance, Pauly et al. (2011) found that preschool children at risk of presenting MLD display more significant deficits in digit naming than in letter naming tasks. In another study, Clarke and Shinn (2004) found that in first grade, the results of a digit naming task correlated highly with those of a standardised mathematics test, and these results were stable from the beginning to the end of the year. However, a study involving Chinese children showed that RAN correlated significantly with arithmetic fluency, and that these correlations were independent of whether the characters were symbols, digits or letters (Cui, Georgiou, Zhang, Li, & Shu, 2017).

In short, the findings above show that there is a relationship between numerical abilities, WM, and RAN in typically developing children, and that the same relationship is found in children with MLD. Despite agreement regarding association between the factors, there are multiple inconsistencies in the results, derived from the multidimensional nature of the WM and RAN constructs, and the nature of the mathematical abilities on which their influence is studied. In the present research, given the numerical tasks selected, which do not require extensive visuo-spatial processing, our interest has focused on the phonological loop and central executive components of WM. Regarding rapid naming tasks, the main aim was to study alphanumeric-RAN with the intention of discerning whether there is a differentiating effect between RAN-Digit and RAN-Letter in typical and atypical development of numerical skills. Additionally, we examine this issue during the early stages of basic numerical skills acquisition, as these are critical for future development of complex mathematical abilities. The study followed a longitudinal design monitoring the development of numerical skills three times over the course of a year, with the use of CBM measures, in relation to performance in WM and RAN tasks. The approach allows us to study whether the relationship between WM, RAN, and curricular numerical abilities differs between the groups based on initial differences in performance or on the trajectory reached during the first year. It also enables us to better understand the role of these predictors in the development of numerical skills in children at risk of developing MLD, and in children with average performance.

## Method

### *Participants*

The participants were 143 first grade students – 69 boys and 74 girls (age, $M = 77.96$ months, $SD = 4.85$; Intelligence quotient (IQ), $M = 107.04$, $SD = 12.55$) – from two private subsidised schools in the Biobío region of Chile, which make up around 50 percent of the schools in the country. These schools receive funding from the state as well as fees for attendance. The sample was divided into two groups based on their performance in the *Prueba para la evaluación de la competencia matemática* (Evaluation of Mathematical Competency Test, EVAMAT-1) standardised mathematics test (García Vidal, García, & González, 2013). The groups were matched on sex, age, and IQ. All individuals in each of the groups had an IQ > 80. The 30th percentile was used as a cut-off score for EVAMAT-1, as has been the case in previous studies (Geary, Hoard, Byrd-Craven, & de Soto, 2004; Jordan & Hanich, 2000). The first group consisted of 32 children at risk of MLD (MLD-at-risk), who scored at or below the 30th percentile in EVAMAT-1, while the typically developing group (non-MLD) comprised 32 children above the 30th percentile for EVAMAT-1. The groups (MLD-at-risk, non-MLD) did not differ significantly in age, $F(1, 62) = .596$, $p = .443$ or IQ, $F(1, 62) = .118$, $p = .733$, and had exactly the same proportion of boys (12) and girls (20). See Table 1 for descriptive statistics.

**Table 1**
Descriptive statistics of the sample by group

| | MLD-at-risk | | Non-MLD | |
|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* |
| IQ | 102.97 | 12.36 | 104.00 | 11.66 |
| Age | 76.34 | 3.19 | 76.94 | 2.96 |
| NCF-0 | 2.19 | 3.15 | 7.84 | 6.98 |
| NCF-1 | 5.94 | 5.96 | 13.28 | 8.36 |
| NCF-2 | 9.19 | 6.50 | 16.50 | 7.18 |
| MNF-0 | 2.59 | 3.44 | 6.47 | 4.71 |
| MNF-1 | 3.81 | 3.58 | 8.28 | 5.29 |
| MNF-2 | 4.53 | 4.08 | 9.38 | 4.82 |
| FDS | 3.38 | 1.39 | 3.74 | 1.03 |
| BDS | 2.22 | 0.94 | 2.48 | 0.96 |
| RAN-Digit | 47.35 | 10.76 | 39.94 | 8.85 |
| RAN-Letter | 52.03 | 15.30 | 47.48 | 15.36 |

*Note*. MLD-at-risk: children at risk of developing mathematical learning disabilities; non-MLD: children with average performance in mathematics; 0 = fall; 1 = middle; 2 = end. FDS: forward digit span, BDS: backward digit span, MNF: Missing number fluency, NCF: Number comparison fluency.

### *Instruments*

#### *Domain-specific cognitive tasks*

*Assessing Student Proficiency in Early Number Sense, ASPENS* (Clarke et al., 2012). This test consists of three parallel CBM measures for the detection and monitoring of progress in mathematics in the first grade. Children are tested individually, with a time limit of one minute per task at each time point. The reliability of the ASPENS measure is in the moderate to high range (.74–.85) (Gersten et al., 2012). The predictive validity of the drop scores in the ASPENS measure for first grade, in TerraNova 3, ranges between .45 and .52. Despite not being adapted to Chilean children, ASPENS is a fairly good fit for the Chilean first grade curriculum. In fact, the correlations between the standardised EVAMAT-1 and each of the subtests of ASPENS across different measures are moderate, which is within the expected range (see Table 2). Two ASPENS tasks were used in the present study: (1) *Number comparison fluency (NCF)*. The task consists of a sheet containing 28 pairs of boxes, with two numbers (between 0 and 99) filling each pair of boxes. For each pair, the child had to indicate which number was the largest; and (2) *Missing number fluency (MNF)*. The task consists of a sheet containing 42 ascending numerical series of three numbers (0-99). In each case, the child had to say the fourth, missing number aloud. In both tasks, the dependent measure was the number of correct responses in a minute.

