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Chapter 1

General introduction
The general assumption in research on academic development is that delays in early academic skills may have long-lasting effects on learning formal reading, writing, and mathematics (e.g., Duncan et al., 2007; Jordan, Kaplan, Nabors Oláh, & Lociuniak, 2006; Muter, Hulme, Snowling, & Stevenson, 2004; Whitehurst & Lonigan, 1998). Although it is claimed that executive functions (EF) are one of the reasons for delays in early literacy and numeracy development (Diamond & Lee, 2011; Duncan et al., 2007; McClelland et al., 2007, NICHD, 2003; Valiente, Lemery-Chalfant, & Swanson, 2010; Welsh, Nix, Blair, Bierman, & Nelson, 2010), research so far has not confirmed this assumption: Research outcomes differ and effects of preschool EF skills on academic skills in the subsequent years are rather small or even non-significant (e.g., Bull, Espy, & Wiebe, 2008; Davidse, De Jong, & Bus, 2013; Diamond & Lee, 2011; Duncan et al., 2007; Kegel & Bus, 2013, 2014; LeFevre et al., 2009; Levy, Gong, Hessels, Evans, & Jared, 2006; McClelland et al., 2007; Welsh et al., 2010). Effects of preschool EF are especially small when controlled for several background variables and moderate to strong effects of early academic skills on later academic development (Kegel & Bus, 2013; Raghubar, Barnes, & Hecht, 2010; Willoughby, Kupersmidt, & Voeger-Lee, 2012). Willoughby et al. (2012) even conclude that there is no causal relation among EF and academic achievement in kindergarten-age. By contrast, Clark et al. (2010, 2013) do find direct relationships between preschool EF and academic achievement in kindergarten-age. By contrast, Lee, 2012). Willoughby et al. (2012) even conclude that there is no causal relation among EF and academic achievement in kindergarten-age. By contrast, Clark et al. (2010, 2013) do find direct relationships between preschool EF and academic achievement at age 5 and 6, even when effects of early academic skills and other background variables are taken into account.

Thus although it is claimed that EF skills are one of the reasons for delays in early academic development (Diamond & Lee, 2011; Duncan et al., 2007; McClelland et al., 2007; NICHD, 2003; Valiente et al., 2010; Welsh et al., 2010), there is no consensus about effects of EF on academic development. In the current thesis the effect of EF on academic development is further explored. It is examined: 1) to what extent EF interferes with benefiting from informal literacy activities that may stimulate early literacy development; 2) whether EF, beyond other general learning skills such as visual-spatial skills and speed of processing, may explain why early literacy and early numeracy skills co-vary substantially. In other words, it is tested whether EF or other general learning skills are essential for numeracy as well as literacy development; 3) whether EF development is causally related to academic development from preschool through Grade 1; and 4) whether serious learning impairments such as severe delays in learning math can be explained by delays in EF. This thesis starts with a review on Executive Functions (EF), followed by an elaboration of the four research questions.

Executive Functions
EF is an umbrella term for three core cognitive processes that are assumed to be relevant in most academic tasks: Inhibition and attention control, working memory, and cognitive flexibility (Diamond, 2013). Attention regulation gradually improves in typically developing preschoolers, for instance by learning to focus on task-relevant aspects and inhibiting non-relevant information or distracters such as noise in the environment. Inhibition and attention control thus seem essential for maintaining on task behaviour, for instance when teacher instructions need to be followed. Working memory helps remembering these instructions and enables performing a task (Davidson, Amso, Anderson, & Diamond, 2006; Diamond, 2013). With increasing age, children are able to remember more information (for instance the number of digits a child can recall improves) and inhibition skills improve, which results in longer sustained attention (Davidson et al., 2006; Diamond, 2013; Gathercole, Pickering, Ambridge, & Wearing, 2004). Brain imaging studies revealed that cerebral networks in the prefrontal cortex are typically activated when tasks strongly appeal to working memory and/or inhibitory skills (Diamond, 2013). The fact that working memory and inhibitory skills develop well into adulthood can be related to maturation of the prefrontal cortex: The prefrontal cortex has the longest developmental period of all brain areas; only after about 20 years full maturity is reached (Diamond, 2002). As preschool development is central in the current thesis, the focus is on attention/inhibitory control and memory development, as these core EF skills develop earlier than cognitive flexibility (Davidson et al., 2006).

