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Does It Pay to Practice?

A Quasi-Experimental Study on Working Memory Training
and Its Effects On Reading and Basic Number Skills

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To my children and to all of
the students who participated
in this study.

“Diversity is essential to
evolution as it allows us to
develop better problem solv-
ing skills” (Milne, 2005, p.
18).

Abstract

This dissertation is based on results from an intervention study targeting working memory training. A group of 46 boys and 11 girls (aged 10.7) that were attending special units in 16 regular schools participated in the study. The treatment group (n = 42) trained at school every day for 30-40 minutes with an interactive computer program (Cogmed training) for five weeks. The performances of the treatment group on reading related measures and basic number skills are compared to those of a group of students (n = 15) that were attending similar special units and received only ordinary special educational instruction. Working memory measures and non-verbal problem solving were compared to students (n = 25) in a control group from a previous study.

In Study I, it was found that reading comprehension and working memory measures correlated and improved at post-tests (T2, T3) for the treatment group to a larger extent than for the comparison group.

In Study II, it was found that working memory measures and basic number skills were highly related. The performance of the boys in the treatment group improved more than that of the boys in the comparison group on basic number test at both post-tests.

In Study III, basic skills assessed three years later (T4) are reported. The treatment group achieved higher scores in reading comprehension compared to pre-tests and compared to the control group.

The treatment group seems to have gained from the cognitive training of working memory with the computer assisted program directly after training, after seven months and at the three year follow-up. The gains were observed on visuo-spatial working memory measure (T2, T3), reading comprehension and on basic number skills in boys (T2, T3, T4).

The possible mechanisms that may be involved in and may explain the observed improvements of performances are discussed: executive function, attention, memory, motivation, emotions. The study has some methodological limitations and more research is needed to substantiate the efficacy of the program.

Keywords: working memory training, attention deficits, special educational needs, reading, basic mathematics, computer assisted instruction

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Abbreviations

ADHD	Attention Deficit, Hyperactivity /Impulsivity Disorder
ANOVA	Analysis of variance
BNST	Basic Number Screening Test
CD	Conduct Disorder
CE	Central Executive
DSM-IV	Diagnostic and statistical manual of mental disorders (4 th rev.)
EF	Executive Function
ES	Effect Size
LD	Learning Disabilities
LTM	Long-Term Memory
ODD	Oppositional Defiant Disorder
PIRLS	Progress in International Reading Literacy Study
PL	Phonological Loop
RCPM	Ravens' Coloured Progressive Matrices
STM	Short Term Memory
VWM	Verbal Working Memory
VS-STM	Visuo-Spatial Short Term Memory
VS-WM	Visuo-Spatial Working Memory
WISC-III	Wechsler Intelligence Scale for Children, (3 rd edition)
WM	Working Memory

1 Introduction

Being able to focus on and complete a specific task and coordinate new and previously consolidated knowledge and experiences is conducive to learning. Several different abilities facilitate this. One of these abilities is the working memory (WM). WM is used not only when instructions or subsections need to be held in the mind in order to complete a particular task, but also to hold back emotion (Bull, Espy, & Wiebe 2008).

With the exception of the articulatory loop (Baddeley's model, see 2.1.3), which does not develop until approximately seven years of age, the organisation of the working memory appears completed in the brain at approximately four to six years of age (Gathercole, Pickering, Ambridge, & Wearing, 2004b). The WM functions subsequently develop linearly and very similarly within each age group during childhood and adolescence until early adulthood (Alloway, Gathercole, & Pickering, 2006).

Linguists emphasise the importance of early linguistic stimulus (e.g., Snow, Burns & Griffin, 1998). Learning, language and problem solving activities most likely affect WM development in a positive way, providing opportunities to develop even further (Goswami, 2008a; Norrelgen, 2002).

Each child comes to the classroom with his or her unique brain organisation, the different components of which have been affected to varying degrees by both cognitive and emotional experiences (Goswami, 2008b; Dehaene, 2009). Many parts of the brain are simultaneously involved in processing information (Goswami, 2008a; Worden, Hinton, & Fischer, 2011). Different areas can cooperate during these activities, or may conflict with each other when solving problems.

Weak WM capability, combined with increased requirements for the storage and processing of information in learning situations could result in failure. Groups of students of various ages have been studied and links between WM, basic skills and attention skills have been found: 4-5 year olds (Alloway, et al., 2005a); 5-8 year olds (St Clair-Thompson, Stevens, Hunt, & Bolder, 2010); 6-8 year olds (Swanson, 2006); 7-11 year olds (Alloway, Gathercole, Adams, & Willis, 2005b); 13 year olds (Alloway, Banner, & Smith, 2010); and students in Grade 9 (Reuhkala, 2001). Students with low WM generally performed less well than other children on reading, mathematics and attention tests.

As age increases, so too does experience and the consolidation of knowledge. Those in a weaker position at the outset may find it difficult to

catch up to their peers. This means that students who find themselves in the lowest percentile at a young age are likely to perform less well at school compared to students and adolescents of the same age (Alloway & Alloway, 2010) and there is a resulting 'rich-get-richer' effect, as is the case with reading development (Stanovich, 2000; Walberg & Tsai, 1983).

Students with WM problems seem to be at greater risk of underperforming in school than their peers, because WM problems in turn affect the ability to understand and remember information and specific instructions, to pursue a plan and to complete 'simultaneous processing', i.e., being able to handle multiple types of information (Das & Naglieri, 1995; Cowan, 2005; Gathercole, Lamont, & Alloway, 2006).

Studies show that WM, but also other cognitive abilities, can predict outcomes in reading and writing (literacy) and mathematics during the school years (Bull & Scerif, 2001; Cain, Oakhill, & Bryant, 2004; DeStefano & LeFevre, 2004; Seigneuric & Ehrlich, 2005; Bull et al, 2008).

The consequences of poor WM are constantly experienced and could have implications on the development of knowledge and self-esteem. Four of the students who participated in this study said:

It's hard to remember mathematical rules.

I don't remember the words.

I cannot learn the tables.

I feel worthless ... every day.

Since students with a low WM capacity seem to underperform in reading and/or mathematics at school in relation to other students of the same age (Vucovic, 2012; Siegel & Ryan, 1989), we should consider working memory capacity as critical for knowledge acquisition.

However, poor WM capability may be difficult to detect in students. It emerged in a study by Gathercole et al. (2006) that teachers did not seem to be aware that some of their students' difficulties in following instructions and completing work were related to a lack of working memory capacity (WM capacity) and attention skills.

Teacher estimations of WM difficulties did not correspond to the actual conditions, according to observations and recently designed WM tests (Alloway, Gathercole, Kirkwood, & Elliot, 2009a). It has also been noted that students with low WM-ability have been placed among the low-performing children. Teachers have attributed this to the students' lack of motivation and attention ability and the fact that they "never listen" (Alloway & Gathercole, 2006).

Individual differences in WM capacity seem to result in differences in the students' ability to solve tasks. Differences in performance on WM measures

may depend on WM capacity, but possibly also on differences in LTM and the way in which an individual is able use strategies available from prior experience (Minear & Shah, 2006). According to research in recent years, differences in performance are due to heredity and environment in collaboration with the development of the brain (Lagercrantz & Olson, 2007).

If individuals' cognitive development could be influenced, this might give rise to significant improvements in the performance, self-esteem and social interaction at school of a great number of students. As much as ten percent of all school students may perform significantly lower on WM measures compared with other peers (Alloway, et al., 2009a).

According to Alloway and Alloway (2010), one means of improving school performance is to identify difficulties through early screening of WM-capacity and subsequently compensate for these. A complementary approach would be to try to directly influence cognitive ability through interactive computerised cognitive training. At the commencement of this study, no research had been carried out regarding how WM training affects mathematics and reading, or whether any resulting improvements in students with attention difficulties would be sustained over time. It was therefore deemed important to investigate these issues in the school environment. The hypothesis was that WM training would have a positive effect on reading comprehension and basic number skills¹, given suggestions that attention capacity is adversely affected by weaknesses in WM (Barkley, 1997) and the positive results that previous studies have shown in WM measures following WM-training (Klingberg, Forssberg, & Westerberg, 2002). The training carried out featured for the most part exercises loading on working memory, and training sessions were continuously adapted to each student's WM capacity.

1.1 Aim

The overall aim of this thesis is to examine the effect of working memory training in students with attention deficits. The thesis is based on three articles concerning the effect of WM training on WM measures and reading and basic number skills.

1.1.1 Studies

Study I

Dahlin, K. I. E. (2011). Effects of Working Memory Training on Reading in Children with Special Needs, *Reading and Writing*, 24(4), 179-191.

¹ In this thesis, the term "basic number skills" is defined as follows: skills in calculations (the four basic arithmetic operations), place value, grouping and completing series.

In Study I, the purpose was to investigate the relationship between working memory measures, working memory training and reading. The questions were:

- a) In what ways are neuropsychiatric and reading measures affected by working memory training?
- b) How are the working memory and reading measures related in pre- and post-tests?

Study II

Dahlin, K. I. E. (2013). Working Memory Training and the Effect on Mathematical Achievement in Children with Attention Deficits and Special Needs. *Journal of Education and Learning*, 2(1), 118-133.

Study II sought to examine the effect of working memory training on mathematics in boys and girls six to seven months following the completion of training. The questions were:

- a) How do children with attention deficits perform in mathematics post-tests after five weeks of working memory training (directly following the training and seven months later) compared with the control group members, who received no extra training?
- b) How do children in the treatment group perform in WM measures in post-tests compared with pre-tests?
- c) How are outcome scores in WM measures, WM training results and mathematics interrelated?
- d) Do boys and girls perform differently in WM measures and/or mathematics?

Study III

Dahlin, K. I. E. (2013). A Three-Year Follow-Up Study: Students' Performances in Reading and Mathematics Three Years after Five-Week Computerised Working Memory Training. Manuscript submitted.

The aim of Study III was to investigate the students' reading and mathematics development three years after the completion of working memory training. The question was:

- a) How do students perform in mathematics and reading assessments compared with a control group at pre-tests and post-tests and approximately three years after the completion of WM-training?

1.1.2 Other issues

- a) How do girls with attention deficits perform in WM training, WM measures, reading and mathematics compared with boys at pre-tests and post-tests.
- b) How do students in the treatment group perform in reading and basic number skills at pre-test compared with students in regular classes?
- c) Do students with or without an ADHD diagnosis perform differently after WM-training?

2 Theoretical background

2.1 Working memory and a variety of abilities

Correlations have been noted between behaviour in the classroom and working memory (e.g., Alloway, Gathercole, Holmes, Place, Elliot, & Hilton, 2009b). Studies show that WM-capacity is associated with a variety of skills (Alloway et al., 2005). Examples include reading (Reuhkala, 2001; Siegel & Ryan, 1989; Nation, 2006); writing and spelling (Swanson & Beringer, 1996; Swanson & Ramalgia, 1992); mathematics and other sciences (chemistry and physics) (Andersson, 2008; Geary, 2011; Gathercole, Pickering, Knight, & Stegmann, 2004a); and problem solving (Krumm, Ziegler and Buehner, 2008; Swanson, 2011). It has also been noted that WM is associated with behaviour ability and attention (Castellanos & Tannock, 2002; Mezzacappa & Buckner, 2010). Studies show that WM-capacity can vary among different students² and adults (Alloway & Alloway, 2010; Alloway et al., 2009a; Bull & Scerif, 2001).

WM can be described as a cognitive system that controls attention, the sorting and collation of verbal and visuo-spatial information, and the integration of both new information and ‘old’ information previously stored in the long-term memory (LTM). Processing information is believed to charge WM when reading, inserting additional information into a task, or integrating both verbal and visuo-spatial elements into a task (Swanson, 2006).

2.1.1 WM is an ‘executive function’

WM can be described as one of several ‘executive functions’ (EFs) and executive function can be defined as “the monitoring and self-regulation of thought and action, the ability to plan behaviour and inhibit inappropriate response” (Goswami, 2008b, p. 295). EFs are cognitive control functions that make it possible to direct attention in order to achieve goals (Baddeley, 1996; Masten et al., 2012) (Figure 1). Examples of EFs include attention, inhibition, working memory, and cognitive flexibility (Cartwright, 2012).

² For the purposes of this thesis, ‘students’ denotes ‘pre-school and school children’.

Swanson, Howard, and Sáez (2006) found that updating³ correlated with both WM and STM.

Willcut, Doyle, Nigg, Faraone, and Pennington (2005) classify the features that organise and control cognitive processes into five areas (1) inhibition and execution, (2) WM and updating, (3) shifting and (4) interference control and, (5) planning. Overall, one can say that EFs make it possible to perform cognitive tasks at a high level, e.g., reading (Goswami, 2008b). EFs make it possible to identify and solve a problem (or carry out a task), consider consequences and understand what is socially appropriate in different contexts (Barkley, 1998). EFs can be said to constitute the very basis of learning (Goswami, 2008b).

Executive functions develop with age and experience (Masten et al., 2012; Cartwright, 2012). It is suggested that brain areas related to EFs develop in parallel to reading acquisition (Cartwright, 2012). Therefore, EFs can be assumed to be significant for reading on phonological and word levels, and for reading comprehension. Studies have also reported relations between EFs and arithmetic (Bull & Scerif, 2001).

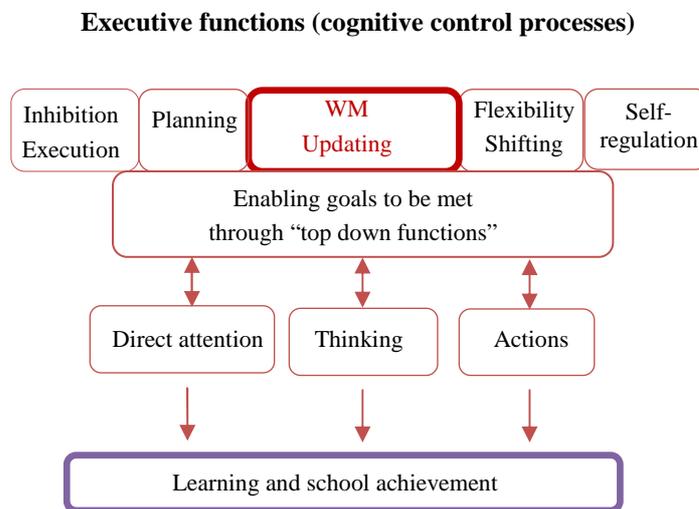


Figure 1. Executive functions make it possible to direct attention, thinking, and actions in order to achieve goals, (cf . Baddeley, 1996; Willcut et al., 2008; Masten et al., 2012) illustrated by K Dahlin, 2013).

³ “Updating requires monitoring and coding of information for relevance to the task at hand, and then appropriately revising the items held in WM.” (Swanson et al., 2006, p. 265-266).

The question of whether EFs, including STM performance, at a very young age (4 years old, $n = 124$) can predict school performance at age 7 (having started school at 5 years) was examined by Bull et al., (2008). EFs were found to aid predictions on how mathematics and reading would develop in general at school. The higher functioning the STM (according to Digit span forward) and EFs, the better the students performed compared with those who started at a lower level and the higher their reading and mathematical development later on.