*Evaluation of Mathematical Competency Test (Prueba para la evaluación de la competencia matemática, EVAMAT-1, version 2.0)* (García Vidal et al., 2013). This is a standardised test used at the end of the first grade to measure performance in mathematics. The test consists of several sets, but in the present study we used only two of these sets: (1) *Set of number tasks*. The set of tasks included the following: six activities where the child had to number four elements

**Table 2**
Correlations between the scores in ASPENS tasks and EVAMAT-1

| | NCF_0 | NCF_1 | NCF_2 | MNF_0 | MNF_1 | MNF_2 |
|---|---|---|---|---|---|---|
| EVAMAT | .554$^{**}$ | .571$^{**}$ | .605$^{**}$ | .578$^{**}$ | .640$^{**}$ | .650$^{**}$ |

*Note*. 0 = fall; 1 = middle; 2 = end. MNF: Missing number fluency, NCF: Number comparison fluency.

$^{**}$ Significant correlation to 0.01 level (2-tailed).

of a set according to size, height, and quantity; four counting tasks in which the child had to count objects and assign a cardinal value within a set of four options; seven sign use tasks (<, > or =) where the child had to count two groups of objects and write the corresponding sign; and six comparison tasks with continuous quantities, in which the child had to mark with a cross where there was more and less water; and (2) *Set of calculation tasks.* This set is made up of seven tasks that measure calculation procedures, calculation strategies and knowledge of concepts used in addition and subtraction operations, specifically: eight addition and subtraction operations where the child had to solve them and write the results on a sheet of paper; thirteen mental addition and subtraction calculations, in which the child had to mark with a cross the correct response from a list of four options; five items of additive decomposition of numbers, where the child had to draw an arrow linking additions with the correct result; five items of number identification, where the child had to circle the smallest number and then write the predecessor and successor numbers; five items of decomposition in tens and units, in which the child had to draw an arrow to connect each number with its corresponding tens and units; and five items of ordinal number use, where the child had to draw an arrow to link each child in a race with their corresponding position (from first to sixth).

For both the number and calculation tasks, the number of correct responses in one minute formed the score, which was converted into percentiles according to the test's standardisation norms. Cronbach's alpha was .88 for the set of number tasks, and .92 for the set of calculation tasks.

### *Domain-general cognitive tasks*

*Culture Fair Intelligence Test (Scale 1, Form A)* (Cattell & Cattell, 1989). In this test, the child is asked to recognise patterns, to reason, and to solve problems. The authors conducted the adaptation to Spanish. The reliability obtained by the split-halves method was .86, and a correlation coefficient of .68 was obtained with the scores from the Primary Mental Abilities Test (TEA-1) (Seisdedos, De La Cruz, Cordero, & González, 1991).

*Rapid Automatized Naming (RAN).* This test is based on Denckla and Rudel's (1976) technique. The child has to name the stimuli presented in a matrix of five rows and ten columns. In the present study, only the serial naming tasks for letters and digits were used. RAN-letters and RAN-digits provide a high degree of test-retest reliability, $r = .90$ and $r = .92$, respectively (Wolf & Denckla, 2005). The score is recorded based on the time spent reading the stimuli.

*Memory Subtests.* The forward and backward digit span tasks from the Wechsler Intelligence Scale for Children (WISC-IV) (Wechsler, 2003) were administered. In the forward digit span subtest, the child was asked to repeat a list of digits at the rate of one digit per second, in the same order in which they were presented by the examiner. In the backward digit span subtest, the child was asked to perform the verbalisation of the digits in reverse order. Cronbach's alpha was .73 for *forward digit span* and .72 for *backward digit span* tasks. The score was the number of correct responses in each subtest. The forward digit span was used as an indicator of phonological loop, and the backward digit span as an indicator of central executive function (e.g., Toll & Van Luit, 2013).

### *Procedure*

The study was approved by the Universidad Católica de la Santísima Concepción Ethics Committee. Consent and assent forms were sent out to parents before the study began. Parents signed the consent forms and children signed (wrote their name on) the assent forms. The study took place in a quiet room at each school. The tests were administered separately and in a fixed order during three different rounds of evaluation, each of which occurred approximately three months apart. The first round took place in May, the second in September, and the third in December, at the end of the school year. Each of the three rounds of evaluation included a set of CBM measures; however, the third round included two additional sets of tests. The first of these were the cognitive tasks – the forward and backward digit span tests and the alphanumeric-RAN tasks – and the final set consisted of the EVAMAT-1 test. Each child was tested individually, and by a trained graduate examiner.

### *Data analysis*

Growth curve analyses (Mirman, 2014) were conducted to analyse the development of children's scores in Number Comparison Fluency (NCF) and Missing Number Fluency (MNF) over the course of one academic year, taking three measures, each separated by a period of three months. The intercept coefficient in the models represents the mean value of each group at the starting point – in this case, at first assessment – whereas the slope term indicates the average linear growth rate over time. All growth curve models had random effects of participants on time term. We conducted these analyses in three stages. First, we calculated two models (one for each task) with Group (MLD-at-risk, non-MLD) and Time (Fall = 0, Middle = 1, End = 2) as factors, without any covariates. Then, in order to look at the effects of covariates of interest, we ran two new models (one for each task). Each of these new models had RAN-Letter, RAN-Digit, FDS, and BDS as time-invariant covariates, including the interaction of each covariate with Group and Time. Finally we compared each of the full models with each of the simplified models using the *anova* function in R (R Core Team, 2016) and ULLRToolbox (Hernández & Betancort, 2016).

## Results

The two models without covariates showed a significant effect of Group and Time, but no interaction between the factors. This means that both groups grew at a similar rate in NCF (MLD-at-risk = 3.50; non-MLD = 4.33) and MNF (MLD-at-risk = .97; non-MLD = 1.45), but with different starting points for both NCF (MLD-at-risk children = 2.27; non-MLD children = 8.21) and MNF (MLD-at-risk children = 2.68; non-MLD children = 6.59) (see Tables 3 and 4).

When RAN-Letter, RAN-Digit, FDS, and BDS as time-invariant were introduced as covariates, the results of these models showed that RAN-Letter and FDS had no significant or marginally significant main effects, or interactions in any of the tasks. Hence, we removed the two non-significant covariates and ran a new simplified model for each task, with only RAN-digit and BDS as covariates. The comparison of each of the full models with each of the simplified models showed no significant differences in each of the tasks; however, the simplified models had slightly higher goodness of fit (as assessed by AIC and BIC) and improved log likelihood. Hence, we opted for the simplified models, because they were the most parsimonious.

