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Behavioral inhibition in children with learning disabilities

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ABSTRACT

Children with reading disabilities (RD, $n = 17$), mathematical disabilities (MD, $n = 22$), combined reading and mathematical disabilities (RD + MD, $n = 28$) and control peers ($n = 45$) were tested on behavioral inhibition with a Go/no-go task in a picture, letter and digit-modality. In contrast to children without RD, children with RD made significantly more commission errors on alphanumeric (letter and digit) modalities compared to the non-alphanumeric picture modality. As compared to children without MD, children with MD made as much commission errors on the picture modality as on the letter modality. No significant interaction-effect was found between RD and MD. These results can be considered as evidence for behavioral inhibition deficits related to alphanumeric stimuli in children with RD but not in children with MD.

1. Introduction

1.1. Behavioral inhibition

Executive functions can be described as the general purpose control mechanisms that coordinate, regulate and control cognitive processes during the operation of cognitive tasks (Miyake et al., 2000) and are localized in the central executive control system of working memory (Baddeley, 1986). Among them, behavioral inhibition is seen as one of the most crucial processes (Miyake et al., 2000). According to Nigg's (2000) taxonomy, behavioral inhibition is a type of effortful inhibition, besides interference control, oculomotor and cognitive inhibition. It is considered as the capacity to suppress a prepotent or dominant response and entails the deliberate control of a primary motor response in compliance with changing context cues (Nigg, 2000). Both the Go/no-go (Luce, 1986) and the Stop-signal task (Logan, Cowan, & Davis, 1984) are frequently conducted measures of behavioral inhibition (e.g., Friedman & Miyake, 2004; Purvis & Tannock, 2000).

1.2. Behavioral inhibition in children with reading disabilities

Reading disabilities (RD) are defined as persisting impairments in reading and/or spelling abilities, at a level that remains significantly below expected given the age, and despite good instruction, and that are not explained by extraneous factors, such as sensory deficits (Schatschneider & Torgesen, 2004; Vellutino, Fletcher, Snowling, & Scanlon, 2004). Prevalence of RD is estimated between 5% and 12% (Schumacher, Hoffmann, Schmal, Schulte-Korne, & Nothen, 2007).

Deficits in phonologically related processes are often considered as the core problem of RD (e.g., Vellutino et al., 2004), but impairments in inhibition are reported as well (e.g., de Jong et al., 2009). Theoretical accounts of reading emphasize the

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important role of behavioral inhibition in the reading process (Schmid, Labuhn, & Hasselhorn, 2011). Poor behavioral inhibition may contribute to poor letter and word recognition. For instance, children with RD have to inhibit inadequate grapheme-phoneme correspondences (for instance reading 'p' as 'b' or 'm' as 'n' or 'nam' as 'man'). Failures to inhibit improper (though more dominant) pronunciations might impair word recognition performance in a more profound manner (Chiappe, Hasher, & Siegel, 2000).

In addition, several studies reported behavioral inhibition deficits in children with RD (e.g., de Jong et al., 2009; Purvis & Tannock, 2000; Schoot, Licht, Horsley, & Sergeant, 2000). Research of de Jong et al. (2009) and Purvis and Tannock (2000) revealed that children with RD had an impaired stop signal reaction time in comparison to control children. However, other studies found no differences between both groups (e.g., Reiter, Tucha, & Lange, 2005; Schmid et al., 2011). For instance, Voorde, Roeyers, Verte, and Wiersema (2010) found no behavioral inhibition problems, as measured by a Go/no-go task, in RD when a baseline measure of functioning was taken into account.

To conclude, mixed results largely depending on the paradigm used, were found concerning behavioral inhibition deficits in children with isolated RD. Paradigms used to assess behavioral inhibition sometimes also depend on working memory, making results difficult to interpret.

1.3. Behavioral inhibition in children with mathematical disabilities

Mathematical disabilities (MD) are defined in exactly the same way as RD, but concerning mathematical abilities (Desoete et al., 2013; Geary, Hoard, Nugent, & Bailey, 2011; Landerl, Bevan, & Butterworth, 2004; Passolunghi, Vercelloni, & Schadee, 2007). Most researchers currently report a prevalence of MD between 3% and 14% of children (Barbaresi, Katusic, Colligan, Weaver, & Jacobsen, 2005; Rubinsten & Henik, 2009; Shalev, Manor, & Gross-Tsur, 2005). Recently, Geary (2011) estimated a prevalence of approximately 7% of children.