The assessment of EF skills is therefore considered important given that EFs have been found to be an important factor for school success (Masten et al., 2012). Some EFs require little emotional control, while others call for a great deal of emotional control, as highlighted by Masten et al.

Preschool children seem to be especially sensitive to assimilating ways of regulating their own emotions and behaviour (Center on the Developing Child at Harvard University, 2011). At school, students must concentrate, follow instructions and rules, and behave “as expected”. Cognitive control is essential to a range of school situations (Masten et al., 2012). EF plays a key role in all of this. Working memory is one of such skills and will be discussed in this thesis.

2.1.2 Definitions of Working Memory

There are several theories suggesting how to define the WM system. Two models are described below selected because of their frequent use in studies in education research and are therefore useful for this thesis when discussing WM, training and education. The first is the four-component Baddeley model (Figure 2) and the second is a three-component model (Figure 3). The main difference between them is that STMs feature inside the WM in Baddeley’s model, while they are considered as separate units outside the WM function in the second model (cf. Engle, Tuholski, Laughlin, & Conway, 1999). Further, in the second model, the central executive (CE) is synonymous with ‘WM capacity’ (cf. i.e., de Jong, 2006), in line with many researchers’ definitions of WM (Dehn, 2008; Alloway et al., 2009a), and features more executive functions in WM than in Baddeley’s model.

Throughout this thesis, ‘STM ability’ signifies the function of continuously storing information for a few seconds without manipulation. ‘WM ability’ however refers to not only the processing of information (verbal, visuo-spatial), but also attention control, planning, sorting and the coordination of information, as in the CE in Baddeley’s model and according to the second model (outlined below).

2.1.3 The first model - a four component model

The model that Baddeley and Hitch introduced in the 1970s has proved effective in explaining a large number of cognitive tasks, such as language and arithmetic (Duff & Logie, 2001), and has been debated, tested and revised. According to this model, WM includes both storing and processing.

The model originally contained Central Executive (CE) with two subgroups: the Phonological Loop (PL), with storage capacity and an articulatory component; and the visuo-spatial storage function, the Visuospatial sketchpad (Baddeley, 1992). Each of these two subgroups has a specialty, which is to deal with verbal and visual information. The model was later revised and 'the Episodic Buffer' was inserted (Baddeley, 2000) (Figure 2).

2.1.3.1 The Central Executive

Baddeley (2007) identifies at least four important functions that are handled in the Central Executive of the WM, i.e., the ability to focus attention, switch attention and divide attention, and to link long-term memory and WM.

The central executive (CE) is likely to affect cognition in general and therefore has great significance for the WM model, but it is not studied as much as other parts of WM (Baddeley, 1996). The CE sorts, controls and manipulates information, but is also responsible for changing the focus of attention if required. Furthermore, it coordinates relevant information from the appropriate subset, obtaining and providing information from LTM (Baddeley, 1992), which occurs via the episodic buffer (Baddeley, 2000; Baddeley, 2007). Baddeley (2007) suggests that attention may be WM's main function and that it is regulated by CE. A reduced ability of WM's CE makes it more difficult to screen out irrelevant information and maintain attention long enough to complete a task (Baddeley, 2007).

2.1.3.2 The Phonological loop

The phonological loop (STM) within the WM consists of 'the phonological store' and the articulatory loop, together referred to as the Phonological loop (PL), and handles the storing of verbal information (Baddeley, 2000). The articulatory loop makes it possible to repeat information so that it can be held longer in memory. Not until students are seven to eight years old do they begin to use this function (Gathercole & Alloway, 2008).

2.1.3.3 The Visuospatial Sketchpad

Visual and spatial information (STM) is stored in the visuospatial function (Baddeley, 2007). Moreover, this function is suggested to be involved in the ability to develop mathematical knowledge among both younger and older students and adults (Holmes & Adams, 2006; Reuhkala, 2001). Spatial abilities were found to also influence reading comprehension results (Shah & Miyake, 1996).

2.1.3.4 The Episodic Buffer

The episodic buffer is assumed to be a storage system that combines information from perception and memory, i.e., the phonological loop, the visuo-spatial memory, the central executive function and long-term memory into a device: an episode. Baddeley (2007) suggests that this is probably attention demanding, while only the retrieval of information from long-term memory demands less attention.

2.1.3.5 Summary

It is believed that together with the central executive and visuo-spatial functions, the phonological loop, by means of its storage and articulatory functions, may be necessary for reading and mathematical skills and for the ability to store important information temporarily (Fayol, Abdi, & Gombert, 1987; Gersten, Jordan, & Flojo, 2005; Adams & Hitch, 1998; Keeler and Swanson, 2001; Pickering & Gathercole, 2004; Wilson & Swanson, 2001; St Clair-Thompson & Gathercole, 2006).

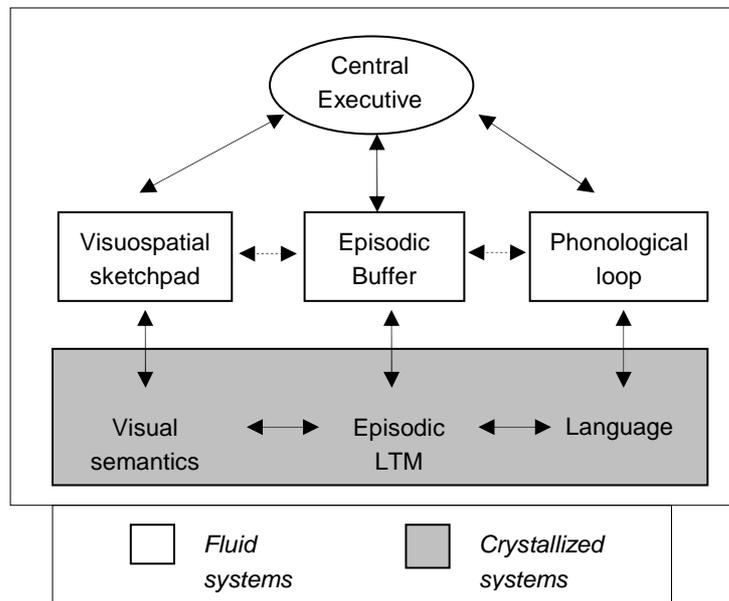


Figure 2. The revised working memory model from 2000 according to Baddeley (2007). Figure 8.1, p. 147: In this initial version, links between the subsystems and the buffer operated via the central executive. It now seems likely that there are also direct links (shown here as dotted lines). Used with the kind permission of Elsevier: lic.nr.212 41501147.

2.1.4 The second model - STM and WM

Another way to differentiate between memories is to use the terms verbal STM and visuo-spatial STM, in contrast to verbal WM and visuo-spatial WM in the CE (Figure 3). Studies show that WM and STM appear to operate independently of each other (Engle et al., 1999; Passolunghi & Siegel, 2004; Alloway et al., 2006; Swanson, 2006).

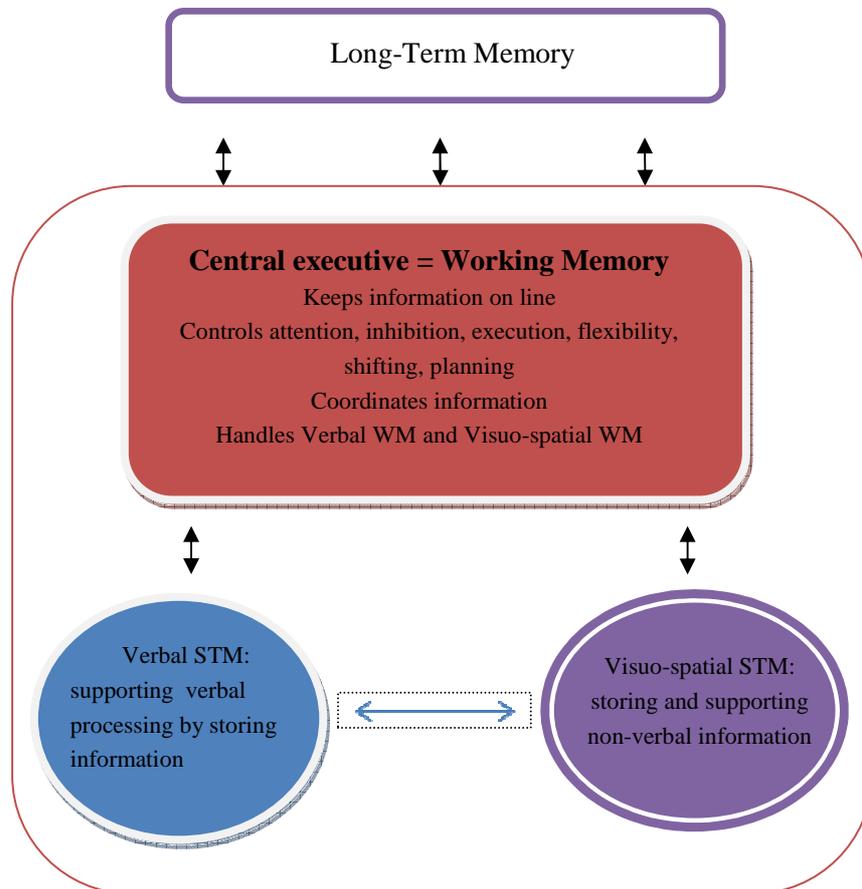


Figure 3. A model summarising components: WM and STMs are separate functions. WM-functions = the central executive (illustrated by Dahlin; cf Dehn, 2008; Cain, 2006; Alloway et al., 2006).

From my point of view, it is important to be able to discuss separate STM and WM components, i.e., verbal and visuo-spatial domains, because in edu-

cation the relationship between processing (in WM) and storing (STM) could be fundamental, since automatised knowledge may facilitate WM processing. This approach is also suggested to be essential in ADHD research (Tillman, Eninger, Forssman, & Bohlin, 2011). Working memory can be considered as a “gateway between short-term memory and long-term memory” (Dehn, 2008, p. 57, 58) (Figure 3).

2.1.4.1 Short-term memory

Short-term memory is passive (Carroll, 1994). One can distinguish the verbal STM (making it possible to store/recall verbal information, numbers and words for a limited period of time) and the visuo-spatial STM (making it possible to store/recall non-verbal information, shape and position for a short time) without being processed (i.e., the information is not manipulated in any way, just remembered exactly as it was given).

2.1.4.2 An extended working memory

The Working memory keeps information on line, controls attention, inhibition, flexibility, shifting and planning, and coordinates information.

The verbal WM is involved in most language and reasoning activities via what we hear, see or read, and it influences the development of words, language comprehension and expression, reading comprehension and semantics (Dehn, 2008).

Visuo-spatial WM is suggested to play the key role in calculation, processing, the integration of information, and even the computation of data with single digits. Furthermore, it is suggested that visuo-spatial function and reading difficulties are related (Smith-Spark & Fisk, 2007; Heiervang & Hugdahl, 2003).

In addition, the links between WM and LTM are important. In the second model, STMs operate outside the WM (Figure 3).

2.1.5 Attention is central

Attention can be described as the ability to always know what to focus on and to be able to do so (Nigg, 2006). The ability to control and maintain attention is assumed to be managed by ‘the central executive’ (Baddeley, 1992; Vellutino, 2003; Gathercole & Pickering, 2001; Swanson & Siegel, 2001). In order to process and store new information in memory, the presence of attention is necessary (Klingberg, 2007; Goswami, 2008a; Cowan, 2005).

Attention deficits affect students in many ways, not only in school situations, but also in peer relationships and possibly the whole of family life (e.g., Nigg, 2006) as some students may also have difficulty controlling their hyperactivity and impulsivity (Tannock & Martinussen, 2001).

For example, St Clair-Thompson (2011) compared age-matched groups of students with and without WM difficulties (mean age 10:2). Each group described was comprised of 38 students (20 female / 18 male). Students with WM problems, tested with the Memory Test Battery for Children (WMTB-C, Pickering & Gathercole, 2001), had both poorer planning and attention abilities (Figure 4) compared with other students but did not, however, have ‘inhibition’ or ‘shifting’ problems.

To take another example, students aged 10 to 19 years (total n = 202) with minor attention problems were compared with students who had ADHD diagnoses. All of the students had learning and behaviour problems, but to varying degrees. It was found that both groups performed better on general cognitive measures than on verbal WM and processing speed (Ek, Westerlund, and Fernell, 2013). This is obviously significant when considering classroom education and to understanding underlying cognitive variables.

Therefore, students with low WM-ability may need assistance, not only with WM-related tasks in school, but also with activities that require planning and attention, as suggested by St Clair-Thompson (2011). In addition, various memory abilities are required in order to develop skills: WM, short-term memory and LTM are all important to cognitive processes.

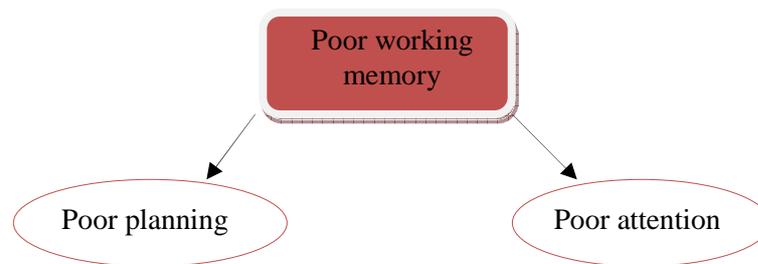


Figure 4. Children with poor WM also demonstrate poor planning and attention abilities (St Clair-Thompson, 2011, illustrated by Dahlin).

2.2 Long-term memory

Closely associated with WM and automatised knowledge is episodic memory in the long-term memory (LTM). Episodic memory is engaged when trying to remember certain passages of a previously read text, accessing that knowledge if required, recognising someone we have met before and maybe even remembering that person’s name (Nyberg & Bäckman, 2007).

With episodic memory, information must be supplied and stored, whether the process is volitional or not according to Nyberg and Bäckman. For example, for a text to be read and understood, a summary of it is stored for a short time in the episodic memory (Carroll, 1994) and integrated with ongoing information from the long-term memory. Baddeley (2000) presented an 'episodic buffer' in his theoretical WM-model (see 2.1.3) with a similar function.

The episodic memory within the LTM seems to be impaired in students with WM-problems (Gathercole et al., 2006). It was found that information loading on the episodic memory, such as storing information about what has happened right now, earlier in the day or the previous night, were hard to remember. Therefore, episodic memory ability most likely has an impact on knowledge acquisition (Gathercole et al., 2006; Nyberg & Bäckman, 2007) and thus affects the ability to remember and use information from, for example, homework completed the previous day.

One explanation for this phenomenon may be that in order to satisfactorily activate memory functions, multiple processes from different parts of the brain must be coordinated (Nyberg & Bäckman, 2007). Consequently, a deficit in one part of the brain might affect learning outcomes.

2.3 Reading and working memory

2.3.1 Reading comprehension and working memory

Studies suggest that reading comprehension is strongly associated with WM (e.g., Swanson et al., 2006; Seigneuric & Ehrlich, 2005), and WM can explain variance in young students' reading comprehension (Cain, 2006).

People who perform well in reading comprehension have better WM-ability compared with those who perform less well in reading comprehension (Carroll, 1994). Reading comprehension is the goal of reading and depends also on vocabulary, the flow at word level, and on the understanding of words and sentences (Seigneuric & Ehrlich, 2005; Cain, 2006).