### *NCF Task*

Model 2 shows the results when time-invariant covariates RAN-Letter and BDS, and their interactions with Time and Group, were added to the model (Table 4). In this model, the main effect of RAN-Letter did not have a significant influence on NC. The interaction of RAN-Letter × Group was significant: when the time on RAN-Letter decreases, the NC scores increase for non MLD-children, but not for MLD-at-risk children (see Figure 1). BDS did not have a significant influence on NC, and the interaction of BDS × Group was not significant, either. However, there was a significant BDS × Group × Time interaction, which reveals that while NC scores increase in non-MLD children over time, independent of BDS score, MLD-at-risk

**Table 3**
Likelihood ratio tests comparing the full models and the simplified models in NCF and MNF tasks

| | *df* | AIC | BIC | log-Likelihood | $\chi^2$ | $df_{\chi}{}^2$ | *p* |
|---|---|---|---|---|---|---|---|
| *NCF* | | | | | | | |
| Simplified Model | 16 | 1092.00 | 1143.00 | −530.00 | | | |
| Full Model | 24 | 1103.00 | 1181.00 | −528.00 | 4.34 | 8 | 0.83 |
| *MNF* | | | | | | | |
| Simplified Model | 16 | 961.00 | 1013.00 | −465.00 | | | |
| Full Model | 24 | 973.00 | 1051.00 | −463.00 | 4.04 | 8 | 0.85 |

*Note*. MNF: Missing number fluency, NCF: Number comparison fluency.

**Table 4**
Growth curves results for effects on NC

| | Estimate | SE | *t* | *p* |
|---|---|---|---|---|
| *Model 1* | | | | |
| Intercept | 2.27 | 1.00 | 2.27 | .003 |
| Slope | 3.50 | 1.41 | 4.20 | .000 |
| Intercept on AG-group | 5.94 | .41 | 8.56 | .000 |
| Slope on AG-group | .83 | .59 | 1.43 | .155 |
| *Model 2* | | | | |
| Intercept | 2.74 | 63.32 | 2.86 | .005 |
| Slope | 3.96 | 118.38 | 4.12 | .000 |
| Intercept on AG | 5.53 | 63.32 | 9.91 | .000 |
| Slope on AG-group | .39 | 118.38 | -.10 | .474 |
| RAN-Letter | −.01 | 63.32 | 1.58 | .917 |
| RAN-Letter × Time | −.02 | 118.38 | .72 | .530 |
| RAN-Letter × Group | −.20 | 63.32 | −2.30 | .025 |
| RAN-Letter × Group × Time | −.04 | 118.38 | −.32 | .231 |
| BDS | 1.62 | 63.32 | 2.50 | .112 |
| BDS × Time | 1.07 | 118.38 | −.63 | .014 |
| BDS × Group | −.45 | 63.32 | −2.53 | .750 |
| BDS × Group × Time | −1.49 | 118.38 | −1.20 | .013 |

*Note*. BDS: backward digit span.

children only show an increase in growth rate of NC scores when they reach at least a 2-digit span in the BDS task (see Figure 2).

### *MNF Task*

Model 2 shows the results when time-invariant covariates RAN-Letter and BDS, and their interactions with Time and Group, were added to the model (Table 5). As with NC, the main effect of RAN-Letter did not have a significant influence on MN. The interaction of RAN-Letter × Group was significant: when the time on RAN-Letter decreases, the MN scores increase for non MLD-children, but not for MLD-at-risk children (see Figure 3). BDS had a significant influence on MN score, and the interaction of BDS × Group × Time was marginally significant ($p = .068$). Figure 4 indicates that, as with NC, while MN scores increase in non-MLD children over time, independent of BDS score, MLD-at-risk children only show an increase in growth rate of NC scores when they reach a high level of BDS.

## Discussion

The aim of this research was to examine the effect of WM and RAN on the development of basic numeric skills in early stages of learning, with the use of Curriculum-based Measurement (CBM) in typically developing children and children at risk of developing MLD. As of today, very little longitudinal data is available on skill development in children with MLD.

We first analysed the growth rate of non-MLD and MLD-at risk children in both number sense tasks (NCF and MNF). The results showed differences between the groups in the intercept of both measures; however, there was no difference in their growth rate, with initial differences remaining stable throughout the year. These results are consistent with previous findings in which differences in performance were observed between MLD-at risk children and children with typical development when comparing symbolic magnitudes (De Smedt & Gilmore, 2011; Mussolin, Mejias, & Noël, 2010; Piazza et al., 2010). This can be explained by the number sense deficit hypothesis that states that the core deficit of developmental dyscalculia (DD) lies in the inability to process magnitudes (Dehaene, 1997; Kaufmann & Von Aster, 2012). As in previous studies, the differences between non-MLD and MLD-at risk children were confirmed in our results; however, they remained stable throughout the assessment period, which coincides only partially with previous findings. For example, Jordan, Hanich, and Kaplan (2003) assessed children with poor and good arithmetical skills throughout the second and third grades. They found that the differences between the two groups in specific cognitive domains,