Besides the important emphasis on number representation (Butterworth, 1999, 2005; Noël & Rouselle, 2011), studies focus on executive functioning as well (Bull & Scerif, 2001; D'Amico & Passolunghi, 2009; De Weerdt et al., 2012). Research has shown that inhibition is predictive for mathematical abilities and necessary in math performance for the active suppression of immature or incorrect strategies (Bull & Scerif, 2001). Children with MD and -to a lesser extent- control children might for instance have the tendency to make table-related or counting-string errors (Geary, 2011). Table-related errors are those mistakes that are in fact correct answers to similar problems in the multiplication table (e.g., '$3 \times 4 = 15$'). A counting-string error can be defined as a wrong answer that follows one of the addends (typically the last one) in the counting string (e.g., $3 + 5 = 6$; Geary, 2011). In contrast to research studying behavioral inhibition in children with RD, to our knowledge, no MD study was conducted with a Stop-signal task and only one study, concerning both ADHD and MD, used a Go/no-go task (Passolunghi, Marzocchi, & Fiorillo, 2005). This study revealed difficulties in inhibiting irrelevant numerical information in solving arithmetic word problems, but did not report any differences between the control children and the children with MD with regard to behavioral inhibition (Passolunghi et al., 2005).

However, some studies investigated prepotent response inhibition in children with MD (Bull & Scerif, 2001; Censabella & Noel, 2005, 2008; van der Sluis, de Jong, & van der Leij, 2004). The prepotent response inhibition of Friedman and Miyake (2004) encloses Nigg's behavioral and oculomotor inhibition. Whereas Nigg (2000) considers the Stroop task (Stroop, 1935) as a measure of interference control, Friedman and Miyake (2004) use this task as a measure of prepotent response inhibition. Results of MD studies using the Stroop task are mixed. Zhang and Wu (2011) reported impairments in children with MD on both a color-word and a numerical Stroop. A study of Bull and Scerif (2001) emphasized a significant correlation between mathematical performance and the level of interference control on a numerical Stroop task (the lower the mathematics ability, the higher the interference). However, no impairments on the numerical Stroop were found by Censabella and Noel (2005), nor by van der Sluis et al. (2004). Moreover, the latter found no impairments on an object version of the Stroop (van der Sluis et al., 2004).

To conclude, studies on behavioral inhibition in children with isolated MD are rare and inconclusive. Paradigms used to assess behavioral inhibition sometimes also depend on other executive functions such as working memory, making results difficult to interpret.

1.4. Comorbidity and shared cognitive risk

Comorbidity can be defined as two or more disorders that co-occur together (Neale & Kendler, 1995). In accordance with Angold, Costello, and Erkanli (1999), we can distinct homotypical from heterotypical comorbidity. The first form refers to the co-occurrence of two disorders from the same diagnostic grouping (e.g., RD and MD), whereas the latter refers to two or more disorders from different diagnostic groupings (e.g., MD and ADHD; Angold et al., 1999). It is estimated that between 3.4% (Badian, 1999) and 7.6% (Dirks, Spyer, van Lieshout, & de Sonneville, 2008) of the elementary school children suffers from both RD and MD.

Research on comorbidity in developmental disorders seems to evolve from single to multiple deficit models (Pennington, 2006). As a consequence, the focus of studies is changing from searching for one correct comorbidity model (e.g., the phenocopy model, see Neale & Kendler, 1995 and Rhee, Hewitt, Corley, Willcutt, & Pennington, 2005 for an overview of these models) to looking for possible shared cognitive risk factors (e.g., McGrath et al., 2011). The multiple deficit model assumes that developmental disorders are multifactorial and that correlations between developmental disorders at the cognitive level may cause comorbidity at the behavioral level (Pennington, 2006). Whereas the single deficit models try to define the relations between developmental disorders in terms of double dissociations, the multiple deficit model investigates these relations in terms of partial overlap (Shanahan et al., 2006).

The fact that inhibition deficits are reported both in RD and MD (e.g., Bull & Scerif, 2001; Purvis & Tannock, 2000; Zhang & Wu, 2011), may point into the direction of inhibition as a shared cognitive risk factor between RD and MD (Pennington, 2006). However, to our knowledge, no study investigated behavioral inhibition in children with RD + MD. Hence, the question about behavioral inhibition as a shared cognitive risk factor remains unanswered.

1.5. Domain-generality versus modality-specificity

In order to gain a better understanding of behavioral inhibition in children with isolated and combined learning disabilities, the issue of modality-specificity of inhibition problems seems to be important. One can assume that behavioral inhibition can be differentiated in terms of modality (Censabella & Noel, 2005), with children with RD having problems with letters and childeren with MD having problems with numbers. As a consequence, results may be influenced by the type of stimulus (Censabella & Noel, 2005; Noël & Rouselle, 2011). The evidence for the modality specificity hypothesis in children with MD and RD is mixed. Some studies reported modality-specific impairments in children with RD (e.g., Swanson, Zheng, & Jerman, 2009) and in children with MD (e.g., Bull & Scerif, 2001; Passolunghi et al., 2005; van der Sluis et al., 2004), whereas others reported domain-general impairments (e.g., Booth, Boyle, & Kelly, 2010; Zhang & Wu, 2011).