Inefficient reading at word level is assumed to limit young and poor readers' reading comprehension (Cain & Oakhill, 2006). The information necessary for understanding is accessible for a very short period of time. If the words are not understood or if word decoding is slow, comprehension will suffer. This is because processing speed will decrease and the information will not be processed in time (Vellutino, 2003; Swanson et al., 2006; Ek et al., 2013). The amounts of information stored in the STM that eventually cannot be processed or coordinated, disappear completely or partially. The faster the speed, the more information can be processed in WM at a time.

However, some students suffer from reading problems on another, higher level (see, for example, Cain, 2006). They find it difficult to make inferences, reflect on content, and evaluate and coordinate the text read with previous experiences and knowledge; in other words, everything that WM contributes. These abilities demand both automatised knowledge (letters, sounds, grammar, word meaning) stored in LTM, the effective coordination in WM of new and previous information/knowledge from LTM, strategies (LTM) and reflection (WM and LTM) in order for the text to be understood (Cain, 2006).

A recent study shows that verbal WM influenced the reading fluency of students ($n = 77$, aged 13-17) with dyslexia (Rose & Rouhani, 2012). They performed poorly in both word and text reading. In text reading, top down and bottom up strategies are used (WM processes). Verbal WM seems to be a strong predictor for 'connected-text' reading, beyond word reading and oral language skills, according to Rose and Rouhani's conclusions.

WM is thus related to reading comprehension, regardless of STM, word decoding or word comprehension skills (Cain, et al., 2004; Swanson et al., 2006). Verbal WM can be measured, for example, by Digit span back.

2.3.2 Reading and verbal short-term memory

Phonological recoding and verbal STM (affect letter knowledge acquisition) are important in early reading development (de Jong, 2006). Both verbal STM and phonological awareness ability were found to be important to reading development as they affected word recognition and subsequently reading comprehension (Dufva, Niemi, & Voeten, 2001). Dufva and colleagues examined the development of phonological memory (verbal STM measured with Word span, Sentence span, Digit span forward), vocabulary skills, listening comprehension and reading skills in 222 students, from kindergarten to Grade 2. They found two stable predictors for reading comprehension and word recognition: listening comprehension and phonological awareness. Further, in pre-school, phonological memory was related to listening comprehension which in turn affected reading comprehension (Dufva et al., 2001). It is noteworthy that some phonological awareness tasks may demand STM abilities, as well as WM and LTM skills.

A meta-analysis shows that an underlying phonological sensitivity is important. The development of letter knowledge and phoneme awareness are related (Melby-Lervåg, 2012), and when training phoneme awareness, verbal short-term memory results (word span measure) were enhanced. The conclusion drawn is that the quality of phonemic representations can influence verbal STM and so it is in that sense important for reading (Melby-Lervåg, 2012). Difficulties in creating these representations cause problems in learning to read for students with dyslexia (Hulme & Snowling, 2009).

In sum, verbal STM and WM is important for teaching students to read i.e., for phonological awareness and word recognition skills, and when higher cognitive processes are involved, such as reading comprehension.

2.3.3 Individual differences

Since there is a relationship between WM capability and reading comprehension ability (e.g., Swanson, et al., 2006; Cain, 2006), students' performances on WM-related measures are indicators of their reading comprehension level, regardless of their vocabulary or word-reading skills (e.g., Cain et al., 2004).

However, it is believed that differences in reading comprehension cannot be explained by one single factor. The relationship between WM and reading may be partially explained by individual differences in WM capacity affecting word reading (Cain & Oakhill, 2006). Students' WM and word reading development was studied at age eight and three years later. Forty-six students with good and poor reading comprehension respectively were compared. There were large individual differences in students with reading comprehension difficulties. It should be noted that some of the poor comprehenders did not display any WM-deficits, suggesting that other factors also affect reading comprehension. The study highlights the importance of implementing individual interventions according to each child's performance, as reading comprehension depends on a number of linguistic and cognitive factors (Cain & Oakhill, 2006).

Moreover, cooperation between the verbal and the visual memory is most likely important, along with the ability to control and hold attention (Vellutino, 2003). For instance, Swanson et al. (2006) found that students ($n = 66$; 22 female / 44 male; mean age = 12.45) with poor reading comprehension skills were deficient in coordinating information in the central executive (according to Baddeley's model).

Thus, cognitive abilities in certain functions of WM seem to affect the development of literacy skills to certain degrees and this may explain why differences in reading ability occur between individuals.

2.3.4 Developmental perspective

Reading and writing are 'new' abilities in a developmental perspective and are therefore likely to depend on existing systems in the brain, given that the brain has not had time to adapt to this development, as opposed to speech. Dehaene (2004) considers that reading, writing and mathematics skills have been of little influence to brain development because they are such 'fresh' skills in the perspective of human development. Many common functions are used for reading and writing but the possibility of there being a specific area that deals with letters: the 'letterbox' VWFA (visual word form area)

(Dehaene, 2004) is currently being discussed. Originally, this area was not associated with letters but with the ability to recognise all kinds of objects and shapes. Links between linguistic and visual areas must therefore develop when learning to read (Dehaene, 2009). This could explain why it takes much longer to learn to read and write than to learn to speak and why it learning to read and write is sometimes perceived as difficult at the outset (Dehaene, 2009).

2.4 Mathematics and working memory

2.4.1 Basic number skills and short-term memory

Verbal and visuo-spatial STM deficits may affect mathematics, as mathematics may rely on STM and executive functions (i.e., shifting and planning) to various degrees depending on the complexity of the task and students' ages, experience and development (Bull & Espy, 2006).

It has been found that number skills in pre-school predicted arithmetic skills in Grade 2 (Locuniak & Jordan, 2008). Also, first graders have been followed throughout the years. Geary (2011) studied 177 students over five years to examine which factors in the first year of school could predict mathematics development five years later. Intelligence, WM, visuo-spatial STM and processing speed were the variables found to be important in mathematics development (e.g., manipulating the amount and use of effective counting strategies and understanding the interrelationship between major and minor numbers) and related to future success in mathematics. Children's "mathematical awareness" including basic skills in arithmetic seems to be significant (Geary, 2011). This can be compared to the importance of language stimulation in giving children a "phonological awareness".

2.4.2 Visuo-spatial WM and mathematics

It is suggested that the visuo-spatial WM and STM seem to be important for mathematical skills. For example, visuo-spatial problems may result in reversed numbers and difficulties in organising and planning word problems (Cherkes-Julkowski & Stolzenberg, 1997; Haskell, 2000). Grade 9 students (aged 15-16) with difficulties in mathematics were examined in two studies (Study 1: n = 62; 36 female / 26 male; Study 2: n = 53; 33 female / 20 male) (Reuhkula, 2001). They had greater difficulty with the visuo-spatial WM-test than the students who performed well on the mathematics test. Something as simple as detailed written information available to each student could compensate for this (Rehkula, 2001).

Moreover, the visuo-spatial WM had an impact on the ability of students in Grade 1 to coordinate abstract knowledge (Haskell, 2000). It is therefore appropriate to use arithmetic tasks in WM research, as all of the WM components are engaged in arithmetic, as suggested by DeStefano and LeFevre (2004). Pickering and Gathercole (2004) point out that WM-deficits affect the ability to process and coordinate information within the WM and with long-term memory (LTM).

Furthermore, visuo-spatial deficits have been found, for example, in students with ADHD and students with special learning impairments (SLI). In six of eight studies in a meta-analysis that examined ADHD, WM and EFs, significant differences were found in the spatial WM of those with ADHD compared with those without a diagnosis (Willcut et al., 2005). Morton (2008) found that 8-11 year olds with SLI ($n = 40$) had greater difficulty with visuo-spatial WM in tasks that demanded 'simultaneous processing' (e.g., visualisation, situation assessment, position in space, copying) compared with age-matched students without SLI ($n = 40$). Morton concludes that tasks requiring the CE and attention are more difficult for students with SLI than for other students without this difficulty.

Visuo-spatial WM can be measured by Span board back (see Methods, 3.5.1).

2.4.3 The central executive may be crucial

Students with mathematics difficulties may have a deficiency not only in STM (the phonological loop, Baddeley's model, see 2.1.3), as proposed by Baddeley and Hitch in the 1970s, but also in other functions of the WM system (Gathercole & Pickering, 2001; Swanson & Siegel, 2001; Thevenot, Barrouillet, & Fayol, 2001). Basic knowledge of mathematics, knowledge of numbers and the four basic arithmetic operations, are primarily dependent on the resources of the central executive (Lemaire, Abdi, & Fayol, 1996). The CE may be crucial as it works with the LTM, the verbal WM and the visuo-spatial functions (Lemaire et al., 1996; Gersten et al., 2005).

As noted with reading, the development of WM's central executive seems to be significant. One example is a study by Swanson (2011): 127 students in Grade 1 (49 female / 78 male) completed word problems in mathematics. Growth in the central executive function, together with intelligence and processing speed, could predict the development of mathematics from Grade 1 to Grade 5, and also in word reading.

Furthermore, it was possible to link the students' performances in mathematics to 'inhibition' results, which Iuculano, Moro and Butterworth (2011) regard as belonging to a function in an expanded CE. In a study of students ($n = 33$, aged 8-9) with and without mathematical difficulties, they found a clear correlation between 'counting' and WM in both groups. There was no difference in performance between the groups according to Digit span and

Word Span task (believed to be served by the phonological loop). These tests were clearly not good instruments for detecting mathematical difficulties.

However, there are several reasons why some students have difficulties in mathematics. Weakness in WM is only one factor that can negatively affect mathematics ability (Chinn, 2004; Gathercole and Pickering, 2001; Adams & Hitch, 1998).

2.5 Correlations between reading and mathematics

Correlations between performances in reading and mathematics tasks have been noted in studies (e.g., Lyytinen & Lehto, 1998). Students with reading problems were found to have slower development in mathematics than students without reading difficulties (Gersten et al, 2005). Lundberg and Sterner (2006) report a significant correlation between reading and arithmetic in 60 students ($r = .68$) and highlight the importance of WM to both reading and mathematics.

A recent study shows that students in Grade 3 with dyslexia may have more difficulties with basic mathematics than other students (Vuovic, Lesaux, & Siegel, 2010). Three groups were compared: students with (1) dyslexia diagnosis, $n = 18$, (2) specific reading comprehension difficulties, $n = 22$, and (3) a comparison group, $n = 247$. Students with dyslexia diagnoses were approximately five to eight times more likely to develop difficulties with ‘fact fluency’ (completing as many single-digit mathematics problems as possible within three minutes) and ‘operations’ (completing an increasingly difficult series of written tasks) compared with the rest. However, there was not a significant difference between the comparison group ($n = 247$) and the other students with reading comprehension problems ($n = 22$). These two groups performed significantly better than the students with dyslexia.

Students with dyslexia seem to have problems with both the central executive and the phonological loop, as do students with problems in mathematics. According to Alloway and Passolunghi (2011), at the age of seven abilities in the phonological loop and visuo-spatial function can already predict future development in mathematics. In addition, at an early age the abilities of the central executive seem to be an indicator of future development in mathematics (Bull & Scerif, 2001).

Deficiencies in the WM seem to have significant impact on both adults’ and students’ individual differences in word reading, reading comprehension, mathematics, and possibly writing (e.g., Swanson & Siegel, 2001; Gathercole & Pickering, 2001). In the Gathercole and Pickering study WM-ability was tested in 57 seven to eight year olds (37 female / 20 male) with or without special educational needs. The students’ learning difficulties appeared to be closely associated with major flaws in WM, especially the abil-

ity to process and store incoming information in the central executive. It resulted in difficulties in reading comprehension, word reading and writing, and arithmetic (the four operations).

All three functions in Baddeley's WM-model (verbal, visual-spatial and central executive) were found to be related to difficulties in mathematics (Wilson & Swanson, 2001). Participants in the study had no reading difficulties, indicating that there are most likely other abilities involved in mathematics but not reading. Nevertheless, weak WM capability seems to be an obstacle to development in both reading and mathematics.

In sum, students with problems in both reading and mathematics seem to have a deficiency in all three of these mentioned functions in the WM, suggesting that multiple abilities are impaired in these students (Gathercole & Pickering, 2001), while others can compensate for a weakness with a strength in another function of the WM (Gathercole et al., 2004b).

2.5.1 Other skills

WM difficulties appear to be a barrier to improvement at school but, as shown above, WM cannot be solely responsible for complex cognitive processes even though it is considered to have a variety of functions (e.g., Baddeley, 2007).

Variations in cognitive development in individuals may also be due to differences in intelligence and the ability to control attention (Engle, et al., 1999) and other specific skills (e.g., Jiménez, Siegel, O'Shanahan, & Ford, 2009). Even more simple tasks (basic knowledge in mathematics, including the four operations) require WM and the link-up to previous knowledge (LTM) is vital, as it is in the case of attention (Lemaire et al., 1996).

Mathematics anxiety can also affect young students' ability to assimilate mathematics, due not only to bad experiences and attitudes, but also to teachers' personalities, and difficulties can sometimes be caused by ineffective instruction (Haskell, 2000; Chinn, 2004).

In sum, it has been found that many students with weak ability in one or more parts of WM underperform at school in reading and/or mathematics in relation to other students (Alloway et al., 2009a; Siegel & Ryan, 1989). Functions required in order to plan, organise, control and correct, develop and use strategies, and coordinate knowledge with action to reach a goal vary in individuals and are recognised as vital variables. This may be what separates individual cognitive ability in such a decisive way and should therefore be considered in work with and studies on students with ADHD problems (Goldstein & Naglieri, 2008). Some of these students could have WM-deficits (Tillman et al., 2011; Alloway & Alloway, 2010).

2.6 ADHD and working memory

Studies show that students with ADHD diagnosis perform less well on visuo-spatial WM and the central executive than controls without ADHD (Castellanos & Tannock, 2002; Biederman et al., 2008). One of the very first WM memory training studies hypothesised that students with ADHD have a lack of attention ability in their WM. If WM training could improve WM capacity, then ADHD-symptoms might decrease (Klingberg et al., 2002). This proved to be true.

Baddeley (1996) suggests that attention capacity (focused attention) is a WM function, and is managed by the central executive function, a coordinating role in his WM model. Perhaps students with severe attention difficulties suffer more than others from WM-deficiency (Castellanos & Tannock, 2002). Tillman et al. (2011) found a relation in students with ADHD diagnoses between attention deficits and verbal WM, and between attention and both verbal and visuo-spatial STM.

A number of recent studies are reporting on the association between ADHD and WM (e.g., Tillman et al, 2011; Alloway & Alloway, 2010; Gropper & Tannock, 2009; Gathercole & Pickering, 2001; Swanson & Siegel, 2001).

2.6.1 ADHD, EFs and WM

A meta-analysis of 83 studies was carried out by Willcutt et al. (2005). The aim was to test the theory that difficulties included in the diagnosis of ADHD are caused by deficits in the executive functions. It was found that planning, inhibition and WM difficulties were common in students with ADHD problems. They found that individuals with ADHD performed less well on several EFs, more specifically in inhibition, planning and WM.