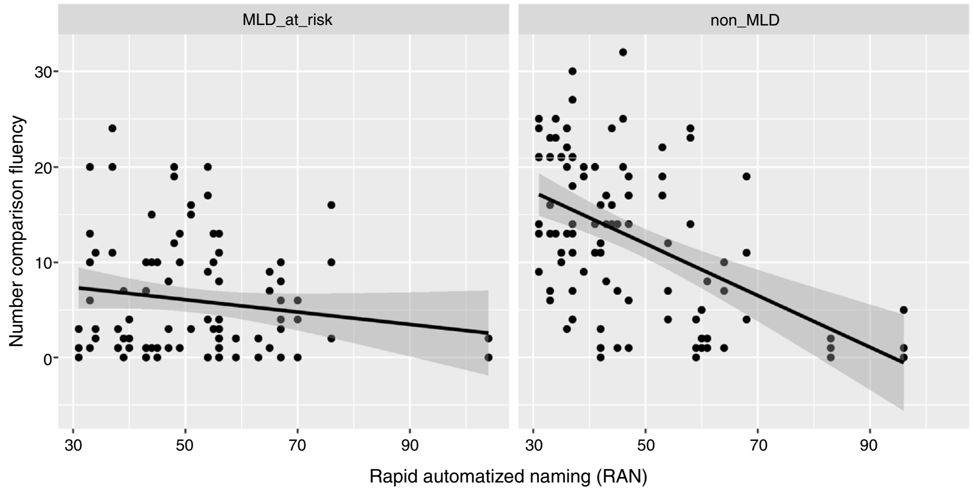

**Figure 1.** Interaction effect between RAN-Letter and Group on NC.

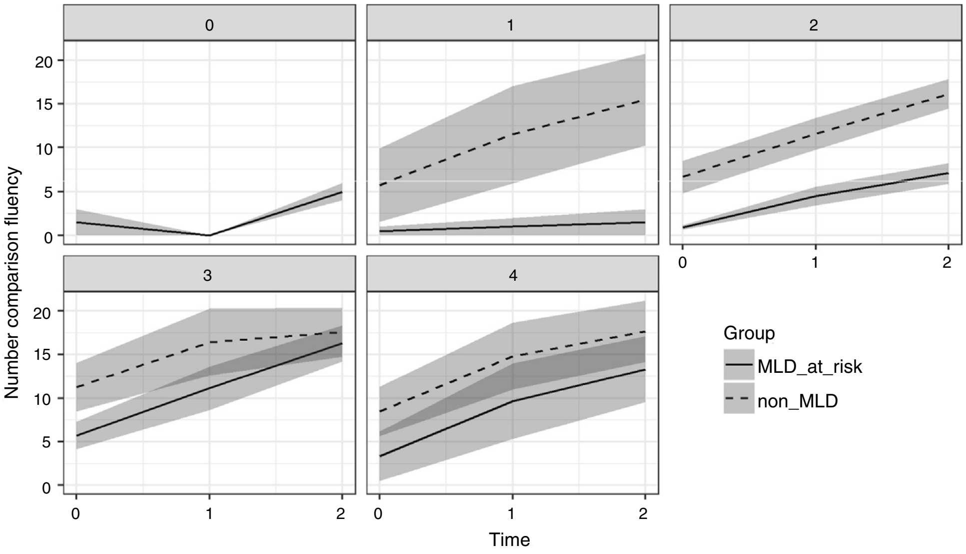

**Figure 2.** Interaction effect between BDS, Group and Time on NC.

**Table 5**
Growth curves results for effects on MN

| | Estimate | SE | *t* | *p* |
|---|---|---|---|---|
| *Model 1* | | | | |
| Intercept | 2.68 | .72 | 3.70 | .000 |
| Slope | .97 | .28 | 3.42 | .000 |
| Intercept on AG-group | 3.91 | 1.02 | 3.82 | .001 |
| Slope on AG-group | .48 | .40 | 1.21 | .232 |
| *Model 2* | | | | |
| Intercept | 3.12 | .71 | 4.37 | .000 |
| Slope | 1.17 | .30 | 3.84 | .000 |
| Intercept on AG | 3.51 | .98 | 3.58 | .001 |
| Slope on AG-group | .30 | .42 | .73 | .469 |
| RAN-Letter | .02 | .05 | .33 | .741 |
| RAN-Letter × Time | −.01 | .02 | −.69 | .495 |
| RAN-Letter × Group | −.15 | .06 | −2.35 | .022 |
| RAN-Letter × Group × Time | −.01 | .03 | −.42 | .679 |
| BDS | 1.72 | .76 | 2.26 | .028 |
| BDS × Time | .44 | .32 | 1.37 | .177 |
| BDS × Group | −.68 | 1.04 | −.65 | .516 |
| BDS × Group × Time | −.83 | .45 | −1.86 | .068 |

*Note*. BDS: backward digit span.

including fact retrieval, appeared to increase over time, while others, such as broad mathematics skills, remained the same. It is worth noting that this study tested older children who performed more complex mathematical tasks than in the present study, so this might explain the differences between groups.

## *WM-number development relationship*

An interesting finding in the present study was that the growth rate of the MLD-at risk and the non-MLD groups varied when covariates were added to the statistical model. However, not all covariates had a significant effect on growth rate. Regarding WM, for example, the results indicated that FDS (phonological loop component) did not contribute to numerical skills growth, unlike BDS (executive component), whose contribution was significant in differentiating the growth trajectories of both the MLD-at risk and the non-MLD group. Two relevant aspects can be derived from this finding. First, the present result is consistent with previous findings indicating that basic numerical tasks, despite not being complex processes, are related to WM (Ansari, 2008; Morsanyi, Devine, Nobes, & Szucs, 2013). Second, the contribution of BDS to numerical processing could be explained in terms of the type of numerical task employed in the study. Thus, performance on symbolic tasks such as NCF and MNF require data processing that must be coded, interpreted, and manipulated simultaneously (Kolkman, Hoijtink, Kroesbergen, & Leseman, 2013), which places high demand on the executive component. The current results are in line with previous research that points to the executive component as the key component in deriving differences between the growth trajectories of MLD-at risk and non-MLD children (Geary, 2011; Geary, Hoard, Nugent, & Bailey, 2012; Kolkman et al., 2014). Crucially we found that BDS affects the growth rate of the groups unequally. BDS did not affect the performance growth in number sense tasks for non-MLD, but it was key for MLD-at-risk, presumably because of the WM resources needed to improve their number skills over time. This can be explained in terms of automaticity of basic number abilities. Children with average performance in first grade have a more advanced knowledge of number than those with MLD, so they are more fluent in handling different numerical codes and operating with them. This implies that their executive control demands are particularly low (Cantlon et al., 2009), which is exactly opposite to the case of children with MLD, who do not seem to have acquired automatization of arithmetic operations, and therefore need to put in place other types of strategies that require greater executive control.