1.6. Objectives and research questions

It is not well understood yet if and how behavioral inhibition deficits are manifested in children with RD, in children with MD and in children with RD + MD. Tasks with more complex designs increase working memory demands (Simmonds, Pekar, & Mostofsky, 2008). In this study, we aim to investigate behavioral inhibition on a task with a limited working memory load, leading to the following research questions:

1. Do children with RD, children with MD and children with RD + MD (without ADHD) show deficits in behavioral inhibition as measured by a Go/no-go task (e.g., Passolunghi et al., 2005; Reiter et al., 2005)?
2. If behavioral inhibition impairments are found in children with learning disabilities, are they modality-specific (e.g., Bull & Scerif, 2001) or domain-general (e.g., Booth et al., 2010)? Is there a difference between performance on alphanumeric and non-alphanumeric behavioral inhibition measures in children with RD, MD and RD + MD?
3. Can behavorial inhibition be seen as a cognitive risk factor of RD and MD (Pennington, 2006)? If the same problems are found both in RD and in MD, this might be considered as an indication for a cognitive risk factor. Behavioral inhibition problems in RD would be similar to behavioral inhibition problems in MD. Hence, the RD + MD group would perform at a similar level than the RD and the MD group (Shanahan et al., 2006). Underadditivity would be the case: performance on behavioral inhibition tasks is the same in children with RD + MD, in children with RD and in children with MD. If the cognitive impairments in MD are independent of those in RD, then the RD + MD group would be the sum or the additive combination of the deficits in each pure group (Landerl et al., 2004; Pauly et al., 2011; van der Sluis et al., 2004; Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005).

2. Methods

2.1. Participants

Four groups of children between 8 and 12 years old participated in this study: control children from third to sixth grade of regular elementary schools and children diagnosed with RD, MD or RD + MD. Control children were recruited through letters to parents distributed in mainstream schools. Children with RD, MD or RD + MD were recruited by purposeful sampling and reputational case selection through referral by psychologists and speech therapists in multidisciplinary rehabilitation centers and through newsletters advertisements and letters to teachers and parents distributed in schools. All children with learning disabilities had a clinical diagnosis by a recognized speech therapist or in a specialized center.

All children were tested on math-, reading – and spelling measures to check if criteria were met. If that was not the case, they were excluded from the study.

Control children were selected in the control group if they had no history of learning, developmental or psychiatric problems and if they achieved a score above the 25th percentile on all math, spelling and reading tests.

Children with MD had to have a clinical diagnosis of MD, no signs of ADHD, no history of other developmental or psychiatric problems and score below the 10th percentile on at least one of the frequently used standardized math tests, measuring mental arithmetic and number knowledge (procedural skills) and fact retrieval. Children with RD had to have a clinical diagnosis of RD, no signs of ADHD, no history of other developmental or psychiatric problems and achieve a score below the 10th percentile on a spelling test and/or reading tests, measuring word reading speed and pseudoword reading. Children with RD + MD had to have a clinical diagnosis of learning disabilities without ADHD, no history of other developmental or psychiatric problems and score below the 10th percentile on at least one math and spelling- or reading test

Table 1
Subject characteristics of the whole sample.

Characteristic	Control ($n = 45$) M (SD)	RD ($n = 17$) M (SD)	MD ($n = 22$) M (SD)	RD + MD ($n = 28$) M (SD)
Age in months	120.91 (10.37)	119.53 (13.41)	117.55 (9.01)	122.29 (12.43)
Male:female	19:26	10:7	6:16	9:11
IQ	108.42 (9.86)[a]	105.18 (8.47)[ab]	94.82 (9.21)[c]	99.57 (11.45)[bc]
Z-score TTR	0.94 (0.62)[a]	−0.27 (0.61)[b]	−0.27 (0.82)[b]	−0.87 (0.71)[c]
Z-score KRT-R	0.80 (0.39)[a]	0.50 (0.52)[a]	−1.02 (0.64)[b]	−0.92 (0.69)[b]
Z-score PI	0.91 (0.41)[a]	−0.90 (0.57)[c]	0.49 (0.51)[b]	−0.90 (0.49)[c]
Z-score EMT	0.90 (0.65)[a]	−0.78 (0.42)[c]	0.41 (0.70)[b]	−0.79 (0.60)[c]
Z-score Klepel	0.84 (0.63)[a]	−0.81 (0.42)[b]	0.47 (0.84)[a]	−0.89 (0.50)[b]

Note: RD = reading disabilities; MD = mathematical disabilities; RD + MD = reading- and mathematical disabilities; TTR = arithmetic number facts test (fact retrieval); KRT-R = Kortrijk arithmetic test revision (procedural mathematical skills); PI = paedological institute-dictation (spelling); EMT = one minute reading test (word reading speed).
Posthoc indices at $p < .05$ indicating differences between groups (a differs significantly from b and c, b differs significantly from c).