Another study showed that students with ADHD and students with WM problems had similar behaviour in classroom situations (Alloway et al., 2009b). The major difference between these two groups of children was their attentive capability, which was poorer in those with impaired WM, while their hyperactivity / impulse control was better.

Moreover, Martel (2009) conducted a review of studies examining ADHD and the ability to control emotions, showing that poor emotional control (depending on temperament and personality) and not cognitive control may be a risk factor for developing behavioural problems. Martel discusses attention deficit, which can be a significant risk factor that may explain behavioural difficulties.

It is important to note here that some children with an ADHD diagnosis have more severe attention problems (ADHD-I, inattention) than others, who may have more hyperactivity problems (ADHD-HI, hyperactivity/impulse) and that some have combined problems (ADHD-C) (Nigg, 2006).

2.6.2 ADHD, reading and mathematics

Reduced ability in WM has been shown to affect not only reading comprehension, problem solving and arithmetic (e.g., Siegel & Ryan, 1989; Gathercole & Pickering, 2001), but also attention, impulse control and planning ability. In addition, ADHD and dyslexia occur simultaneously in some students (Knivsberg, Reichfeldt, & Nødland, 1999; Snowling, 2006) and the presence of dyslexia in students with ADHD clearly makes it harder to develop satisfactorily in school.

It is suggested that students with ADHD may be at risk of performing below their cognitive abilities (Ek, Westerlund, Holmberg, & Fernell, 2010). Sixteen year old students were investigated in three groups: (1) ADHD group (n = 39), (2) behaviour and learning problem group (n = 80), and (3) a comparison group (n = 417). IQ (WISC: full scale IQ, verbal IQ, performance IQ) had been previously measured at 10-11 years of age. Ek and her colleagues found that the ADHD group and the behaviour and learning problem group performed less well when compared with the control group in mathematics, Swedish and English.

It was found in a recent longitudinal study (Miller & Hinshaw, 2010) that preadolescent girls with EF deficits and ADHD (n = 140) developed more poorly at school over a period of 5 years compared with girls without these problems (n = 88). However, poorer EF scores in childhood predicted lower mathematics achievement in all girls. Another study showed that students with ADHD often have difficulty expressing themselves in writing (Mayes & Calhoun, 2006).

It should be noted that not all students with ADHD have WM difficulties but the risk of failing in school is probably greater for students with both ADHD and WM problems (Alloway & Alloway, 2010). It therefore seems reasonable to distinguish between those students with low WM capacity and other students with ADHD (ADHD-I, ADHD-C, ADHD-HI) since they require different types of intervention. Students with both ADHD and low WM capacity need more specific help with their learning than some other students with ADHD who instead need an enhanced environment and help in regulating their behaviour, depending on the type of problems they have (Goldstein & Naglieri, 2008).

2.7 In the classroom

2.7.1 Consequences of a low WM capacity

Deficiencies in WM show themselves in the most diverse situations. Some examples of situations in which working memory is loaded to different degrees are: listening while taking notes; remembering instructions; and plan-

ning what to do at school, work, home, or with friends. Cognitive development may be inhibited by insufficient cognitive functioning. For instance, remembering rules or words and making calculations at school may be perceived as difficult without adequate opportunity or time to train (formally and informally), structured instruction, or access to aids such as written instructions, tables and calculators. Three boys in this study expressed what they experienced as a problem at school, as follows:

I can't learn the tables (boy, Grade 7).

... I'm allowed to have a calculator sometimes (boy with significant reading and mathematics difficulties, Grade 9).

Hopelessly hard every day – I don't get any help ... (boy with dyslexia, Grade 7).

If an individual is forced to depend on mental capacity, it may place him or her in a vulnerable position (Alloway & Gathercole, 2006). It may also be difficult for a student to identify which oral or written information is important if a teacher's style is wordy or tedious and as a result a certain amount of relevant information is quickly forgotten (Pickering & Gathercole, 2004).

Additionally, a poorly functioning WM affects self-confidence and subsequently has a negative effect on knowledge development. Three girls in this study responded in the following ways to the question of how it feels to not know how to perform tasks at school:

Irritating, pain every day – I'm a loser – should know (girl with dyslexia, ADHD and Asperger's syndrome, Grade 8);

Boring and slow ... it takes much longer than for the others, and then it's boring. Every time we have maths, I am disappointed in myself because I don't know ... lose confidence ... ask my friend for the answer when I don't know how to do it (girl difficulties in mathematics, Grade 6);

It's embarrassing – everyone else knows. Scary to say the wrong answer –others may laugh (girl with dyslexia and ADHD, Grade 6);

Difficult – I feel nervous all the time (girl with mathematical difficulties, Grade 7).

Finally, it can be next to impossible to follow a discussion whilst remembering what it was you wanted to say or ask. The result could be that the 'wrong' question gets answered (Greene, 2003/2009).

2.7.2 Sensitivity

Studies have been carried out on students' sensitivity in learning situations (e.g., Poskiparta, Niemi, Lepola, Ahtola, & Laine, 2003). Poskiparta and colleagues examined groups of students. Many factors were compared, including how dependent students were on the teacher and how motivation developed from kindergarten to Grade 2. In kindergarten, there was no significant difference between the groups. However, changes were apparent in Grade 1: the poor readers' optimistic attitude to work, attention to instructions and positive comments decreased. Furthermore, negative comments about their own work and unwillingness to work on a task increased. This was shown not only in reading tasks, but also in all other subjects; it was 'contagious'. The good readers tolerated stress well and were not negatively affected by challenges and difficult tasks. In Grade 2, the difference between the groups was greater (Poskiparta et al., 2003) (Figure 5).

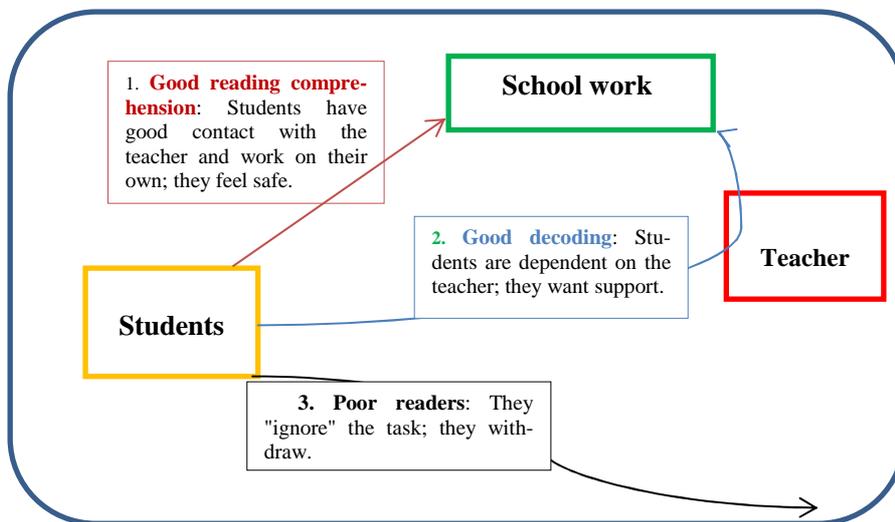


Figure 5. The motivation in Grade 2 influences behaviour in learning situations (compiled by Dahlin, K. I. E., 2012, from Poskiparta et al., 2003, and according to Niemi's description, seminar in Gävle, 031009).

Another study showed that students with poor development in both reading and mathematics seemed to be the least likely to concentrate on tasks,

seemed more often to ‘hide’ and developed more slowly than other students already in the very first semester of Grade 1 (Lepola, Niemi, Kuikka, & Hannula, 2005). Remarkably, the influence of motivation in decoding, reading comprehension and mathematics was already in evidence in pre-school class regardless of previous knowledge in mathematics and reading-related skills.

In a more recent study (Niemi et al., 2012) more than a thousand Finnish students were followed from preschool to Grade 1. None of the students could read at school entry. Here, the same phenomenon as in the Lepola et al. study was noted. Some students performed less well in Grade 1 in maths and reading compared with the rest. There was no development at all for some students after eight months in Grade 1 (Niemi et al., 2012).

To prevent students from ‘hiding’ and losing motivation, students with mathematical difficulties should be identified and stimulated as early as in preschool and Grade 1 (Lepola et al., 2005).

Sonuga-Barke et al. (2009) reported in a large international study (n = 728, students and adolescents with ADHD diagnosis) how negative and positive environments affect the interaction between genes and thus exert influence on behaviour and emotion. Certain individuals may be more sensitive to negative experiences than others.

2.7.3 Losing focus

It is suggested that some students with learning and attention problems do not have attention problems in all situations, but only when there are high demands on cognitive ability (Swanson & Siegel, 2001). So what happens when this occurs? Kane et al. (2007) examined in a laboratory the extent to which students' (n = 124, 88 female, aged 17-34 years) thoughts ‘went away’ (‘mind-wandering’) and when it happened. They found that when dealing with tasks demanding a greater degree of self-effort and concentration, those with low WM capacity were ‘mind-wandering’ more often than those with a higher capacity.

All tasks requiring the use of attention seem to be affected by WM ability. WM capacity may therefore predict an individual’s ability to control attention on these kinds of tasks and provide clues as to future cognitive consequences.

Another study in a school context found that students' thoughts could wander (‘zone out’) in classroom situations (Alloway & Gathercole, 2006). The students were in Grade 2 and had impaired verbal WM capability. The conclusion drawn is that this may be due to WM being overloaded and as a result not all of the information required for completing a task is able to be kept in the mind and has thus faded away. As a result, the students lost their focus.

2.7.4 Succeeding in learning situations

Good readers use a variety of abilities in order to understand a text. They normally have motivation and interest and can make inferences and create internal images (Vellutino, 2003). They have cognitive abilities such as attention skills, analytical skills and a good memory (Snow & Polselli Sweet, 2001).

However, other students may not have all of these skills and for that reason perform differently. To teach in a way that is entirely based on the student's own quest for knowledge (i.e., being left to work alone in most learning situations) can cause frustration and affect school work, well-being, self-esteem and behaviour (Klingberg, 2007). Students can sometimes be perceived as inattentive and 'forgetful' since they may find it difficult to follow instructions and acquire strategies if not enough help and advice is given, and as a result fail to complete tasks adequately (Alloway et al, 2009a). They will probably avoid situations that they consider to be unpleasant, which could be negative for knowledge development, peer relationships and their future lives (DuPaul, Eckert, & McGoey, 1997) (see Figure 5).

The fact that joy and motivation promote learning should be familiar to anyone who works in education (Snow, Griffin, & Burns, 2005; Hulme & Snowling, 2009). However, to constantly fail to be aware of this can leave a student too daunted to try more, which feeds a downward spiral. 'Demotivation' can have devastating consequences (according to Hattie, 2009). It is much easier to influence students in a negative direction (e.g., humiliate a person or their work in front of others) than to try to build a student's motivation.

'Errorless learning' (giving students the tools they need to find out for themselves the correct spelling or basic facts required) eventually generates automatised knowledge stored in the LTM and is suggested to be effective in learning situations (Gathercole et al., 2006). Positive learning situations thus generate positive attitudes to learning (Light et al, 2009).

Hattie (2009) has analysed a large number of studies, and compiled the results. According to Hattie, motivation affects learning with a medium effect, $d = 0.48$.

Finding ways to reduce anxiety in learning situations and test situations and to influence attitudes towards school work is important because all of this is related to different degrees to school results (Hattie, 2009).

Students seem to have relatively good self-images and a good understanding of their own abilities and how far they should strive. However, aiming only as far as is expected but not further may be an obstacle to development (Hattie, 2009).

Yet, in terms of their own experiences and feelings, students with difficulties are perhaps the students about whom we know the least (Cefai & Cooper, 2010).

2.7.5 Teaching style

According to a study by Gathercole et al. (2006), teaching style is of prime importance. School performance was affected by the way teachers gave instructions, their confidence that the students had understood what was expected of them, the way they guided students through a task, gave feedback, and not least by how they prepared students for an assignment. Miller and Hinshaw (2010) stress the importance of well-structured information and material. WM processing depends on how much a student is able to focus on at a time, the student's own engagement and varied teaching methods. Students' training in remembering is also significant. Short-term memory (storage capacity) can be affected to some extent by structuring the information, presenting it in an attractive way, making it interesting and important (Miller & Hinshaw, 2010), and by developing strategies to 'schedule' processing (Ehrenstein, Schweickert, Sangsup, & Proctor, 1997).

An estimation study revealed that students felt that the most important feature of a teacher ($d = 0.72$) by far was the ability to create a good relationship with the students. Students also appreciated it if the teacher had both breadth and depth of the topic (Hattie, 2009). The use of visualisation, for example, to imagine the work process and strategies related to a task could increase concentration and engagement compared with students who did not receive this kind of instruction ($d = 0.48$, a medium effect) (Hattie, 2009).

2.7.6 WM and increased demands

Studies show that the working memory can become overloaded (Niaz & Logie, 1993; Klingberg, 2007). 'The working memory overload hypothesis' corresponds well to the difficulties that some students may have.

In recent years, the importance of considering the cognitive load of teaching has been highlighted (Klingberg, 2007; Verhoeven, Schnotz, & Paas 2009; Clark, Nguyen, & Sweller, 2005; Paas, van Gog & Sweller, 2010). In 'the cognitive load theory' (CLT), the load on cognitive ability is the cue. When information is too demanding, WM may be overloaded, resulting in complications, especially for beginners in a particular field, but this can be mitigated by effective teacher instruction that takes into account the limitations and strengths of cognitive ability in individuals.

Learning and thinking capacity decreases if pressure is too great and exceeds the limited ability of WM. One goal is to relieve WM and streamline the memory processes. WM's construction and mitigation must be considered in order to make learning as efficient as possible. The CLT emphasises the difference between three kinds of WM-load: (1) load depending on the task (intrinsic load), (2) effective instruction (germane load), and (3) the unnecessary WM-load (extraneous load) (Verhoeven et al., 2009; Clark et al, 2006).

Unnecessary cognitive load, the cost of dealing with unnecessary information, should be reviewed and removed. Students are unable to control this; it is the teacher's responsibility.

Extraneous cognitive load is defined as unnecessary extra load due to poorly designed instruction (Verhoeven et al., p. 371, 2009).

To meet these requirements, in order to understand more fully how teaching environments (e.g., instructions) affect learning, Verhoeven et al. suggest that the relationship between cognitive load and different types of instructions needs to be studied further. The value of this theory and research is discussed and reported in a review by Paas et al. (2010). They state that studies show that the theory is useful in teaching.

2.7.7 Automatised knowledge

Changes in brain activity after training specific skills have been investigated. Shaywitz and Shaywitz (2004) noted how activity decreased in the frontal parts of the cortex⁴ and increased in the posterior part of the brain for 144 students who had improved their reading skills and managed to read with fluency after months of phonologically-based training. Shaywitz and Shaywitz emphasise the importance of students practicing word reading over and over again in order to create an accurate picture of each word.

Fluent reading is one of several skills necessary to developing good reading abilities and should be included in literacy learning programmes. When information is stored in the long-term memory, it is no longer as dependent on the front parts of the cortex (frontal lobes) as it was previously (Ingvar, 2007). When a cognitive problem can be solved quickly and easily it does not require a great deal of effort, i.e., thoughts.