Impurity is a main problem in studies on EF skills. Other cognitive processes may affect EF skills, which makes it difficult to measure EF skills. Phonological processing for instance may influence performance on the Wisconsin Card Sorting Test, a test often applied when measuring executive functions (Miyake et al., 2000). Moreover some researchers prefer using single tests for measuring sub-skills, whereas others use several tests and make a composite measure (Garon, Bryson, & Smith, 2008). These differences in tasks and scoring methods may explain why there is no consensus about the structure of EF and about best ways for assessing EF (Van der Ven, 2011).

When assessing EF in preschoolers, it is essential that tasks are not too complex (i.e., involve not too many operations at the same time as is common for adult EF assessments) (Garon et al., 2008). EF tests used in the current thesis
Chapter 1

General introduction

EF in relation to Early Literacy Development

If attention regulation is essential for developing early academic skills, you might for instance expect that children who experience difficulties with ignoring distracters will also have more difficulties with acquiring early literacy skills such as vocabulary and letter knowledge (Lonigan et al., 1999). However, demonstrating that EF is related to early literacy skills does not answer the question which EF skills relate to early literacy development and how these skills interfere. It is well known that informal literacy activities such as shared book reading are a vital incentive for the development of early literacy skills (Levy et al, 2006; Sénéchal, Pagan, Lever, & Ouellette, 2008). Even within low-SES samples, shared book reading has a positive effect on literacy development (Bus, Van IJzendoorn, & Pellegrini, 1995). More specifically, shared storybook reading strongly effects vocabulary development and comprehension, and to a lesser extent code-related knowledge (Mol & Bus, 2011).

As a starting point for the first study, it seemed a plausible hypothesis to assume that children with poor working memory or inhibition may benefit less from shared book reading, resulting in delays in vocabulary and letter knowledge (code-related knowledge). Results of a NICHD study (2003) indeed prove that delays in EF may disrupt the beneficial effects of home activities on literacy development, but effect sizes were small and it was not specified which home activities became less beneficial. In the first study (chapter 2), it was therefore investigated whether effects of shared book reading on vocabulary and letter knowledge are moderated by EF. More specifically it was tested whether children with low EF skills benefit less from shared book reading, and consequently lag behind in early literacy skills.

In order to retrieve a reliable view of how frequently children were read to, a book-cover recognition test was applied in addition to asking the parents about the frequency of shared book reading (Sénéchal, LeFevre, Hudson, & Lawson, 1996). Unlike questionnaires about book reading activities, the book-cover recognition test is not vulnerable for social desirable answers (Sénéchal et al., 1996). Contrary to questions, the book-cover test taps children’s actual knowledge about age-appropriate books. An up to date storybook list was composed out of top 100 book sales and library loan numbers, capturing the children’s preschool years. In order to avoid false positives due to familiarity with the main character on the cover from television or other sources, three questions tapping into specific book knowledge were asked: “Who is this/who are these”; “What is the name of the story”; and “Can you tell me where the story is about?” Because both a home literacy environment (HLE) questionnaire, including an author recognition test for adults (Cunningham & Stanovich, 1990), and a storybook-cover recognition test were applied, it was also possible to test whether book-cover recognition predicts vocabulary and letter knowledge over and above frequency of shared book reading as reported in the HLE questionnaire and author recognition test for adults. This would imply that the storybook-cover recognition test is indeed a more reliable indicator of shared book reading activities.

For this study, 228 children just starting school in the Netherlands (age range 4;3-4;9) were tested. Spread over six sessions of about half an hour, several early literacy, numeracy, EF, and intelligence skills were assessed.

EF as Explanation for Co-variance among Early Numeracy and Early Literacy Skills

Interestingly, children who lag behind in early literacy often lag behind in early numeracy as well (e.g., Krajewski & Schneider, 2009). This may suggest that equal learning mechanisms or environmental factors underlie both academic domains (Simmons & Singleton, 2008). EF skills might be one of the learning mechanisms underlying both academic domains, as research reports positive correlations among early numeracy and EF (e.g., Espy et al., 2004), and early literacy and EF (e.g., McClelland et al., 2007). Which EF skills cause overlap may, however, depend on which early numeracy and literacy skills are targeted (LeFevre et al., 2010; Purpura et al., 2011). Moreover, it seems likely that other learning mechanisms and experiences may explain the overlap between literacy and numeracy as well. Visual-spatial skills, vocabulary, speed of processing,
Causal Relations among EF and Academic Development from Preschool through Grade 1