(Dirks, Spyer, van Lieshout, & de Sonneville, 2008; Murphy, Mazzocco, Hanich, & Early, 2007). Due to this checking of the clinical diagnosis 65 (33.85%) control children and 15 (7.81%) children with learning disabilities were not included in this study.

The analyses were conducted on the rest of the children ($n = 112$, 58,33%). The final sample consisted of 45 control children, 17 children with RD, 22 children with MD and 28 children with RD + MD. Mean age was 10 years. Subject characteristics are presented in Table 1.

In Table 1 the scores on the various measures were converted into Z-scores based on the whole sample to compare groups with analyses of variance (ANOVA). These analyses revealed that children with RD + MD did significanlty worse (c-index) than children with RD (b-index) or MD (b-index) and that all clinical groups differed significantly from control children without learning disabilities (a-index) on fact retrieval tested with the TTR (see posthoc indexes in Table 1). In addition, the MD group (b-index) and the RD + MD group (b-index) differed significantly from the control group (a-index) and the RD group (a-index) on number knowledge and mental arithmetics tested with the KRT-R. In addition, the children with RD (c-index) and those with RD + MD (c-index) differed significantly from their control peers (a-index) and their peers with MD (b-index) on spelling. Moreover, the group with RD (c-index) and the group with RD + MD (c-index) differed significantly from the control group (a-index) and the group with MD (b-index) on word reading fluency. Finally, the children with RD (b-index) and with RD + MD (b-index) differed significantly from the control children (a-index) on pseudoword reading.

To illustrate where the children are relative to the normative sample on the test, the mean cumulative percentage (Cum%), percentile (pc) and standard scores (SS) will be given. The mean Cum% on the TTR for the control group, the group with RD, the group with MD and the group with RD + MD were 66.24 (SD = 20.52), 33.12 (SD = 22.64), 32.42 (SD = 27.22), and 18.19 (SD = 21.98) respectively. The mean pc on the KRT-R for the control group, the group with RD, the group with MD and the group with RD + MD were 64.04 (SD = 17.39), 52.06 (SD = 21.23), 7.82 (SD = 7.93), and 11.27 (SD = 17.75) respectively. The mean pc on the PI-dictation for the control group, the group with RD, the group with MD and the group with RD + MD were 81.38 (SD = 21.61), 3.53 (SD = 3.36), 59.09 (SD = 31.58), and 4.81 (SD = 8.41) respectively. The mean SS on the EMT (word reading speed) for the control group, the group with RD, the group with MD and the group with RD + MD were 11.71 (SD = 2.34), 5.35 (SD = 2.03), 10.00 (SD = 2.48), and 5.12 (SD = 2.14) respectively. The mean SS on the Klepel (pseudoword reading) for the control group, the group with RD, the group with MD and the group with RD + MD were 12.38 (SD = 2.19), 6.82 (SD = 1.67), 11.50 (SD = 3.29), and 6.58 (SD = 2.06) respectively.

2.2. Measures

2.2.1. IQ, mathematics, reading and spelling measures

We calculated an estimated IQ, using an abbreviated version of the Dutch WISC-III (Wechsler et al., 2005). This shortened version, recommended by Grégoire (2000), has a high correlation ($r = .93$) with Full Scale IQ (Kaufman, Kaufman, Balgopal, & McLean, 1996) and consists of four subtests: vocabulary, similarities, picture arrangement and block design.

The arithmetic number facts test (TTR; De Vos, 1992) is a numerical facility test consisting of five subtests with arithmetic number fact problems: addition, subtraction, multiplication, division and mixed exercises. Children have to solve as many items as possible in 5 min; they can work 1 min on every colon. The TTR is a standardized test that is frequently used in Flemish education as a measure of number fact retrieval (e.g., Stock, Desoete, & Roeyers, 2010).

The Kortrijk arithmetic test revision (KRT-R; Baudonck et al., 2006) is a standardized test on mathematical achievement which requires that children solve mental arithmetic and number knowledge tasks. The KRT-R is frequently used in Flemish education as a measure of procedural mathematical skills (e.g., Stock et al., 2010).