Automatised capabilities mean just that: to perform or to do something with minimal effort, without worrying about how it is done. This is the essence of learning and what the result should be (Logan, 1997). Automatisa-tion is an important basis for further development of mathematics (LeFevre & Bisanz, 1987).

If the requirements for either processing or storage become too great, information will unfortunately be partially lost (Gathercole & Alloway, 2008). This is where exercises, which consolidate students' knowledge, are useful because the load on the WM decreases if it is easy to retrieve the desired information, i.e., if knowledge is automatised. As a result, we are able to read or write a word directly because we know it well and do not need to make an effort.

⁴ "The cortex is the outer layer of the brain that we use for our highest brain functions, and it is divided into sections, or lobes." (Cartwright, 2012, p. 27).

It was noted that students in Grade 2 with impaired verbal WM capability forgot words or letters when writing, as well as long instructions. In addition, they seemed to have difficulty integrating knowledge from LTM, which impeded their knowledge development (Alloway & Gathercole, 2006). In reading, knowledge and decisions must be integrated in order to integrate external knowledge, i.e., knowledge of letters and sounds and their relationships, word meaning, grammar and syntax (e.g., Snowling, 2006).

The ability to solve mathematical problems is partly dependent on WM capability and partly on the ability to recall and use facts, i.e., knowledge of arithmetic, rules and calculation strategies that are stored in LTM (Chinn, 2004). It may also be that mathematics problems are dependent on a particular function of WM that manages specifically mathematical tasks (Wilson & Swanson, 2001; Thevenot et al., 2001).

A student solving mathematical problems, from the simplest to the more challenging, must first choose and be able to download and use the appropriate stored knowledge of symbols, number facts, rules and strategies from LTM. This information must then be stored (STM), processed and integrated with new facts (WM) and lastly the results evaluated (Chinn, 2004).

2.7.8 Who suffer from WM-deficits?

Different types of learning disabilities may include WM problems: students/adults with ADHD (attention difficulties with or without hyperactivity/impulsivity), CD (conduct disorder, severe behavioural problems), dyslexia (high illiteracy due to phonological difficulties), difficulty dealing with numbers and their values, students with specific language impairment (SLI) and LD (general learning difficulties) (Alloway, & Gathercole, 2006; Klingberg et al., 2005; Norrelgen, 2002; Castellanos & Tannock, 2002; Kazdin, 1998; Gathercole & Pickering, 2001).

It is not unusual to have more than one difficulty. Basic number difficulties often occur with dyslexia and sometimes with behavioural and social problems, as well as attention difficulties (Roodenrys, Kolosky, & Grainger, 2001; Snowling, 2006; Lundberg & Sterner, 2006). The more attention difficulties experienced, the greater the learning difficulties present (Mayes, Calhoun, & Crowell, 2000).

Disruptive behaviour in school in combination with other problems increase the risk of low school performance. This was proved in a large longitudinal study examining the relationship between Grade 9-12 students' behaviour problems, health and school performance (McLeod, Uemura, & Rohrman, 2012). Results from more than six thousand students were analysed (54% female, 46% male). Data from the National Longitudinal Study of Adolescent Health (USA) were used. The results showed that attention problems, drugs and delinquency were related to declining school performance, but not depression. In addition, students with attention problems and

one or more additional problems achieved a lower level of education compared with those who 'only' had one problem. The conclusion drawn is that behaviour problems in students are not due to low learning ability, but rather to attention problems and both school and social contexts (McLeod et al., 2012).

Finally, stroke survivors may have impaired WM function (Johansson & Tornmalm, 2012) and some older people may experience decreased function in WM with increasing age (Dahlin, Erica., Bäckman, Stigsdotter Neely, & Nyberg, 2009).

2.8 Strategies, physical exercise and music training

Below are examples of training that appears to have generated improvements in WM related measures.

Skilled students seem to learn and use strategies more easily than less skilled students (e.g., Alloway et al., 2009b). For example, a relationship was found between the knowledge of strategies in mathematics and verbal ability in WM. Students with mathematics difficulties performed significantly lower on tasks related to verbal and visual-spatial WM compared with age-matched students and their results were equated to much younger students (Keeler & Swanson, 2001). Different kinds of strategies have been investigated.

One example is Burton's and Daneman's study about re-reading and eye movements. They investigated eye movements during reading and found that it is possible to compensate for a poor WM by revisiting unfamiliar words or significant sections, thereby 'uploading' information into the working memory (Burton & Daneman, 2007).

Furthermore, eye closure helps memory by reducing cognitive load (Vredeveltdt, Hitch, & Baddeley, 2011), lessening disturbance from the environment, making it easier to concentrate on a task and thus enhancing the ability to learn.

Repeating instructions and words are other examples of strategies. Several studies show that repeating words aloud is an effective way to remember them (Caretti, Borella, & De Beni, 2007).

It was indeed found, in a study of five to six year olds entering school in England, that WM plays a crucial role in learning when working on tasks that require both storage capacity (STM) and processing (WM) (Gathercole, Durling, Evans, Jeff Cock, & Stone, 2008). The students who were taught the strategy of repeating instructions (storing the information again) performed better than other students.

Strategy training via the ‘Memory Booster’⁵ programme was completed by half of the participants of a study with a total of 254 students (6-8 years old) over a period of six to eight weeks. The training yielded improvements directly after training and also five months later in WM-related tests, mental arithmetic and the ability to follow instructions in the classroom. It did not, however, improve performance in mathematics and reading (St Clair-Thompson et al., 2010).

Training with abacuses improved results on the visuo-spatial STM, but not phonological ability or the CE in WM (Lee, Lu, & Ko, 2007). Thirty-two students (mean age = 12.5) participated in this study. Half of them served as a control and the others received mathematics training twice a week after school for 90 minutes at a time. They first trained calculations with and after without abacuses, and then manipulated the trained calculations and the abacuses mentally. The duration of the training period was one year. The training affected measures on trained skills, visuo-spatial storage and WM measures (storage and request-processing such as Digit backward) but not phonological skills (Lee, et al., 2007).

Individuals can to some extent affect STM unaided by scheduling the processing (Ehrensstein et al, 1997). Having good metacognitive abilities makes it possible and easy to develop the necessary strategies autonomously: facilitating remembering, questioning and reflecting, and ‘staying on track’ when solving problems (Goswami, 2008b). However, it is challenging for an individual to discover without assistance strategies that could compensate for learning problems (Snow et al., 2005).

In a review, Halperin and Healey (2012) suggest that physical exercise and directed positive play with parents (such as cognitive challenges with positive feedback) may be beneficial for students with ADHD and could possibly facilitate growth in some of the cortical regions and in turn affect functioning skills.

Music Training in six year olds 75 minutes per week for 30 weeks improved results in a problem solving tests (Bilhartz, Bruhn, & Olson, 2000). Seventy-one students participated in lessons (e.g., hearing and repeating rhythms, distinguishing different tones) along with parents. Thirty-six belonged to the treatment group and as many to the control group, which did not receive any treatment.

⁵ Memory Booster; Leedale, Singleton, and Thomas (2004) as cited in St Clair-Thompson et al., 2010.

2.9 Working memory, environment and learning situations

It is necessary to draw on experience from different disciplines because education cannot be influenced by neuroscience alone (Worden et al., 2011). Goswami (2008b) summarises the factors that affect cognitive development by way of the term 'neuroconstructivism'. It describes how genes, environment, learning situations and brain cells interact continuously. This concept explains how cognitive change and development is achieved by taking biological constraints into account, which help shape cognitive ability. These biological constraints affect brain development. Genes, one of these biological constraints, need help in order to be activated, a process that occurs through both inside and outside neurons and from outside of the body via events and the environment.

Experience and environment can make genes 'turn on' or 'turn off' and produce different effects in individuals depending on individual sets of genes (Hulme & Snowling, 2009), which may explain differences in personality and sensitivity, as investigated by Poskiparta et al. (2003) (see 2.7.2).

The reason for changes in WM-related test results following different types of training is most likely due to the fact that both brain structures and memory are malleable. They can adapt to new conditions and can also be partially rebuilt (Nyberg & Bäckman, 2007, p. 113) in both young and old (Dahlin, Erica. et al., 2009). This plasticity allows us to learn new things throughout our lives and well into old age, but stimulus is necessary for the brain to develop (Lagercrantz & Olson, 2007).

However, according to Dehaene (2004; 2009), not all parts of the brain are malleable. His theory, 'the neuronal recycling hypothesis', explains how the brain reorganises existing circuits in the brain. Learning is dependent on this redistribution and on existing circuits acquiring new functions (Dehaene, 2004). The brain is changing in this respect but the total capacity for transformation is therefore limited (Dehaene, 2004). The brain can develop many new features in existing areas of its cortex through learning. This is probably because some parts of the brain allow themselves to be reorganised, while others do not. The brain's overall structure depends on an individual's specific genetic patterns. When we acquire new knowledge, circuits are reorganised in our 'very old' brains (Dehaene, 2009), if they are among those that are changeable.

Dehaene thus believes that there are limitations to how the brain can change and believes that there are major limitations to what we can learn.

Is it possible to influence an individual's ability in WM directly by training specific WM-tasks? One major question is whether this working memory training may then generate improvement in non-trained abilities. A large number of studies are currently addressing this area.

Below are examples of different kinds of training studies that affect WM, each with a brief description, including their different variations.

2.10 Working memory-training

2.10.1 Activities in the brain after WM-training

Changes in brain activity have been noted through the use of MRI⁶ before and after WM training (Cogmed training). Studies show increased activity in the frontal lobe after five weeks of computerised WM training (Westerberg & Klingberg, 2007; Olesen, Westerberg, & Klingberg, 2004).

Four weeks of daily training with a different WM programme (visuo-spatial tasks) showed increased activity in the predominantly right hemisphere of nine men aged 26 to 32 years with a university education. The increased activity was assumed to be due to the demands posed during the exercise: to repeatedly try to solve tasks using attention and storage and manipulation of the information given (Hempel et al., 2004). No untrained abilities improved.

Fifteen adults participated in a training study (Jolles, Grol, Van Buchem, Rombauts, & Crone, 2010) in which fMRI⁷ was used to examine brain activity during the first and last weeks of the six-week training. fMRI was completed again six months later. The training consisted of two components: first, WM-consuming tasks with a researcher from the study (approx. 3 hours per week overall); and second, exercises at home for three days (7-10.5 times in total, 25 minutes at a time). The results on trained tasks improved, as did activities in the brain, which differed depending on whether it was a low or high-loading task. The changes persisted six months later.

Adults trained with a computer programme for two months on their own computers. The programme included three different types of items. The training lasted approximately 25 minutes at a time and participants were encouraged to practice daily. After each five-day period, the results were mailed to the project managers who also gave feedback. Psychological tests and MRI scans were carried out before and after training. Changes were found in areas considered important for WM functions (Takeuchi et al., 2010).

A review of fMRI studies (Dahlin, Erica. et al., 2009) shows that training in WM and EFs⁸ does affect brain activity. In their studies, Dahlin, Erica et al. found altered activity in the brain after updating-training, but results dif-

⁶ Magnetic Resonance Imaging

⁷ functional Magnetic Resonance Imaging

⁸ Executive functions

ferred slightly in the young participants compared with the elderly⁹. In one study, the elderly participants improved on ‘updating’ and performed better after five weeks of training compared with the baseline results of the younger participants. Another study examined both the ‘updating’ and ‘inhibition’ abilities. These abilities were tested with the n-back (updating), which showed improvements, and with the Stroop test (inhibition, see 3.5.1), which did not show improvements. In another study, no effects on untrained abilities were found. In sum, WM training, such as updating-training, seemed to generate effect on trained abilities (Dahlin, Erica. et al.).

A treatment group and an active control group were formed to study the effects of WM training on 30 psychology students (26 female, 4 male; mean age=20:3) using a variety of tasks. The results show enhancements to intelligence (nonverbal tests) in the treatment group. Brain activity was investigated and had increased, also indicating that processes related to LTM were affected (Jaušovec & Jaušovec, 2012).

2.10.2 Effects on WM measures

Below are examples of different groups of students and adults who have participated in WM training studies with various designs in the last two years (2010-2012).

Students with ADHD on medication and without were studied. It was found that the students on medication improved on visuo-spatial WM measures, while students not taking medication improved on all WM results, verbal and visuo-spatial WM and STM, results that persisted six months after training. The students were 8 to 11 years old (n = 25, 4 girls / 21 boys) and trained at school or at home (Holmes et al., 2010). IQ did not improve after either the exercises or medication. They trained (Cogmed training) for approximately five weeks. No control group participated.

Students with attention problems or hyperactivity problems improved on the WM tests and behaviour (based on teacher ratings) compared with baseline in a pilot study (n = 9, age range 8-10.5) (Mezzacappa & Buckner, 2010). The participants trained with a computerised programme for five weeks (Cogmed training). No control group participated.

Students with SEBD (social, emotional and behavioural difficulties) (mean age = 12.94; matched groups; n = 7 per group, 3 boys / 4 girls; a passive control group) improved on WM tests (Digit span, spatial span) compared with pre-test (Roughan & Hadwin, 2011). One group trained for five weeks (Cogmed training) at school (in the mornings before school started).

⁹ Older participants seemed unable to automatise the trained ‘letter-memory’ as much as the younger participants. This may be due to decreased function of the dopamine system related to increasing age (Dahlin, Erica et al., 2009).

Adolescents (14 and 15 years old) who were term born (n = 19) and adolescents who had low birth weight (n = 16) trained (Cogmed training) at home daily for five weeks (Løhaugen et al, 2011). They were compared with a non-treatment group (n = 11). The training yielded effects in both training groups on WM measures. The low birth weight group enhanced its results on verbal learning and those with the lowest IQ improved significantly from the training. These positive results persisted six months later.

Survivors of childhood cancer (n = 9) completed a computerised cognitive training programme (Captain's Log) in a 12-week period at home (Hardy, Willard, & Bonner, 2011). No control group was used. The students had leukaemia, brain tumours, and attention and working memory deficits. They improved in measures of working memory and attention.

2.10.3 Effects on reading and mathematics

A few studies target mathematics and problem solving (e.g., Holmes, Gathercole, & Dunning, 2009; D'Amico, 2006; Witt, 2011) and reading comprehension (Chein & Morrison, 2010; Loosli, Buschkuehl, Perrig, & Jaeggi, 2012) after WM training.

In the Holmes et al. (2009) study (treatment group: n = 22, 10 female / 12 male; control group: n = 20, 5 female / 15 male) no effects in mathematics were noted directly after the training, but effects were found six months after the training. However, only the treatment group was retested.

Witt (2011) found enhanced results in 9-10 year old students in Grade 5 (n = 38) in addition tasks after WM-training. Chein and Morrison (2010) found (n = 22) enhanced reading comprehension after WM training. Loosli et al. (2012) studied students 9-11 years old (n = 40: 20 in the treatment group matched to 20 in the control group). The treatment group improved on reading single words and text compared with the control group which did not receive any extra training.

2.10.4 Evaluation of effects

I would like to briefly outline a number of questions raised by researchers regarding WM training and research in this relatively new area.