## *RAN-number development relationship*

As stated earlier, RAN could be a predictor of early numerical abilities (Cui et al., 2017; Georgiou et al., 2013). The findings of the present study indicate that performance in RAN-Letter contributed significantly to the performance of the groups in both CBM tasks administered, unlike RAN-Digit, whose effect on the tasks was not significant. This result does not fit with previous findings (Pauly et al., 2011; Van der Sluis, de Jong, & van der Leij, 2004). We consider that the recall of Arabic numbers may require, from an early stage, an exclusively phonological access path, while letters could be mediated by other representations, such as orthographic representations or even conceptual representations, which become activated during access to phonological representations. In fact, it has been shown that in early stages of development, the association between alphanumeric codes is weak, but progressively both routes are integrated into a single alphanumeric network of access to the lexicon (van den Bos, Zijlstra, & Spelberg, 2002). Support for this statement can also be found in the neuroimaging literature,

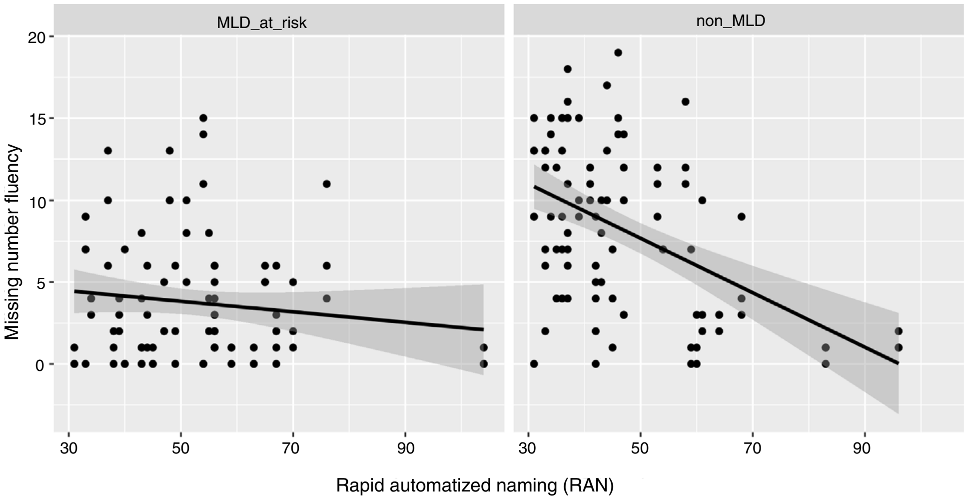

**Figure 3.** Interaction effect between RAN-Letter and Group on MNF.

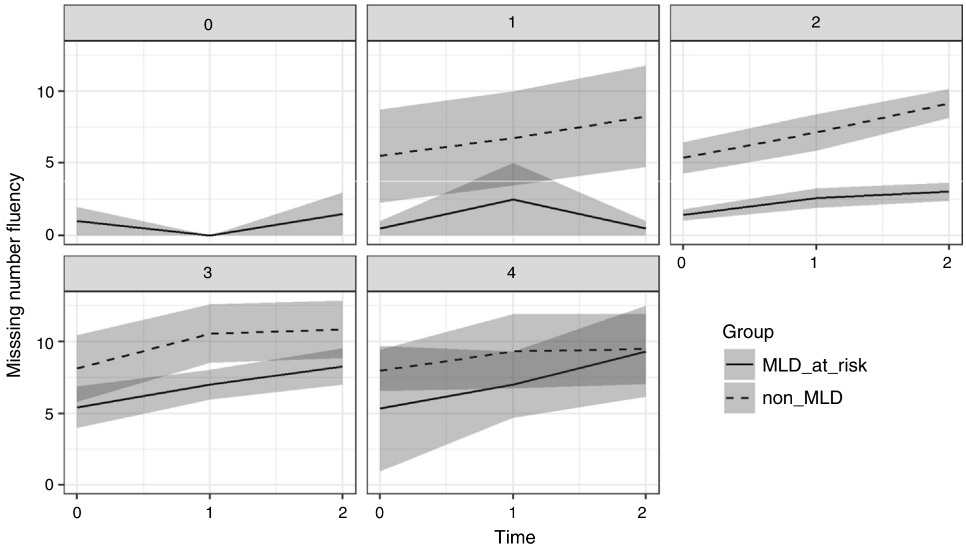

**Figure 4.** Interaction effect between BDS, Group and Time on MNF.

where neural differences have been reported for the visual recognition of letters and numbers (Park, Hebrank, Polk, & Park, 2012).

We found that RAN-Letter does not contribute significantly to the development of numerical skills. However, it does have differential effects on non-MLD and MLD-at-risk children in numerical abilities. Our results showed that as RAN-Letter time decreases, performance for numerical skills increases, but only for the non-MLD group. This may be due to the level of automaticity acquired by non-MLD children to perform both tasks, which children at risk of MLD do not develop. It is worth emphasising that RAN measures the degree of automaticity during the recall of phonological labels from a symbolic input. In turn, completion of the proposed numerical tasks requires, at least in part, a similar exercise. We propose that children at risk of MLD do not have a proper analogue representation of number, so they cannot perform numerical tasks under the expected degree of automaticity; instead they need to use alternative strategies that require more intensive use of other mechanisms such as WM.

Although our results are conclusive in highlighting that certain components of WM are relevant to the development of numerical abilities, a possible limitation of our work is that only one task was used to measure either executive control or phonological loop, which cannot fully represent the WM construct. Another aspect that might raise questions is that the WM tasks we used require the handling of digits whose processing may overlap with that of number tasks. Future studies should take this into account in order to tease apart possible confounds and more widely assess the contribution of WM to prediction of typical and atypical mathematics skills.