Furthermore, all children were tested with standardized Dutch reading measures. Word reading speed or fluency was assessed by the one minute reading test (EMT; Brus & Voeten, 2010) and pseudoword reading by the Klepel (Van den Bos, Spelberg, Scheepstra, & de Vries, 2010). Both reading tests consist of lists of 116 unrelated words. Children are instructed to

Fig. 1. Visualization of the Go/no-go task.

read as many words as possible in 1 (EMT) or 2 min (Klepel) without making errors. On both tests, the raw scores were the numbers of words read correctly.

Furthermore, all children were tested with a standardized Dutch spelling measure. Spelling was assessed with Paedological Institute-dictation (PI-dictation; Geelhoed & Reitsma, 2000), a Dutch standardized test in which children have to write down the repeated word from each sentence. The test consists of nine blocks of 15 words. Each block has a higher difficulty level and testing is stopped once a child made seven or more errors in a block.

2.2.2. Behavioral inhibition measure: the Go/no-go task

In line with Nigg (2000) and in congruence with e.g., Passolunghi et al. (2005) and Reiter et al. (2005), a Go/no-go paradigm (not depending on high working memory load) was used to assess behavioral inhibition of stimuli, with very limited working memory demands (Simmonds et al., 2008).

The concept of a Go/no-go task with three different modalities was based on Van De Voorde et al. (2010). The task was programmed in Affect 4.0 (Hermans et al., 2005). The frequency of go trials was 75%. A fixation cross was presented at the beginning of each trial for 500 ms. Afterwards, a stimulus (e.g., a bird) was shown. As soon as the participant reacted, the stimulus disappeared and was replaced by a white screen. If the reaction of the participant took longer than 300 ms, the stimulus disappeared after 300 ms and was replaced by the white screen. The participant could still react when this white screen was shown. To make sure that intertrial interval was kept constant at 2250 ms, the duration of the white screen presentation varied between 1450 ms and 1750 ms, depending on how fast the participant reacted on the stimulus presentation. For instance, if the participant reacted 250 ms after onset of the stimulus representation, the white screen was presented for 1500 ms. We refer to Fig. 1 for a trial representation.

The task consisted of two formats (alphanumeric and non-alphanumeric) and three modalities, measuring a picture (non-alphanumeric), a letter (alphanumeric) or a digit modality (alphanumeric). Since we were especially interested in group comparisons (RD, MD, RD + MD, control), modalities were presented in a fixed order. Before the start of each modality, five practice items were administered to ensure that the participants understood the task instructions. The practice trials contained a mixture of go and no-go trials and all children responded 100% correct. They reacted in an appropriate manner. Hence, their MRT was between 150 ms and 1750 ms. A condition contained no more than two visual stimuli. In that way, the influence of other cognitive processes was minimized (Van De Voorde et al., 2010). Each condition consisted of 45 go trials (the picture of a bird in the first modality, letter 'a' in the second and number '1′ in the third) and 15 no-go trials (a butterfly, 'm' and '6′, respectively). Children were asked to push the spacebar when a go stimulus appeared, but not when a no-go stimulus appeared on the screen and to do that as accurately and quickly as possible. In order to effectively eliminate confusion in children with RD, all instructions were presented to the participants both in a visualized and verbal modality (Smith-Spark & Fisk, 2007; Vukovic, Lesaux, & Siegel, 2010).

Mean reaction time of the correct go trials (MRT) and commission errors were used as dependent measures. Commission errors were considered as measure of behavioral inhibition, while MRT mainly measures response speed (Van De Voorde et al., 2010). Commission errors are those errors where the child pushed the spacebar during a no-go trial. Since accuracy on the go trials was very high (96.14% in the picture modality, 95.85% in the letter modality and 95,17% in the number modality), omission errors were not analyzed. Omission errors are these errors where the participant did not press the spacebar during a go trial.

2.3. Procedure

2.3.1. Data collection

All children were tested by a trained researcher in a quiet room at home for three different sessions. To maximize vigilance and persistence in completing tasks, breaks were included. During the first session, tests were used to tap mathematics and spelling. In the second session, reading and intelligence were measured. During the last session, the Go/no-go task was administered. The task was presented on a desk top, the CRT screen was placed in front of the participant (refresh rate: 75 H). Sound was presented via two speakers (for the instructions) located at the left- and right side of the screen. Maximum response time was 1750 ms. Missing values were replaced by the group mean, this was the case for 1.8% of the data.

2.3.2. Statistical analysis

After assumptions of normality and homogeneity were met, 2 (RD versus no RD) × 2 (MD versus no MD) × 3 (picture-, letter- and digit modality) factorial repeated measures analyses were carried out to examine task performance in control children and children with learning disabilities. Multivariate analyses of variance (MANOVAs) for repeated measures were

Table 2
Correlations between intelligence, age, commissions and reaction times of correct responses for the Go/no-go task.