Long-term effects of EF in preschool on academic development in the subsequent years are hardly investigated or only cover a short period of time (e.g., Clark et al., 2010; Foy & Mann, 2013; McClelland et al., 2007; Welsh et al., 2010). Although researchers claim that EF skills may explain why children lag behind in academic development (e.g., Diamond & Lee, 2011; Duncan et al., 2007; McClelland et al., 2007; NICHD, 2003; Valiente et al., 2010; Welsh et al., 2010), correlations may in fact also imply that if you perform well on numeracy and literacy skills, you automatically develop your EF skills. Studies rarely measured the numerous familial or environmental variables that may confound observed associations. For instance, positive associations between EF and academic skills may be explained in part or in whole by educational style or EF ability of caregivers. A causal relation among EF and academic skills becomes more plausible when changes in EF over half a year or more are related to changes in academic skills over the same period (Willoughby et al., 2012). Investigating changes in EF is also preferable over assessment of EF at one particular point in time, because EF skills strongly develop between age 5 and 8 (e.g., Davidson et al., 2006; Diamond, 2002). This implies that children who lag behind in preschool EF skills, not necessarily will lag behind in EF in Grade 1. As a result children may not experience difficulties with reading and mathematics in Grade 1 despite underdeveloped preschool EF skills. In order to test causal effects of EF on academic skills, academic and EF skills were tested at the beginning and end of Grade 1. A few schools were not able to participate in the second assessment due to time constraints; the longitudinal analyses are based on 87 children from 7 schools who completed both measurements.

The first goal was testing whether preschool EF (short-term memory and inhibition) is related to math, reading, and writing skills in preschool and subsequently in Grade 1. The risk of obtaining spurious outcomes was reduced by controlling for intervening variables such as educational level of the mother (Willoughby et al., 2012). In the long-term tests, preschool numeracy and literacy skills, both moderate to strong predictors of academic achievement in Grade 1, were also controlled for (e.g., Jordan, Kaplan, Nabors Oláh, & Locuniak, 2006; Whitehurst & Lonigan, 1998). Due to the small number of schools (7 different schools were involved), Huber-White estimates and a Complex Sample General Linear Model analysis (CGLM, SPSS 19) were preferred over multilevel analysis.

For testing causal relationships among EF development and academic development from preschool through Grade 1, a Fixed Effect Analysis (FEA) was applied in a repeated measure design for EF and academic skills. Fixed Effect Analysis is an alternative for covariate adjustment when evaluating the causal relationship between EF and academic performance. The main advantage of a FEA is that it captures all the measured, but also unmeasured time invariant covariates that may cause spurious outcomes, which strengthens conclusions about causality (KeGel & Bus, 2014; Willoughby et al., 2012). When using FEA it is not necessary to measure, or know, the potential confounder variables (Allison, 2009). In a repeated measures design, ideally the same tests are applied at pre- and post-test. However, when capturing development from preschool through Grade 1, it is impossible to apply exactly the same tests, because of bottom and
ceiling effects in both academic and executive skills (Paris, 2005; Paris & Luo, 2010). Testing whether children can solve addition problems up to 20 is for instance useful in Grade 1, but not in preschool. In order to be able to compare repeated measures of EF, numeracy and literacy, all tests were standardized. In this third study (chapter 4), it was tested whether EF development (memory and inhibition) was causally related to academic development (math, reading, and writing) from preschool through first grade.

Can EF be at the Root of Serious Learning Impairments?

The role of EF in the development of serious delays in math or literacy was further explored by means of a case study approach (chapter 5). Two 9-year old monozygotic twin girls were referred to the university clinic because of a severe delay in math development in combination with delays in working memory and visual-spatial skills. This case enabled us to explore to what extend EF skills may underlie a serious delay in math development.