## *Conclusions*

We have found that domain general and domain specific skills are important to identification of children at risk of MLD. Our findings suggest that the joint participation of both domains is the correct approach to understanding the acquisition, as well as the typical and atypical development of numerical skills. These findings further represent a contribution towards detection and early intervention, suggesting that both RAN-Letter and BDS should be included as part of MLD early detection protocols. Especially relevant is the measurement of the central executive component, due to its involvement in the development of number tasks that are not automatized, especially in the case of children at risk of MLD. Along the same lines, it would be appropriate to carry out interventions testing aspects of basic domain-specific (number sense) and domain-general (RAN and WM) skills in parallel, in order to better understand the effect of both dimensions on the development of more complex arithmetic skills, as well as their effect on the configuration of MLD profiles.

## Funding

This study was supported by CONICYT-Chile [FONDECYT REGULAR No. 1161213]; and the Spanish Ministry of Economy and Competitiveness [Programa Ramón y Cajal, RYC-2014-16948].

## References

Ansari, D. (2008). Effects of development and enculturation on number representation in the brain. *Nature Reviews Neuroscience*, *9*(4), 278–291. http://dx.doi.org/10.1038/nrn2334

Aragón, E. L., Navarro, J. I., Aguilar, M., & Cerda, G. (2015). Cognitive predictors of 5-year-old students' early number sense. *Revista de Psicodidáctica*, *20*(1), 83–97. http://dx.doi.org/10.1387/RevPsicodidact.11088

Butterworth, B., Varma, S., & Laurillard, D. (2011). Dyscalculia: From brain to education. *Science*, *332*(6033), 1049–1053. http://dx.doi.org/10.1126/science.1201536

Cantlon, J. F., Libertus, M. E., Pinel, P., Dehaene, S., Brannon, E. M., & Pelphrey, K. A. (2009). The neural development of an abstract concept of number. *Journal of Cognitive Neuroscience*, *21*(11), 2217–2229. http://dx.doi.org/10.1162/jocn.2008.21159

Cattell, R. B., & Cattell, A. K. S. (1989). *Test de Factor "g"*. Escala 1 and 2. (Seisdedos, De La Cruz, Cordero, & González, 1991). Madrid: T.E.A. Ediciones (Originally published in 1950).

Chu, F. W., vanMarle, K., & Geary, D. C. (2016). Predicting children's reading and mathematics achievement from early quantitative knowledge and domain-general cognitive abilities. *Frontiers in Psychology*, *7*, 1–14. http://dx.doi.org/10.3389/fpsyg.2016.00775

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. http://dx.doi.org/10.1177/0022219413494239

Clarke, B., Doabler, C. T., Smolkowski, K., Baker, S. K., Fien, H., & Strand Cary, M. (2016). Examining the efficacy of a Tier 2 kindergarten mathematics intervention. *Journal of Learning Disabilities*, *49*(2), 152–165. http://dx.doi.org/10.1177/0022219414538514

Clarke, B., Gersten, R., Dimino, J., & Rolfhus, E. (2012). *Assessing student proficiency in early number sense (ASPENS) [Measurement instrument]*. Longmont, CO: Cambium Learning Group.

Clarke, B., & Shinn, M. R. (2004). A preliminary investigation into the identification and development of early mathematics curriculum-based measurement. *School Psychology Review*, *33*(2), 234.

Cowan, R., & Powell, D. (2014). The contributions of domain-general and numerical factors to third-grade arithmetic skills and mathematical learning disability. *Journal of Educational Psychology*, *106*(1), 214–229. http://dx.doi.org/10.1037/a0034097

Cui, J., Georgiou, G. K., Zhang, Y., Li, Y., & Shu, H. (2017). Examining the relationship between rapid automatized naming and arithmetic fluency in Chinese kindergarten children. *Journal of Experimental Child Psychology*, *154*, 146–163. http://dx.doi.org/10.1016/j.jecp.2016.10.008

Cummings, K. D., & Petscher, Y. (Eds.). (2015). *The fluency construct: Curriculum-based measurement concepts and applications*. New York: Springer. http://dx.doi.org/10.1007/978-1-4939-2803-3

Dehaene, S. (1997). *The number sense: How the mind creates mathematics*. New York: Oxford University Press.

Denckla, M. B., & Rudel, R. G. (1976). Rapid 'automatized' naming (R.A.N.): Dyslexia differentiated from other learning disabilities. *Neuropsychologia*, *14*, 471–479. http://dx.doi.org/10.1016/0028-3932(76)90075-0

De Smedt, B., & Gilmore, C. K. (2011). Defective number module or impaired access? Numerical magnitude processing in first graders with mathematical difficulties. *Journal of Experimental Child Psychology*, *108*(2), 278–292. http://dx.doi.org/10.1016/j.jecp.2010.09.003

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. http://dx.doi.org/10.1016/j.lindif.2015.12.011

Foegen, A., Jiban, C., & Deno, S. (2007). Progress monitoring measures in mathematics: A review of the literature. *Journal of Special Education*, *41*(2), 121-139. http://dx.doi.org/10.1177/00224669070410020101

Fuchs, D., & Fuchs, L. S. (2006). Introduction to response to intervention: What, why, and how valid is it? *Reading Research Quarterly*, *41*(1), 93–99. http://dx.doi.org/10.1598/RRQ.41.1.4

Fuchs, L. S., Fuchs, D., & Compton, D. L. (2012). The early prevention of mathematics: Its power and limitations. *Journal of Learning Disabilities*, *45*(3), 257–269. http://dx.doi.org/10.1177/0022219412442167

García Vidal, J., García, B., & González, D. (2013). *EVAMAT-Prueba para la evaluación de la competencia matemática*. Madrid: EOS.