	Age	Intelligence	Comm Pict	MRT Pict	Comm Letter	MRT Letter	Comm Digit
Age	–	–	–	–	–	–	–
Intelligence	.10	−.06	−.26	–	–	–	–
Comm Pict	.00	−.09	.58*	–	–	–	–
MRT Pict	−.24	−.03	−.17	–	–	–	–
Comm Letter	−.19	−.13	.58*	−.15	–	–	–
MRT Letter	−.17	.11	−.17	.77*	−.11	–	–
Comm Digit	−.18	−.11		−.15	.72*	−.13	–
MRT Digit	−.16			.73*	−.07	.78*	−.18

Note: Comm = commission errors; MRT = mean reaction time; Pict = picture-modality; Letter = letter-modality; Digit = digit-modality.
* $p < .001$.

executed to test the effect of stimulus modality on task performance of the groups. The 2 × 2 design instead of analyses with the four groups (control, RD, MD and RD + MD), was chosen to gain the necessary information about the performance of the RD + MD group. A significant interaction between the RD and MD factor provides evidence for the underadditivity hypothesis, whereas no interaction-effect points in the direction of RD + MD as an additive combination of RD and MD (Willcutt et al., 2005). Post hoc tests (Bonferroni) were conducted when significant main – and interaction effects were found.

3. Results

3.1. Correlations

As shown in Table 2, all correlations with intelligence and measures of the Go/no-go tasks were <.30. The same was true for correlations with age and measures of the Go/no-go tasks, meaning that these variables only explained a very limited part of the variance. Hence controlling for these variables seems not appropriate. In addition, similar results were found when age and intelligence were used as covariate in the analyses.

3.2. Commission errors

A significant main effect of the within-subjects factor modality (i.e., pictures, letters or digits) was found ($F(2,107) = 11.07$, $p < .001$, $\eta^2 = .17$). Contrasts revealed that all children made more commission errors in the letter modality than in the picture modality ($p = .002$) and more commission errors in the letter modality than in the digit modality ($p = .009$). There were no significant main effects for the between-subjects factors RD ($F(1,108) = 0.16$, $p = .689$) and MD ($F(1,108) = 0.64$, $p = .426$). The interaction effect RD*MD was not significant neither ($F(1,108) = 2.06$, $p = .154$). There was a significant interaction-effect between the within-subjects factor modality and the between-subjects factor RD ($F(2,107) = 3.24$, $p = .043$, $\eta^2 = .06$). Finally, a trend was found for the interaction effect of MD and modality ($F(2,107) = 2.76$, $p = .068$, $\eta^2 = .05$) and for the three-way interaction RD × MD × modality ($F(2,107) = 2.66$, $p = .080$, $\eta^2 = .05$). Children with RD obtained significantly more commission errors in the letter -($p = .003$) and digit modalities ($p = .009$) compared to the picture modality. Children with RD + MD made significantly less commission errors in the digit modality than in the letter modality ($p = .021$). Post hoc tests revealed only a trend of a difference between the RD group and the RD + MD group on the digit modality ($p = .090$). Means and standard deviations of commission errors are presented in Table 3 and the mean of commission errors made by the different groups is visualized in Fig. 2.

Table 3
Means and standard deviations of commissions and reaction times of correct responses for the Go/no-go task.

Go/no-go	Control (*n* = 45)	RD (*n* = 17)	MD (*n* = 22)	RD + MD (*n* = 28)
	M (SD)	M (SD)	M (SD)	M (SD)
Commission errors				
Picture-modality	4.87 (2.98)	4.35 (2.45)	5.23 (3.13)	4.50 (2.84)
Letter-modality	5.49 (2.81)	7.00 (3.12)	5.82 (3.61)	5.65 (3.17)
Digit-modality	4.80 (3.42)	6.76 (3.61)	5.14 (2.87)	4.36 (2.67)
MRT				
Picture-modality	365.80 (42.45)	403.26 (73.64)	370.73 (53.82)	382.17 (51.49)
Letter-modality	371.05 (53.22)[a]	419.38 (86.10)[ab]	397.12 (55.68)[ab]	417.36 (74.77)[b]
Digit-modality	373.80 (61.05)[a]	417.43 (87.55)[ab]	394.24 (60.81)[ab]	425.71 (81.21)[b]

Note: RD = reading disabilities; MD = mathematical disabilities; RD + MD = reading- and mathematical disabilities; MRT = mean reaction time.
Posthoc indices at $p < .05$ (a differs significantly from b).