Studies that have examined the effects of WM training are difficult to compare because of the diversity of their designs and groups (Dahlin, Erica. et al., 2009). Too few studies have been carried out in order to draw firm conclusions, such as whether training has an effect on untrained abilities, or how groups of students or adults can benefit from training (Morrison & Chein, 2011). Not all studies are experimental and randomised. Different tests are employed and the groups are of differing sizes.

SBU (The Swedish Council on Health Technology Assessment, 2009) evaluated studies employing computer-assisted training for children with

ADHD by reviewing six studies (2005-2009). They concluded that there is too little evidence to draw any conclusions from these studies where the benefits of computerised WM-training for children with ADHD are concerned. Fifteen studies (1998-2008) failed to meet the criteria established by the reviewers (e.g., randomisation, ADHD problems according to two independent sources/rating scales) and were therefore excluded from the review.

Shipstead, Redick, and Engle (2012) analysed a large number of studies and established that hasty conclusions had been drawn in some of them, while finding no evidence that WM or other abilities improve through cognitive training. Shipstead and his colleagues believe that more experimental studies need to be conducted in order to answer the question of whether it is in fact the WM training that is causing increased WM-capacity. Hulme and Melby-Lervåg (2012) believe that improvements noted in WM measures after training have explanations other than training effects, such as becoming familiar with the programme during training and thus improving results.

In addition, Morrison and Chein (2011) have carried out a review of studies targeting WM-training. Although they conclude that WM-training seems to improve some untrained skills, they believe that many questions surround the studies. A number of factors can affect the results, e.g., the expectation that students and parents may have during training leads to greater efforts by the students of the treatment group compared with the placebo group at post-test. The placebo-group probably realises relatively early on in the process that the training is a placebo. Another factor is the effort students make during training. In addition, some studies use control groups that are not involved in the study. None of the studies analysed here used self-assessments or examined student motivation, which could be considered as a weakness (Morrison & Chein, 2011).

In a separate study, Chein and Morrison (2010) found improvements in reading comprehension after WM training. They suggested the enhancements on WM measures could predict the level of improvements in reading comprehension. They recently joined the discussion on whether WM training can actually change the capacity in WM (Morrison & Chein, 2012). The way in which we measure WM capacity is obviously also highly significant. They highlight the dilemma of control groups losing motivation and interest.

Researchers are discussing and questioning the value of cognitive training in students with ADHD diagnoses. Shah, Buschkuehl, Jaeggi, and Jonides (2012) point out the importance of considering sample sizes, different measures, participants and the specific training programmes used when comparing studies. Furthermore, they found that individual differences are not considered in ADHD and cognitive training studies. There is a large discrepancy between the various difficulties that people with ADHD exhibit. Motivation and reward can also affect results. Shah et al. note that training might work for certain groups, but also that in the current situation too few

studies are being carried out to enable discussion on the effectiveness of cognitive training (Shah et al, 2012).

Logie (2012) discusses how current cognitive training programmes may provide improvements to the highly specific tasks trained, resulting in the development of valuable strategies and enhanced motivation during the exercises. Another issue is how low and high-performing individuals may be affected differently. Logie discusses the construct of WM, i.e., WM may contain a whole range of different cognitive systems operating to different degrees depending on the difficulty of the task. WM research should not, which is often the case, be based on the theory that the 'culprit' is simply a lack of attention capacity. Theories and methods therefore need further development (Logie, 2012).

Gibson, Gondoli, Johnson, Steeger, and Morrissey (2012) discuss theories and methods. They emphasise that Cogmed training affects only one of the two major components suggested to be affected by training, i.e., attention and not WM measures (Gibson et al., 2011 as cited in Gibson et al., 2012). Some researchers believe that attention is the most important component of knowledge acquisition (e.g., Cowan, 2005) and almost equal to the CE, while others highlight the importance of attention, memory skills and other individual abilities combined. Gibson et al. believe that we do not fully comprehend training effects. Perhaps theories should be revised or the programme. If it is possible to influence both components, i.e., attention and memory skills, then a valuable instrument might be developed with implications for both research and individuals.

Rather than commenting on previous studies or weaknesses in programme design, testing, and applications, Jaeggi, Buschkuhl, Jonides, and Shah (2012) discuss future research. They believe that it is important to use existing data and carry out more studies on training, transfer effects and underlying mechanisms. Finally, in addition to this, it is obviously essential to study improvements in a longitudinal perspective (Conway & Getz, 2012).

This raises the question of whether the brain's WM capacity can indeed improve and if that, in turn, can enhance other skills. Compared with other fields, there is a shortage of research on working memory training, but in my opinion it would be logical to consider all of the available components, measures, results and experiences from these studies as a starting point and progress from there. Apter (2012) takes this approach. He identifies areas of importance (which I have also tried to highlight in this thesis) for research and affecting classroom situations: attention, mental effort, motivation and self-efficacy, memory skills and strategies, and more effective use of 'longer term memories'. He also points out that the evidence is not strong enough to suggest that WM training may be effective for skills other than those being trained.

Scepticism exists regarding the value of WM training, while others are more optimistic. The following is certain: WM training engages researchers

from different parts of the world and more studies need to be completed in this particular area. “Both within and beyond the academic community we are fascinated with the notion of improving mental capacity” (Morrison & Chein, 2011, p. 208).

2.10.5 This study

Previous studies show that students with ADHD improved in behaviour and WM measures (Klingberg et al., 2005) after five weeks of WM-training (Cogmed training) and that brain activity increased after training (Olesen et al., 2004). Further, these studies show effects immediately after and/or three to six months after training, but to my knowledge studies have yet to determine whether results persist over longer periods or to establish the effect of training on reading and mathematics. Effects on reading and mathematics (arguably the most important skills for school success) that persist and do not fade away are clearly the most important. In order to fill these two gaps, a study on WM training, mathematics and reading development with a longitudinal approach was conducted.

The hypothesis posed for this study is therefore that scores on WM measures are enhanced by WM training, which has a positive effect on reading comprehension and mathematics in students with attention deficits. This is based on the theory that attention capacity is adversely affected by weaknesses in the WM (Barkley, 1997) and that WM capability has been found to relate to reading and mathematics and may be influenced positively through structured interactive training (see the literature review above).

The overall aim is to examine the effect of working memory training in students with attention deficits.

The effects of training with a five-week computerised WM programme in mathematics and reading (and conducting neuropsychological tests) on boys and girls (9-12 year olds) with attention problems and with special educational needs are investigated at pre-test, approximately six weeks later (directly after training), approximately seven months later, and 3.3 years later. The relationship between WM capability and other measures is also examined.

3 Methods

3.1 Design

3.1.1 Study features – an overview

The purpose of this study was to allow students with attention deficits to train with an interactive computerised working programme to examine whether the training had any effect on their WM, mathematics and reading skills. The participants were students with attention difficulties who had been placed in special units. The training was to take place at school and the parents were to receive progress reports at every stage. The students (n = 42, 7 girls / 35 boys) were to undergo different types of tests, including neuropsychological tests, and basic skills tests, both prior to and following the training. Results were compared with those of the control group (n = 15, 4 girls / 11 boys), who were tested at the same time intervals. Twenty-seven students participated in the follow-up mathematics and reading-related tests (Time 4) which were conducted over three years later. All of the data collection and interventions took place at the students' schools, with the exception of teacher and parent ratings, which were submitted in writing and sent by post. The results of the intervention and the relationship between variables are examined by way of statistical analysis.

3.1.2 Intervention – quasi-experimental design

In an 'experimental design', the action is given to one or more groups that are subsequently compared with control groups (Table 1). The importance of including some kind of placebo in the control groups is underlined. If the participants are randomly divided into treatment and control groups, the study is said to have an experimental design. Alternatively, if participants are not randomly divided into experimental and control groups, the study is considered to have a quasi-experimental design (Mertens, 2005). There are several types of quasi-experimental design, e.g., when only one group is used ('one group post-test design', 'one-group pretest-post-test design') or when two groups are included in the study but only post-tests are carried out ('post-test only design'). In the absence of either the pre-test or the control

group, these types of designs are regarded as less reliable than designs in which both variables are included (Shadish, Cook, & Campbell, 2002).

Table 1
Quasi-Experimental Design: Pretest – Intervention - Post-Test

<i>Groups</i>	<i>Pre-test Time 1</i>	<i>Intervention</i>	<i>Post-test Time 2</i>	<i>Post-test Time 3</i>
Experiment group	yes	yes	yes	yes
Control group	yes	—————▶	yes	yes

Note. The treatment and control groups (not randomised) are tested at the same time intervals. The treatment group is given an intervention and groups are compared.

3.1.3 The ‘nonequivalent comparison group design’

The ‘nonequivalent comparison group design’ is perhaps the most common quasi-experimental design (Shadish et al., 2002, p. 136). It uses pre-test as well as post-test in a treatment group and a control group (see Table 1). This present WM-study features this particular design.

In this study, we first approached students and parents about participating and then formed the treatment group in a first phase. The control group was then established in a second phase. We discussed randomly assigning the students from each special unit to the experimental and control groups (a placebo control group). Ethical issues, such as allowing students in the control group to spend considerable time working on an application unlikely to be beneficial, led us to rule out the idea. Students in the control group would most likely discover that their programme was not bona fide, which would probably result in their efforts waning, thus nullifying the purpose of the placebo. The decision was thus made to establish a non-training control group selected from different classes.

3.2 Participants

3.2.1 A pilot study

To evaluate the tests and the logistics of the training, three students (2 female / 1 male) with attention deficits being educated in a special unit (Grades 3-5) took part in a pilot study.

3.2.2 Main study – Study I-II

Fifty-seven students participated in the intervention study (Table 2). Forty-two students formed the treatment group and the control group numbered 15. Students were in Grades 3 to 5 and had been placed in special units in or near the school to which they belonged. These special units were primarily intended for students with attention disorder, which was one of several criteria for participation in this study.

The students were all judged to be in need of special assistance due to merger difficulties. Seventeen had an ADHD diagnosis (13 in the treatment group; 4 in the control group). The treatment group came from nine different schools and the control group from seven. Table 2 shows descriptive statistics of the treatment and control groups at T1.

Table 2
Participants in the Treatment and the Control Groups

Time 1	Treatment group	Control group	Total
Mean age at T1	10.7	10.7	10.7
Boys	35	11	46
Girls	7	4	11
Diagnosis			
Dyslexia; male/female	2/0	1/1	4
Dyslexia + ADHD; male/female	1/1	1/0	3
ADHD; male/female	8/3	3/0	14
Placement at Time 1			
Special units	42	15	57

Note. Treatment group, n = 42; Control group, n = 15; Mean age SD =1.1.

3.2.3 The longitudinal study - Study III

Twenty-seven students (treatment group: n = 18; control group: n= 9) participated in the longitudinal section of the study. They came from 21 different schools and were selected from the students who had taken part in the previously implemented intervention study (Study I-II).

Seventeen students were now in a normal-sized class and ten in a special unit. The number of students with an ADHD diagnosis was nine in the treatment group and four in the control group. All 27 students were interviewed. Table 3 shows descriptive statistics of the treatment and control groups at T4.

Table 3
Descriptive statistics: Students Participating in the Longitudinal Section of the Study (T4)

Time 4	Treatment group	Control group	Total
Mean age at T4	14.09	13.78	14.0
Boys	15	6	21
Girls	3	3	6
Diagnosis			
Dyslexia; male/female	0/1	0/1	2
Dyslexia + ADHD; male/female	2/1	1/1	5
ADHD; male/female	5/1	2/0	8
Placement at Time 4			
Regular/ special units	12/6	5/4	17/10

Note. Treatment group, n = 18; control group, n = 9; Total, n = 27; mean age = 14.0, SD=1.1

3.2.4 Regular classes

Students in Grades 3 and 4 (n = 19) took part in test evaluations prior to the project starting (Table 4). Twenty-four students in Grade 3 then completed tests (reorganised to some extent according to the evaluations) one week apart in order to test reliability. Reliability in the control group (n = 15) could also be measured at six-week and seven-month intervals (pre and post-test) since the members did not receive any treatment.

Students in Grades 3, 4 and 5 from different schools and regular classes took the tests once. They all completed tests in reading and some in non-word reading, basic number skills, addition and/or subtraction as well, so

that the results of the special units could be compared with those of students from normal-sized classes.

One test was normed in England. It was important to find out how Swedish students in regular classes would perform on the test (see Articles II and III for details) to be able to value the norms and compare them to those of Swedish students of the same age.

Table 4
Number of Students Who Took Part in the Test Evaluations)

Regular classes	Grade	N
Test evaluations: grades	3, 4	19
Testing reliability: completing tests 1 w. apart	3	24
Completing tests once: Reading and mathematics	4, 5	190
Total		233

Note. The students completed reading and mathematics tests either once or twice.

3.2.5 Extern control group - Study 1

Since the control group did not complete the neuropsychological tests, we were granted permission to use results from a previous study by Klingberg et al. (2005) (Study I). These students ($n = 25$) had been randomly selected to form the control group and all had ADHD diagnoses. This control group used a non adaptive five-week training programme.

3.3 Selection

3.3.1 Procedures for the initial selection

Based on information from the Schools Agency of Stockholm County and its surrounds regarding special units and their orientation, contact was made with principals by telephone. If the response was positive, teachers and parents were sent written information about the study. The students were included (in the order in which written consent was received) if they met the following criteria determined by the research team:

- a) 9-12 years of age
- b) being educated in a special unit
- c) attention problems (according to the judgements of teachers or psychologists) or a ADHD diagnosis

d) first language = Swedish

e) no ODD, autism or developmental disabilities in the form of reduced IQ

Schools and students were asked whether they were interested in participating in the study and we then formed the treatment group. Other students from various classes were subsequently invited to join the study's control group.

The composition of some of the special units had changed since the first inquiry and therefore could not participate: some students had moved to regular classes and/or changed schools. This led to other schools being invited to participate.

3.3.2 The second selection

Psychologists interviewed the parents of the students in the experimental group for 30-40 minutes to ensure that the students did indeed have attention difficulties. The parents were also asked to complete ODD-ratings (Oppositional Defiant Disorder). Assessments by teachers and psychologists from each school formed the basis for participation in the control group.

3.3.3 The third selection – the longitudinal study

Some of the students from the treatment and control groups of a three-year follow-up study were re-contacted. Before these students were selected for participation, it was decided to ask two-thirds of the control group ($n = 10$) and twice as many ($n = 20$) from the experimental group to complete reading and mathematics measures once again. The inquiry resulted in nine students (3 female) of the control group (2 with ADHD) and 18 (3 female) (4 with ADHD) from the experimental group agreeing to participating in the follow-up. Due to of limited financial resources, it was not possible to follow up on all fifty-seven students.

3.3.3.1 Losses

Two students were eliminated before the study began: a boy, due to Oppositional Defiant Disorder (ODD); and a girl, due to low IQ. One boy in the control group completed, at his parents' initiative, WM-training between T2 and T3 and was therefore excluded from the analyses. Lastly, another boy discontinued his participation after having only partially completed pre-tests.

3.4 Procedure

3.4.1 Test evaluation

All of the students who participated in the study were of differing ages (from 9 to 12 years), were being educated in special units and had attention deficits. We thus assumed that some of the students would be weak in one or more areas. In order to minimise total failures and to avoid any detrimentally effects to the students' self-esteem, it was decided that the tests would start easily so that all of the participants could perform at least some tasks. To enable measurement of the abilities of the older or higher-performing students, the tests' level of difficulty was to increase progressively. In addition, we required parallel versions of the test because repeated testing would be carried out to compare the results over time.