Early numeracy development is based on two numerical systems: A small number system containing only representations for numbers under 4 and an approximate number system (ANS) (Berger, Tzur, & Posner, 2006; Dehaene, 2011; Halberda & Feigenson, 2008; Wynn, 1992). The small number system enables comparing amounts under 4 without counting, referred to as subitizing, which is already evident in 4-5 months old infants (Berger et al., 2006; Wynn, 1992). The small number system is an exact numerical representation system (Dehaene, 2011). The approximate number system (ANS), by contrast, is based on the numerical ratio and develops well into adulthood (Halberda & Feigenson, 2008; Izard, Sann, Spelke, & Streri, 2009): While babies can compare magnitudes with a ratio of 1:2, adults can discover differences with a ratio of 7:8 (Halberda & Feigenson, 2008). Both numerical representation systems seem to have an innate basis, as becomes evident from Wynn’s study (1992) showing that typically developing babies know that 1+1 equals 2 and not 1 or 3. Neuroimaging studies show that the IntraParietal Sulcus (IPS) underlies the neuronal code for numerical quantity (Dehaene 2011, Molko et al., 2003; Price, Holloway, Räsänen, Vesterinen, & Ansari, 2007). Combined with counting skills that emerge around the age of 2-3, the ability to recognize small numbers at a glance helps children understanding that every numerical set has a cardinal number. By means of counting numbers under 4, children realize that the final number represents the total amount (Dehaene, 2011). As a result of linking numbers to quantities children also develop insights in relations among numbers and start understanding that in addition problems such as 3 + 2 the answer must exceed 3, and, vice versa, in subtraction problems such as 3 – 2 the answer must be below 3 (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Dehaene, 2011; Duncan et al., 2007; Krajewski & Schneider, 2009). These insights are vital for learning simple sums.

The twins’ delay in mathematics was so severe that standardized tests were not sufficient for finding out which core numeracy skills were especially underdeveloped. For testing their knowledge of early numeracy skills such as subitizing, magnitude comparison, and the relations among the numbers 0-10, some paradigms have been reproduced from published sources using E-prime software 2.0.8.90 (Psychology Software Tools, 2013) or MS PowerPoint. Tests were displayed on a 1280 by 1024 resolution screen with a computer running the Windows XP operating system. Using those paradigms, the twins’ performance was compared to that of 8 control participants, matched for gender, educational level, and age. A magnitude comparison task was administered using an eye-tracker (Tobii T120), which enabled exploring differences in problem-solving by looking at eye-fixations and reaction time per ratio (ratio’s ranged from 1:2 to 7:8). Memory load on all tests was compared in order to estimate effects of EF on math problems. As scores on subtests of the WISC-III NL 3rd edition (Wechsler, 2005) tapping into visual-spatial abilities were all significantly below the norm, the role of visual-spatial skills as an alternative explanation of math problems was further explored using number sense tests with different demands on visual-spatial skills.

For every test, the percentage of correct responses (PCR) and in case of the eye-track tasks, the mean reaction time (RT) for the correct trials was recorded. The presence of a deficit was tested using Crawford and Howell’s (1998) modified t-test, which compares the twins’ performance with the control group’s performance. This technique, specially developed for case studies, enabled us to test whether a single patient is significantly impaired compared to a small control group. Crawford and Garthwaite’s (2005) residual standardized difference test (RSDT) permitted us to test the significance of the dissociation between two tasks. For intra-group statistical analyses, paired sample t-tests and linear regressions were applied.

Commonly children with dyscalculia do have some basic numeracy knowledge, but as long as skills are not automatized, counting strategies often
need to be applied. The use of counting strategies results in longer processing times compared to typically developing peers (e.g., Kucian et al., 2011; Moeller, Neuburger, Kaufmann, Landerl, & Nuerk, 2009). In such cases, number sense training can have a positive effect (Kucian et al., 2011). As the twins’ number sense impairment was more severe than in more common cases of dyscalculia, we wondered whether training of core number sense skills would be effective. The twins received an intervention targeting basic number sense skills (Räsänen, Salminen, Wilson, Aunio, & Dehaene, 2009; Wilson et al., 2006). Their responsiveness to this intervention is described in the final part of chapter 5.

In the final chapter it is discussed to what extent EF skills explain delays in early academic development. Highlighted topics are: 1) the strength of the relationship between EF and academic skills; 2) evidence for a causal relationship among EF and academic development, despite the fact that delays in EF at age four are poor predictors of math and reading in Grade 1; 3) the importance of EF compared to other cognitive skills for explaining overlap between numeracy and literacy development; 4) the role of EF in serious impairments in basic numerical understanding; and 5) how useful training of EF is when early academic skills lag behind. The discussion ends with practical implications for early education and suggestions for future research.