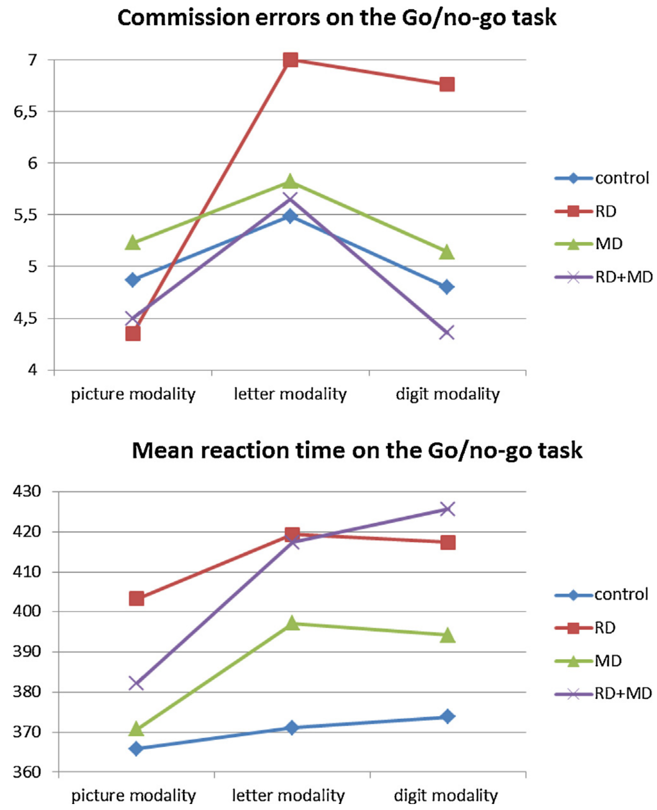

Fig. 2. Plotted means of the control group, the group with reading disabilities (RD), the group with mathematical disabilities (MD) and the comorbid group (RD + MD) on the picture (1), the letter (2) and the digit (3) modality of the Go/no-go task.

3.3. *Mean reaction time*

A significant main effect of MRT was found ($F(2,107) = 15.30$, $p < .001$, $\eta^2 = .22$). All children were significantly faster in the non-alphanumeric picture condition than in the alphanumeric letter – ($p < .001$) and digit conditions ($p < .001$). Moreover, there was a significant main effect of RD ($F(2,107) = 7.70$, $p = .007$, $\eta^2 = .07$), children with RD performed significantly slower than children without RD on all modalities ($p = .020$). No significant main effect of MD ($F(1,108) = 0.28$, $p = .599$) and no interaction effects of MD and RD ($F(1,108) = 0.91$, $p = .342$) were found. There was no significant interaction effect between the within-subjects factor modality and the between-subjects factor RD ($F(2,107) = 1.08$, $p = .344$); neither was there a three-way effect of RD, MD and modality ($F(2,107) = 0.37$, $p = .691$). However, a significant interaction-effect was found between modality and MD ($F(2,107) = 3.72$, $p = .027$, $\eta^2 = .07$). Moreover, children with specific MD were faster on the picture modality than on both alphanumeric tasks, namely in the letter–($p < .001$) and the digit modality ($p < .001$). The same was true for children with RD + MD ($p = .001$ and $p = .002$, respectively). Post hoc analyses revealed that the RD + MD group was significantly slower than the control group on both alphanumeric tasks, namely in the letter – ($p = .023$) and the digit modality ($p = .018$). A trend was found for a slower performance of children with RD in comparison with control children on the picture – ($p = .083$) and the letter modality ($p = .063$). Means and standard deviations of MRT are presented in Table 3 and the MRT of the different groups is visualized in Fig. 2.

4. Discussion

4.1. *Behavioral inhibition deficit*

A first purpose of this study was to examine if children with RD, children with MD and children with RD + MD experienced deficits in behavioral inhibition. Results concerning commission errors point in the direction of less adequate behavioral inhibition skills in children with RD, but not in children with MD. Despite the small effect size, these RD findings are in line with several other studies (e.g., Purvis & Tannock, 2000; Willcutt et al., 2005). For instance, the study of Purvis and Tannock (2000) revealed that elementary school children with RD had a slower stop signal reaction time in comparison to control children. Our MD results are in congruence with e.g., Censabella and Noel (2008), who did not find any differences between children with MD and control children on measures of behavioral inhibition.

4.2. Modality-specific and alphanumeric versus domain-general errors?

A second aim of this study was to investigate whether behavioral inhibition deficits were modality-specific or rather domain-general. It was found that the RD group committed more commission errors in the alphanumeric letter and digit conditions than in the picture condition. These results seem to be in line with other RD studies. For instance, the study of van der Schoot, Licht, Horsley, & Sergeant (2000) revealed a behavioral inhibition deficit on a letter version of the Stop-signal task in children with RD, and Schmid et al. (2011) did not find any differences between the control children and children with RD on a picture version of this task. However, in contrast with our findings and those of e.g., Schmid et al. (2011), a study of de Jong et al. (2009) revealed significant deficits on a picture version of the stop signal task. These mixed results may partly be explained by the task impurity problem (Miyake et al., 2000). Tasks measuring behavioral inhibition, always implicate also other executive functions (e.g., working memory) or other lower cognitive processes (van der Sluis, de Jong, & van der Leij, 2007). These results underline the need to control for this task impurity (e.g., Van De Voorde et al., 2010), as was done in our study by choosing for a task with only one go and one no-go stimulus.