Standardised testing is generally designed to work in multiple contexts and groups of people, not in one specific type of school or class (McMillan, 2004; American Educational Research Association, 2002). Some of the tests were therefore compiled expressly for this study. The test samples were evaluated in students in regular classes that all students, from the weakest to the strongest, attended. We were able to evaluate the tests by first analysing the results and subsequently discussing them with each student individually (Figure 6, 7). Corrections to content or design were made if deemed necessary. This was carried out with students in Grades 3 and 4.

Many students seemed to get stuck on words with double subscription when reading non-words because they were uncertain about short and long vowels. For this reason, the tests were also partially measuring spelling and knowledge of short and long vowels instead of basic skills in phonological decoding alone. It also emerged that students found nonsense words with more than one syllable easier to read. The conclusion drawn from this is that they most likely had a greater chance of recognising at least one part of the word in question, which was advantageous. As a result, we revised the phonological tests to include more monosyllabic words at the beginning and no words with double subscription.

Nonsense words are harder to read than real words and measure vocabulary development more effectively than reading real words (Dehn, 2008). Dehn indicates that the best nonsense words are those containing no more than two syllables and with no similarity to known syllables. Further, the words must not contain any segments that rhyme (Dehn, 2008). Since the words were to be read aloud phonetically (as they sounded) and the correct-sounding word was to be selected from two options, it was important for both words to be of equal difficulty, ie if one word had a cluster at the beginning (klikt), then the second word should have one too (fläst).

To ensure the reliability and validity of the test material, the tests were evaluated with students in Grades 3 and 4 (Figure 6). Twenty-two students completed different versions of the tests one week apart. In addition, correlations were calculated in the control group between the different test runs, which could be regarded as a test of reliability since the control group did not undergo any extra training.

3.4.2 Briefings

A joint information meeting was held for all of the schools interested in taking part in the study, and two further briefings (for parents and for teachers) were held at each school before the study commenced. The entire research team, i.e., psychologists, researchers and a study coordinator, took part in these meetings (Figure 7).

Students received both written and verbal information about the study, WM, what would be expected of them (e.g., completing tests on numerous occasions) and, where the treatment group was concerned, how the daily training would be organised.

3.4.3 Test implementation

Longer untimed tests and short timed tests both featured in this study. The tests all began at a low level before progressively increasing in difficulty.

To ensure that basic skills tests were conducted in exactly the same way for all students, the same person tested virtually all of the students each time (T1, T2, T3 and T4) and gave the teachers, parents and students information before the study began. Instructions for each test were provided in writing and read to all of the participants prior to the completion of the test, some items were attempted (in the same way for all students) before the tests started and all of the students were given equal time in which to complete the different tests. The neuropsychiatric tests were conducted by psychologists.

The students were all tested individually in a room near the classroom to ensure that the information and test conditions would be as consistent as possible. Basic knowledge was tested in three 30-minute segments with breaks of at least 15 minutes in between. The duration of the neuropsychiatric test was approximately one hour.

3.4.4 The training programme

The experimental group trained at the school with an interactive computerised programme (Cogmed working memory training) every day for five weeks and each session took approximately 40 minutes to complete. The training was completed in conjunction with an adult in a secluded room at roughly the same time each day, as far as it was possible. The students each

took home a daily training report intended to show their caregivers how the training was progressing, and this returned with the students the following day. A psychologist provided support by telephoning the schools and the members of each group once a week.

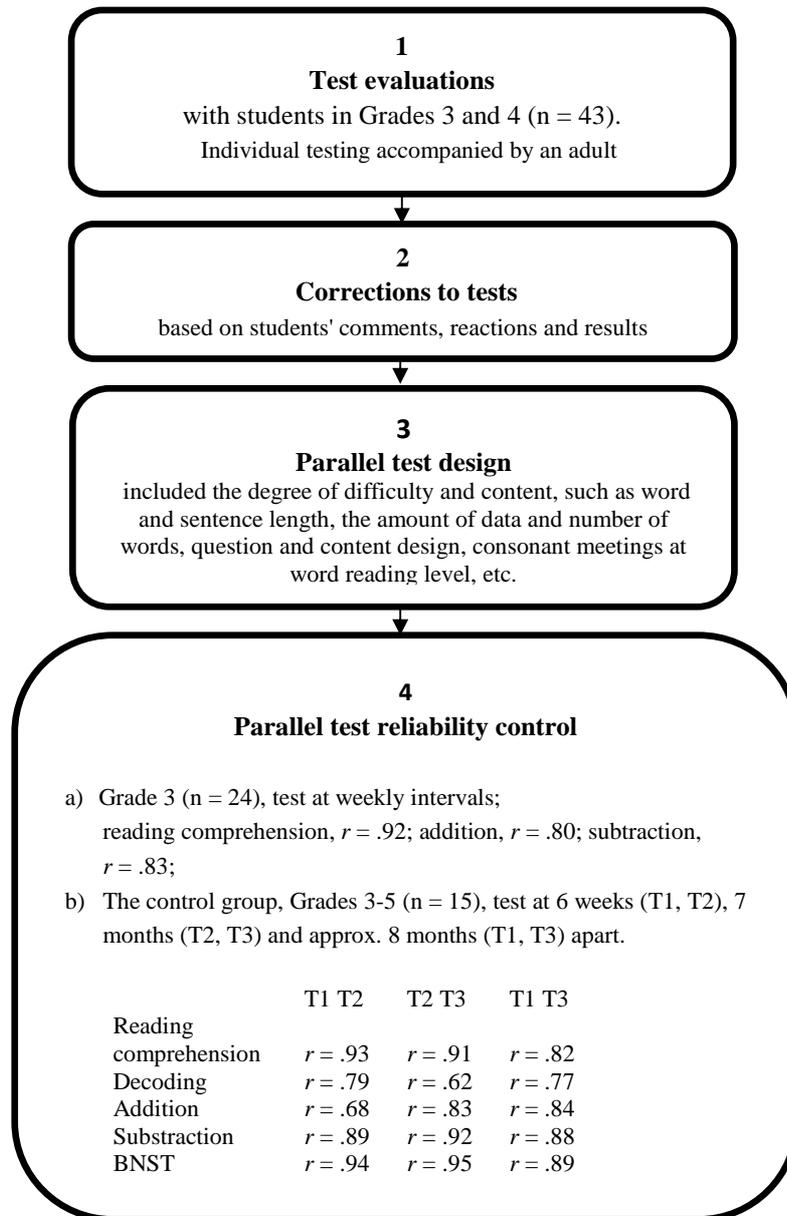


Figure 6. Description of procedures when evaluating the test.
Note. T1, Time 1 = pre-test; T2, Time 2 = first post-test; T3, Time 3 = second post-test;
BNST = Basic number screening test.

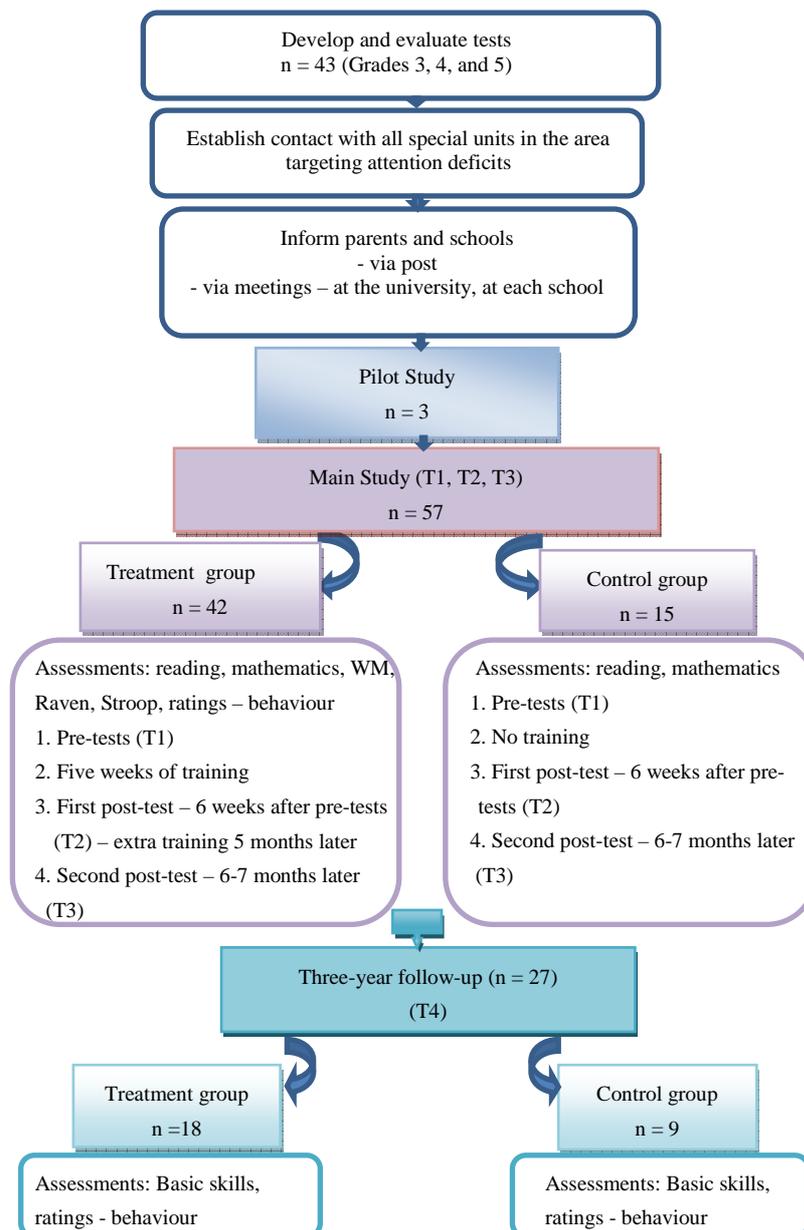


Figure 7. Description of the study design: preparation and study implementation, schedule of tests conducted at T1 (pre-test), T2 (post-test), T3 (post-test) and T4 (post-test). The intervention for all of the members of the experimental group was carried out for five weeks immediately after the pre-test. Fourteen students trained for a further two weeks immediately before T3 (additional training).

3.4.5 The pilot study

A pilot study was organised and completed by three students from one of the participating schools. It was conducted in the same way as the main study with a few exceptions: corrections to a test and the addition of a test compiled after the pilot study. The students trained with the WM training programme for five weeks and tests were carried out before and immediately after training and six to seven months later (for a description of the study, (see Figure 7).

3.4.6 The intervention study – Study I-II

All of the students in the intervention study ($n = 57$, mean age = 10.7, SD = 1.1) completed pre-tests (Time 1, T1). The experimental group ($n = 42$) trained for five weeks thereafter with a computerised training programme for 30 to 40 minutes per day.

Rewards were given after one week's training, in the form of a simple item or event (ice cream, picnic etc.).

Students then completed post-tests on two occasions: at approximately six-week (Time 2, T2) and seven-month (Time 3, T3) intervals. Fourteen randomly selected students trained for an additional ten days before the final post-test. The students in the experimental group also completed neuropsychological tests and each child's behaviour was rated by both teachers and parents (DSM-IV). The control group performed the same reading and mathematics tests at the same intervals as the experimental group, but did not undertake the WM, Stroop or Raven's tests due to limited financial resources.

3.4.7 The longitudinal study – Study III

Twenty-seven students participated in long-term follow-up tests (Time 4; T4) approximately three years after the testing at six to seven months (T3) had been implemented. All of the students completed the same type of testing in basic number skills and reading as three years previously. Further, all of the parents and teachers completed DSM-IV-ratings at T4.

3.5 Measures

The results from four reading-related tests, four basic number tests, four WM-tests, a non-verbal problem solving test, an inhibition test and estimates from parent and teacher ratings (DSM-IV), as well as the scores from the training programme, were exploited.

3.5.1 Neuropsychological measures - Study I-II

Psychologists administered neuropsychological measures to the experimental group members three times: before the intervention, immediately after the completion of training and approximately 7 months later (T1-T3). The control group did not undertake these tests not only due to financial reasons, but also because data was available from an active control group with almost exactly the same age range as the actual treatment group.

Digit span forward was used to measure verbal STM: an increasing number of digits are presented orally, commencing with two in the first series. The child is asked to repeat each series of numbers in the same order in which they were presented (WISC III, Wechsler Intelligence Scale for Students). The phonological loop (STM) is charged (phonological storage and articulation), according to Swanson (2006).

Verbal WM (WISC III, Wechsler Intelligence Scale for Students) was measured using Digit span back. An increasing number of digits are presented, as in the case of Digit forward, but in this case the digits are repeated in reverse order. The central executive function is loaded (Swanson, 2006).

Span board forward, which is part of the Wechsler Adult Intelligence Scale (WAIS-NI), was used to measure the visuo-spatial STM. The psychologist points to two blocks from a total of ten. The child is asked to identify them in a different collection of ten blocks and to point to the two blocks in the same order as the adult. According to Swanson (2006), the visuo-spatial function is loaded (STM).

Span board backwards was used to measure visuo-spatial WM. In this section of the test, the position of the blocks is to be repeated in reverse order (backwards) (Wechsler Adult Intelligence Scale, WAIS-NI). This test is believed to load on visuo-spatial short-term memory (STM) and the central executive function in WM.

Stroop was used to measure the ability to control and prevent impulses. Sixty out of 100 names of colours are written in rows of 10 words and printed in a different colour from the colour indicated by each word. The participant must name the colour in which each word is printed as quickly and accurately as possible. The time taken and number of correct answers are noted (Lezak, 1995).

Raven's Coloured Progressive Matrices (Raven) were employed to measure non-verbal problem-solving skills. The test consists of characters that are incomplete and the students select one of six different pieces to complement

each figure. One point is accorded for each correct answer with a maximum attainable score of 36 points. The test has no time limit.

Parent and teacher ratings (DSM-IV) were used to estimate students' behaviour with the same frequency as the other tests. The questionnaire consists of 18 questions, the first nine of which concern attention, while the others relate to impulse control and hyperactivity.

3.5.2 Information from teachers and parents

Before pre-tests and during the long-term follow-up, teachers and parents were asked to answer questions about each student's school situation, strengths, learning outcomes and particular difficulties in various subjects.

3.5.3 Reading

Reading comprehension. Narrative texts from the Progress in International Reading Literacy Study (PIRLS) and the IEA Reading Literacy Study (PI-SA) were used in the parallel reading comprehension tests. The questions appeared at the end of the original versions and each child was expected to complete all of the questions which included both multiple choice and constructed-response questions. Since the tests were intended for both weaker and stronger readers, and both younger and older children, they were modified in two following ways: (1) all versions of the tests were divided into roughly equal sections, with one to two questions per section so that ultimately six questions remained at the end of the last section; (2) the administrator wrote down the answers to the constructed-response questions based on the child's verbal responses and then read them back aloud to the child to ensure that their answers had been captured correctly. We wanted to eliminate the risk of students being hindered by any potential writing difficulties when answering the questions. Seven of the questions were multiple-choice while six were constructed-response questions. The students were awarded one to three points for each correct answer with a maximum overall score of 19 (see Study I). Three parallel versions of the tests were used.