Geary, D. C. (2011). Cognitive predictors of achievement growth in mathematics: A 5-year longitudinal study. *Developmental Psychology*, *47*(6), 1539. http://dx.doi.org/10.1037/a0025510

Geary, D. C. (2013). Early foundations for mathematics learning and their relations to learning disabilities. *Current Directions in Psychological Science*, *22*(1), 23–27. http://dx.doi.org/10.1177/0963721412469398

Geary, D. C., Hoard, M. K., Byrd-Craven, J., & De Soto, M. C. (2004). Strategy choices in simple and complex addition: Contributions of working memory and counting knowledge for children with mathematical disability. *Journal of Experimental Child Psychology*, *88*, 121–151. http://dx.doi.org/10.1016/j.jecp.2004.03.002

Geary, D. C., Hoard, M. K., Byrd-Craven, J., Nugent, L., & Numtee, C. (2007). Cognitive mechanisms underlying achievement deficits in children with mathematical learning disability. *Child Development*, *78*(4), 1343–1359. http://dx.doi.org/10.1111/j.1467-8624.2007.01069.x

Geary, D. C., Hoard, M. K., Nugent, L., & Bailey, D. H. (2012). Mathematical cognition deficits in children with learning disabilities and persistent low achievement: A five-year prospective study. *Journal of Educational Psychology*, *104*(1), 206–223. http://dx.doi.org/10.1037/a0025398

Georgiou, G. K., Tziraki, N., Manolitsis, G., & Fella, A. (2013). Is rapid automatized naming related to reading and mathematics for the same reason(s)? A follow-up study from kindergarten to Grade 1. *Journal of Experimental Child Psychology*, *115*(3), 481–496. http://dx.doi.org/10.1016/j.jecp.2013.01.004

Gersten, R., Clarke, B., Jordan, N. C., Newman-Gonchar, R., Haymond, K., & Wilkins, C. (2012). Universal screening in mathematics for the primary grades: Beginnings of a research base. *Exceptional Children*, *78*(4), 423–445. http://dx.doi.org/10.1177/001440291207800403

Henry, L., & MacLean, M. (2003). Relationships between working memory, expressive vocabulary and arithmetical reasoning in children with and without intellectual disabilities. *Educational and Child Psychology*, *20*(3), 51–63.

Hernández, J. A., & Betancort, M. (2016). *ULLRtoolbox*. Retrieved from https://sites.google.com/site/ullrtoolbox/

Hinton, V., Flores, M. M., & Shippen, M. (2014). Response to intervention and math instruction. *International Journal of Education in Mathematics, Science and Technology*, *1*(3), 190–201. Retrieved from http://dergipark.gov.tr/ijemst/issue/8002/105086

Jiménez, J. E., & de León, S. D. C. (2017). Análisis factorial confirmatorio de Indicadores de Progreso de Aprendizaje en Matemáticas (IPAM) en escolares de primer curso de Primaria. *European Journal of Investigation in Health, Psychology and Education*, *7*(1), 31–45. http://dx.doi.org/10.30552/ejihpe.v7i1.193

Jordan, N. C., & Hanich, L. B. (2000). Mathematical thinking in second-grade children with different forms of LD. *Journal of Learning Disabilities*, *33*(6), 567–578. http://dx.doi.org/10.1177/002221940003300605

Jordan, N. C., Hanich, L. B., & Kaplan, D. (2003). Arithmetic fact mastery in young children: A longitudinal investigation. *Journal of Experimental Child Psychology*, *85*(2), 103–119. http://dx.doi.org/10.1016/S0022-0965(03)00032-8

Kaufmann, L., & von Aster, M. (2012). The diagnosis and management of dyscalculia. *Deutsches Ärzteblatt International*, *109*(45), 767–777. http://dx.doi.org/10.3238/arztebl.2012.0767, quiz 778

Kolkman, M. E., Hoijtink, H. J., Kroesbergen, E. H., & Leseman, P. P. (2013). The role of executive functions in numerical magnitude skills. *Learning and Individual Differences*, *24*, 145–151. http://dx.doi.org/10.1016/j.lindif.2013.01.004

Kolkman, M. E., Kroesbergen, E. H., & Leseman, P. P. (2014). Involvement of working memory in longitudinal development of number – Magnitude skills. *Infant and Child Development*, *23*(1), 36–50. http://dx.doi.org/10.1002/icd.1834

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. http://dx.doi.org/10.1037/0022-0663.100.1.150

Lembke, E., & Foegen, A. (2009). Identifying early numeracy indicators for Kindergarten and first grade students. *Learning Disabilities Research & Practice*, *24*(1), 12-20. http://dx.doi.org/10.1111/j.1540-5826.2008.01273.x

Locuniak, M. N., & Jordan, N. C. (2008). Using kindergarten number sense to predict calculation fluency in second grade. *Journal of Learning Disabilities*, *41*(5), 451–459. http://dx.doi.org/10.1177/0022219408321126

Mazzocco, M. M. M., & Grimm, K. J. (2013). Growth in rapid automatized naming from grades K to 8 in children with math or reading disabilities. *Journal of Learning Disabilities*, *46*(6), 517–533. http://dx.doi.org/10.1177/0022219413477475

Mazzocco, M. M. M., & Rasanen, P. (2013). Contributions of longitudinal studies to evolving definitions and knowledge of developmental dyscalculia. *Trends in Neuroscience and Education*, *2*(2), 65–73. http://dx.doi.org/10.1016/j.tine.2013.05.001

Meyer, M. L., Salimpoor, V. N., Wu, S. S., Geary, D. C., & Menon, V. (2010). Differential contribution of specific working memory components to mathematics achievement in 2nd and 3rd graders. *Learning and Individual Differences*, *20*(2), 101–109. http://dx.doi.org/10.1016/j.lindif.2009.08.004

Mirman, D. (2014). *Growth curve analysis and visualization using R*. Florida, USA: Chapman & Hall/CRC.

Morsanyi, K., Devine, A., Nobes, A., & Szucs, D. (2013). The link between logic, mathematics and imagination: Evidence from children with developmental dyscalculia and mathematically gifted children. *Developmental Science*, *16*(4), 542–553. http://dx.doi.org/10.1111/desc.12048

Mussolin, C., Mejias, S., & Noël, M. P. (2010). Symbolic and nonsymbolic number comparison in children with and without dyscalculia. *Cognition*, *115*(1), 10–25. http://dx.doi.org/10.1016/j.cognition.2009.10.006

Park, J., Hebrank, A., Polk, T. A., & Park, D. C. (2012). Neural dissociation of number from letter recognition and its relationship to parietal numerical processing. *Journal of Cognitive Neuroscience*, *24*(1), 39–50.