Analyses with the RT of correct go trials revealed a main effect of RD. Children with RD performed significantly slower on all modalities, indicating a domain-general response speed deficit. Children with MD showed significantly faster performance on the picture condition than on the digit and the letter modality, which seems to indicate an alphanumeric deficit in MD.

Concerning children with MD, results seem to point in the direction of a speed-accuracy trade-off. Children with MD made no more commission errors than control children and children with RD + MD made less commission errors in the digit than in the letter modality. In contrast, their MRT was slower on the alphanumeric than on the picture stimuli. These findings suggest that children with MD slowed down their speed in order to make fewer errors. MD studies on executive functioning revealed similar findings (e.g., Mazzocco & Kover, 2007). This asks for further investigation.

4.3. Cognitive risk factors

The last objective of this study was to study if behavorial inhibition could be seen as a cognitive risk factor, underlying both RD and MD (Pennington, 2006). In contrast with the cognitive risk hypothesis, children with RD + MD even made less commission errors than children with isolated RD. In addition, children with RD+ MD were faster on the picture modality than on the digit and (to a lesser degree) the letter modality. MRT deficits were reported in children with RD as well as in children with MD, with children with MD especially having problems with alphanumeric stimuli, while impairments on all kind of stimuli were found in children with RD. To conclude, no support was found for behavioral inhibition as a shared cognitive risk factor of RD and MD.

In congruence with e.g., van der Sluis et al. (2004) and Pauly et al. (2011), the results of this study support the hypothesis of the comorbid group as an additive combination of RD and MD. They might indicate that RD and MD have a distinct cognitive profile (Landerl, Fussenegger, Moll, & Willburger, 2009). However, post hoc analyses revealed only differences between the control and the comorbid group. Based on our research, it is not possible to explain this lack of results. They might be due to our task, to the small sample with a risk of type 2 errors or just to the fact that the deficits in the isolated groups were too small to capture.

4.4. Limitations and future directions

Besides the limitations mentioned above, some others should be pointed out as well. First, testing took place during three sessions, the first two sessions lasting up to at least 1 h. To avoid drop out, to minimize disinterest and extra efforts of both children and parents and to maximize their feelings of enthusiasm and well-being, all children were tested in a quiet room at home. Hence, we did not have as much control of circumstances as we would have had if testing took place in a laboratory.

Secondly, children were only referred to the RD + MD group if they scored below the 10th percentile on math and reading or spelling tests (Geary, 2011). This indicates that some children of the specific MD group also had reading or spelling scores below the 25th percentile and some children of the specific RD group math scores below the 25th percentile. However, analyses concerning reading, spelling and math scores revealed different profiles for all clinical groups (see Table 1). Further research with more severe selection criteria would be enlightening.

Thirdly, picture-, letter- and digit modality were tested in fixed order. This decision was made to minimize the possible influence of automatisation problems children with learning disabilities often suffer from (e.g., Geary, 2004). As a consequence, we were not able to control for learning and fatigue effects. Almost all children considered the first condition (picture modality) as the hardest, while overall, their performance on this condition was the best. Besides, small differences were marked between the digit and the letter conditions. Future research with counterbalanced tasks is hence advised.

Finally, screening allows one to get a (much) clearer and more pure view on the topic by isolating the problem, but the screening of this study reached some limits as well. We were not able to control for the possible co-occurrence of other undiagnosed disabilities. For instance, one out of four children with learning disabilities suffers from motor problems (Pieters et al., 2012), but due to practical restrictions, only parent questionnaires were used to assess this topic. Despite the fact that our results are in line with many other studies (e.g., D'Amico & Passolunghi, 2009; Purvis & Tannock, 2000), we cannot completely rule out that the absence of comorbid undiagnosed motor or other problems might have influenced (MRT) results.

5. Conclusion

Overall, this study showed small symbolic or alphanumeric behavioral inhibition deficits in children with RD, but no inhibition problems in children with MD. Hence, behavioral inhibition cannot be seen as a shared cognitive risk factor. In addition, indications were found for symbolic or alphanumeric response speed deficits in MD and domain-general response speed deficits in RD. No significant interaction-effects were found between RD and MD, suggesting that problems in children with RD + MD are just the additive combination of the impairments in children with RD and MD.

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