Passolunghi, M. C., & Siegel, L. S. (2004). Working memory and access to numerical information in children with disability in mathematics. *Journal of Experimental Child Psychology*, *88*(4), 348–367. http://dx.doi.org/10.1016/j.jecp.2004.04.002

Pauly, H., Linkersdörfer, J., Lindberg, S., Woerner, W., Hasselhorn, M., & Lonnemann, J. (2011). Domain-specific Rapid Automatized Naming deficits in children at risk for learning disabilities. *Journal of Neurolinguistics*, *24*(5), 602–610. http://dx.doi.org/10.1016/j.jneuroling.2011.02.002

Peng, P., Namkung, J., Barnes, M., & Sun, C. (2016). A meta-analysis of mathematics and working memory: Moderating effects of working memory domain, type of mathematics skill, and sample characteristics. *Journal of Educational Psychology*, *108*(4), 455–473. http://dx.doi.org/10.1037/edu0000079

Piazza, M., Facoetti, A., Trussardi, A. N., Berteletti, I., Conte, S., Lucangeli, D., & Zorzi, M. (2010). Developmental trajectory of number acuity reveals a severe impairment in developmental dyscalculia. *Cognition*, *116*(1), 33–41. http://dx.doi.org/10.1016/j.cognition.2010.03.012

Presentación-Herrero, M. J., Mercader-Ruiz, J., Siegenthaler-Hierro, R., Fernández-Andrés, I., & Miranda-Casas, A. (2015). Funcionamiento ejecutivo y motivación en niños de educación infantil con riesgo de dificultades en el aprendizaje de las matemáticas. *Revista de Neurología*, *60*(1), 81–85.

R Core Team. (2016). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from https://www.r-project.org/

Raghubar, K. P., Barnes, M. A., & Hecht, S. A. (2010). Working memory and mathematics: A review of developmental, individual difference, and cognitive approaches. *Learning and Individual Differences*, *20*(2), 110–122. http://dx.doi.org/10.1016/j.lindif.2009.10.005

Rasmussen, C., & Bisanz, J. (2005). Representation and working memory in early arithmetic. *Journal of Experimental Child Psychology*, *91*(2), 137–157. http://dx.doi.org/10.1016/j.jecp.2005.01.004

Rodríguez, C., & Jiménez, J. E. (2016). What cognitive and numerical skills best define learning disabilities in mathematics?/¿ Qué habilidades cognitivas y numéricas definen mejor las dificultades de aprendizaje en matemáticas? *Estudios de Psicología*, *37*(1), 115–134. http://dx.doi.org/10.1080/02109395.2015.1129825

Rodríguez, C., van den Boer, M., Jiménez, J. E., & de Jong, P. F. (2015). Developmental changes in the relations between RAN, phonological awareness, and reading in Spanish children. *Scientific Studies of Reading*, *19*(4), 273–288. http://dx.doi.org/10.1080/10888438.2015.1025271

Simmons, F. R., & Singleton, C. (2008). Do weak phonological representations impact on arithmetic development? A review of research into arithmetic and dyslexia. *Dyslexia*, *14*(2), 77–94. http://dx.doi.org/10.1002/dys.341

Tobia, V., Bonifacci, P., & Marzocchi, G. M. (2016). Concurrent and longitudinal predictors of calculation skills in preschoolers. *European Journal of Psychology of Education*, *31*(2), 155–174. http://dx.doi.org/10.1007/s10212-015-0260-y

Toll, S. W., & Van Luit, J. E. (2013). The development of early numeracy ability in kindergartners with limited working memory skills. *Learning and Individual Differences*, *25*, 45–54. http://dx.doi.org/10.1016/j.lindif.2013.03.006

Toll, S. W. M., Van der Ven, S. H. G., Kroesbergen, E. H., & Van Luit, J. E. H. (2011). Executive functions as predictors of math learning disabilities. *Journal of Learning Disabilities*, *44*(6), 521–532. http://dx.doi.org/10.1177/0022219410387302

Träff, U. (2013). The contribution of general cognitive abilities and number abilities to different aspects of mathematics in children. *Journal of Experimental Child Psychology*, *116*(2), 139–156. http://dx.doi.org/10.1016/j.jecp.2013.04.007

Träff, U., Olsson, L., Östergren, R., & Skagerlund, K. (2017). Heterogeneity of developmental dyscalculia: Cases with different deficit profiles. *Frontiers in Psychology*, *7*, 2000. http://dx.doi.org/10.3389/fpsyg.2016.02000

van den Bos, K. P., Zijlstra, B. J. H., & Spelberg, H. C. (2002). Life-span data on continuous-naming speeds of numbers, letters, colors, and pictured objects, and word-reading speed. *Scientific Studies of Reading*, *6*, 25–49. http://dx.doi.org/10.1207/S1532799XSSR 0601_02

Van der Sluis, S., de Jong, P. F., & van der Leij, A. (2004). Inhibition and shifting in children with learning deficits in arithmetic and reading. *Journal of Experimental Child Psychology*, *87*, 239–266. http://dx.doi.org/10.1016/j.jecp.2003.12.002

Wechsler, D. (2003). *Wechsler Intelligence Scale for Children* (4th ed. (WISC-IV)). San Antonio, TX: The Psychological Corporation.

Wolf, M., & Denckla, M. B. (2005). *Rapid automatized naming and rapid alternating stimulus tests (RAN/RAS)*. Austin: PRO-ED.

Xenidou-Dervou, I., Van Luit, J. E., Kroesbergen, E. H., Friso-van den Bos, I., Jonkman, L. M., van der Schoot, M., & van Lieshout, E. C. (2018). Cognitive predictors of children's development in mathematics achievement: A latent growth modeling approach. *Developmental Science*, e12671. http://dx.doi.org/10.1111/desc.12671