Decoding. In order to measure word decoding, a non-word test specifically designed for this study was employed. "Read the word pairs, preferably aloud because that is easier. One word will be a nonsense word – an invented word. The other word will sound like a real word but will be spelt incorrectly. It will be spelt the way it sounds, so you might not recognise it. Listen to the words as you read them and then decide which of the two words sounds like a real word. Underline the word that sounds like a real word". A pair of words could be as follows: sib – sâv (*sâv* means 'sleep', but should be spelt *sov*). Students were given two minutes to read as many words as possible.

They were encouraged not to guess, but to ignore the questions that they were unsure about instead and proceed to the next question. Each correct answer generated one point and each incorrect answer generated one minus point so as to minimise any guesswork. The maximum score attained was 63 points. Students considered this test to be difficult, an opinion that was voiced by students in both the regular and special units, and for this reason it was never assigned as the first or final test of the day. Three parallel versions were used.

Orthographic reading. The ‘orthographic test’ was used to measure spelling and orthographic ability. In this case, it was important to recognise the listed words quickly and decide whether they were spelt correctly or not by putting a cross (x) beside the word considered correct, and a minus (-) next to the word considered incorrect. The words were taken from stories written by other similarly-aged students. Students were given two minutes to read as many words as possible. The students all regarded the test as easy and fun. The maximum score attained was 75 points. Three parallel versions were used.

3.5.4 Basic number skills

Addition and subtraction – verification tasks. A paper by Lemaire et al. (1996) describing and discussing ‘verification tasks’ and the notion of ‘right or wrong’ formed the basis for the design of the arithmetic test. In the space of two minutes, the student determines whether equations have been calculated correctly (e.g., $4 + 5 = 8$) by marking a cross or a minus sign in the box to the right of each problem. Three parallel versions were used. (See Article II for more details).

Basic number screening test. The Basic Number Screening Test (BNST) (Gillham & Hesse, 2001) was employed to test number skills. It consists of 30 different tasks in mathematics, including the four basic arithmetic operations, grouping and completing series (see Articles II and III for details). Two parallel versions were available. Correlation was according to manual: $r = .92$. (See Chapter 3.4.1. and Study II).

3.5.5 Training scores

Training results were converted into indices (the start index, results of all of the exercises from Day 1; and the max index, the highest achievement index for the 5 weeks of training) and used in the analyses.

3.5.6 Skewness

Calculations can reveal whether or not test results are skewed in either direction, i.e. if there are any ceiling or floor effects, if the tests are too easy or difficult. It is important for the groups to perform close to both each other and to zero (Shadish et al., 2002). Tables 5, 6, and 7 all show that the tests are not skewed; e.g., the BNST is close to zero in both groups.

Table 5
Treatment Group Descriptive Statistics: WM and Raven

Measures	Min	Max	Mean	SD	Skewness	SE
T1 Span board forward	2.50	6.50	4.54	0.94	.277	.365
T1 Span board back	0.50	6.00	3.96	1.11	-.758	.365
T1 Digit forward	3.00	6.50	4.24	0.73	.654	.365
T1 Digit back	2.00	5.00	3.02	0.74	.435	.365
T1 Raven	12.00	35.00	27.38	5.05	-.636	.365

Note. n = 42; SD =Standard Deviation; SE = Standard Error.

Table 6
Treatment group Descriptive Statistics: Basic number skills and Reading

Measures	Min	Max	Mean	SD	Skewness	SE
T1 reading comprehension	0.00	15.00	8.45	3.70	-.204	.365
T1 decoding	5.00	20.00	11.74	3.83	.085	.365
T1 addition	4.00	25.00	17.19	5.44	-.589	.365
T1 subtraction	1.00	24.00	12.07	5.43	.179	.365
T1 basic number skills	3.00	26.00	14.05	6.53	.053	.365

Note: n = 42; SD =Standard Deviation; SE = Standard Error

Table 7
Descriptive Statistics in the Control Group: Basic Number Skills and Reading

Measures	Min	Max	Mean	SD	Skew-ness	SE
T1 reading comprehension	2.00	16.00	10.13	5.01	-.413	.580
T1 decoding	0.00	27.00	13.67	6.41	.278	.580
T1 addition	10.00	30.00	19.27	6.43	.328	.580
T1 subtraction	0.00	27.0	14.20	7.60	.367	.580
T1 basic number skills	7.00	27.00	16.80	6.73	.062	.580

Note: n = 15; SD =Standard Deviation; SE = Standard Error

3.5.7 Conversations – Qualitative data

A better understanding of students who “can’t remember”, “never finish” or “don’t want to work” might lead to more critical thinking where teaching is concerned and facilitate the extension of students with poorer working memory capacity compared with their peers, who may as a consequence be performing less well in school subjects. Conversations can also help to pinpoint essential factors to focus on when working with students with concentration problems and weaknesses in one or more school subjects.

The students in this study were in Grades 5 to 9 when these conversations took place. The aim was to gain insight into their school experience and find out what they perceived to be easy or difficult at school, what they required in order to be able to concentrate well and how they felt when they were unable to solve a problem or did not understand. Their responses are integrated as examples into the text of this present thesis at appropriate places in order to enhance the text and provide insight into the participating students’ thoughts. The conversations are otherwise not reported.

3.6 The training programme

The training programme was originally developed for students with ADHD (Klingberg et al., 2005; Cogmed training). The programme is computerised and interactive: it adapts to each child’s abilities, features both verbal and visuo-spatial WM items and provides immediate feedback on the data generated (for further information, see Studies I and II). The training was carried out each school day for approximately 40 minutes per day. An example of a verbal exercise is to listen to three syllables and repeat them immediately in the same order. The following task is to specify four syllables, and so on. If a student is unable to perform a task, then the exercise is terminated (to be

repeated on another day) and a new task appears on the screen. An example of a visuo-spatial practice is to specify, in reverse order, the asteroids that have recently appeared on the computer screen by clicking the mouse. There are approximately 100 tasks per exercise.

3.7 Analysis

Analysis and data collection were carried out according to a pre-test-intervention-post-test design (Mertens, 2005). An experimental group was compared with a control group that received no additional treatment, and the tests were formulated with the same test intervals for both groups (Figure 7). Analyses were conducted using two statistical programmes: SAS (9:1) and SPSS (16.0). Analyses of variance, in the form of a multivariate mixed model with covariates which controlled for gender, pre-test (baseline) performance and ages, were employed for comparisons between the intervention and control groups. Correlation was analysed by regression analysis and correlation analysis and groups were compared using an independent *t*-test (Pearson two-tailed). Results at later points in time (T2, T3, T4) were compared with the results at T1 (Time 1) by means of a dependent *t*-test (paired samples *t*-test) and the mixed model with covariates.

Cohen's *d* also was used to calculate the effect size. *d* is the difference between the groups in terms of SD (standard deviation): Cohen's $d = M1 - M2 / SD$ and can be defined as the difference between two means, $M1 - M2$, divided by a pooled SD (mean SD of the two groups) (McMillan, 2004). An effect size $d = .20$ is considered small, $d = .50$ medium, and $d = .80$ large.

An effect size (*d*) of 1.0 for a subject indicates an increase of 1 SD (standard deviation). According to Hattie (2009), this signifies an increase equivalent to two to three years of development and a 50% increase in development speed. If $d = 1.0$ in an intervention study, it effectively means that the treatment group outperforms as much as 84% of the control group participants. Applying Cohen's *d*, which takes into account differences in the form of SD, is different from estimating statistical significance. Strong significance does not necessarily denote large effect size. Small effect size should not be ruled out for an intervention without careful consideration; it could be an important component of a broader context and it is sometimes easier to implement than an intervention with a larger effect size (Hattie, 2009).

3.7.1 Reliability

Many factors can affect reliability. Test length is one such example, i.e., a longer test is more reliable than a shorter test. Reliability can also be influenced by *what* a test measures (Mc Millan, 2004). Moreover, tests must be designed so that all students feel capable of completing at least some of the

tasks and are not exposed to abnormally high pressure which could affect motivation. Therefore, both timed and untimed tests and both long and short tests were used in this study. All of the tests started at a low level before progressively increasing in difficulty.

Re-test power should then be controlled (parallel test) (Mc Millan, 2004). This study's re-test power was controlled by giving the test to students at weekly intervals and calculating correlation (see Figure 6 and 3.4.1, Test Evaluation). A pilot study is necessary in order to evaluate planning and test-instruments (McMillan, 2004). We completed a pilot study with three student participants.

If test sessions are too long, reliability can be compromised and the sessions can begin to lose meaning for the participants. According to McMillan (2004), 30-60 minutes can be an appropriate duration. The reading and mathematics tests were conducted in three half-hour segments with at least 15 minutes between each segment while the neuropsychological tests were carried out over a one-hour session. Reliability must be met in order to be able to speak of valid results (McMillan, 2004).

3.7.2 Internal validity

Human assumptions determine whether or not a study is valid, i.e., whether the treatment causes the effects that are observed. The validity of an experiment is never certain, even in a randomised trial, but it is possible to a degree (Shadish et al., 2002). Each study requires high accuracy and appropriate analyses, regardless of its design.

To conclude that a treatment effect is caused by the treatment, one must be able to ensure as far as possible that any possible change in post-tests compared with pre-tests and controls is being caused by the intervention and not some other effect. Internal validity is thus achieved. This may be threatened by a range of circumstances (Mertens, 2005; Shadish et al., 2002). Mertens (2005) identifies various areas that should be considered in order for validity to apply: changes in any/some participants during the course of the study, maturity/development over time, and also a brief period of fatigue during a test session.

It could be assumed that if a participant tires after completing some of a test that the individual will perform less well on the remainder of the test. This is probably the case for everyone. If each test is performed in the same manner in both the experimental and control groups, these differences are checked. This study compared the same students on three occasions at the same time intervals. Each of the study's tests was carried out in exactly the same manner for both the experimental and control groups.

Further, a study must be identical for all participants, each participant must be given the same instructions, and no modifications of any kind should be allowed during the study (Mertens, 2005). The tests or instructions

given were not altered in any way during this study. An example of a modification during the execution of this study is that a student went through the training programme between the two post-tests, an initiative of the parent. This led to the student's results being excluded from the analyses. Finally, participants should be adequately informed (Mertens, 2005) and in this study, the students, parents and teachers were all given both written and verbal information regarding the study.

3.7.3 External validity

External validity concerns a study's usability and credibility, which can vary depending on the design of the study. A precise account of the study's planning, selection, implementation, testing and analyses is required in order to use the results from an experiment in other contexts. To replicate the study, and to compare and use the results of the study's implementation on a larger population, other age groups, people with different kinds of problems, or in other environments, it is also important to carefully describe the information that has been given, the participants and the way in which the test cases were conducted (McMillan, 2004).

Being aware of the 'pitfalls' makes it possible to discuss the studies' implementation and results. If, for example, it is believed that an operation in a class will change the teacher's style of teaching, thereby increasing his or her awareness of what is being measured in the study and thus affecting the results, it would be helpful to complement the study with observations and/or interviews from before and during the implementation of the study. In addition, it can be difficult to compensate for unpredictable events, such as familial factors and being 'aware of being a subject' which can affect the results (Mc Millan, 2004; Shadish et al., 2002) and is called "Hawthorn effect".

It is unlikely that every 'threat' will occur in every kind of study. It is best to avoid or address these threats prior to commencing the study but it is nonetheless impossible to predict every scenario that may arise (Shadish et al., 2002). External validity is achieved by being able to determine/measure cause and effect, e.g., the kind of individuals and abilities that are affected by a particular action, under certain circumstances and through specific measurements, regardless of variations in population or other circumstances. This allows the results to be generalised. However, there are a number of additional phenomena that can influence test results, such as statistical calculations (Shadish et al., 2002; Trochim & Donnelly, 2008).

3.7.4 Threats to validity

Different types of threats to validity are discussed by Shadish et al. (2002) and Trochim and Donnelly (2008). One such threat is 'a regression to the

mean' and the way in which a test is correlated from one time to another. Regression to the mean, skewness and differences in pre-test results in relation to post-test are discussed in this section.

3.7.4.1 Regression to the mean

When groups are not randomised and a test is not perfectly correlated 'regression to the mean' can occur. Regression to the mean is a statistical phenomenon and can happen when using non-random samples and when the pre-and post-test results do not correlate perfectly. If a selected group closely resembles the average of a population at the first round of testing, then there is not much room to approach the medium at post-testing, i.e., there is regression to the mean. However, if a group is far from average, above or below, there is more room for regression (Trochim & Donnelly, 2006). This occurs, for example, when the poorest readers are selected and their results are compared with those of more skilled readers or a larger population.

Firstly, one way to reduce the regression is to measure multiple times. It is very unlikely for extreme results to persist over time. Dual pre-test and post-test measurements can also be used on groups at different times to ensure the design of a quasi-experimental study (Trochim & Donnelly, 2008). In this study, we used pre-tests and two post-tests for all of the students in the treatment and control groups (i.e., reading and mathematics) with the same time intervals.

Secondly, the use of multiple variables when selecting participants is also an important aspect (Shadish et al, 2002). A number of variables determined whether students qualified to participate in this study or not (see 3.3 - Selection).

Thirdly, the lower the correlation between two measurement points, the greater the regression to the mean (Trochim & Donnelly, 2006). It is therefore very important to use reliable instruments and to calculate the correlation between the measurements in order to analyse and ensure the reliability of the test (Table 8, Figure 6). The more two tests correlate, the more reliable the tests are. Correlations were calculated in Grade 3 (n = 24). Perfect correlation only occurs very rarely (Trochim & Donnelly, 2006).

3.7.4.2 Is it possible to calculate the regression to the mean?

According to Trochim and Donnelly, (2006, p. 166), it is possible to estimate precisely the percentage by which a group can be expected to shift between pre-test and post-test towards the medium of a larger population at post-test. The formula is:

$$Prm = 100 (1 - r)$$

Prm = percent of the regression to the mean, and r = the correlation between the two measures. Trochim and Donnelly give the following examples: if $r = 1$, there is no regression to the mean (i.e., 0%). If $r = .5$, $.2$, or 0 , there is a 50%, 80% or 100 % regression to the mean respectively.

How to calculate regression to the mean

Example: Basic number screening test (BNST) (Time 1 - Time 3) in boys

It is necessary to know: (i) the pre-test means and (ii) the post-test means for the selected group (boys) ($n = 35$), (iii) the post-test means for the whole population ($n = 57$) and (iv) the correlation between tests.

Pre-test for the treatment group boys at T1: 15.29

Post-test for the treatment group boys at T3: 18.83

Post-test for the whole group at T3: 17.77

Correlation for the whole group, T1-T3: $r = .91$ (regression = 9%)

Prm = $100(1 - r)$

The difference, $17.77 - 15.29 = 2.48$ (expected result at T3), 9% (0.223) of which is due to regression to the mean, and then remains: 2.257. However, boys improved more: $18.83 - 17.77 = 1.06$, which signifies an improvement of $2.257 + 1.06 = 3.317$.

The expectation is that boys, if not given a treatment, should have the same mean at T3 as the larger group ($m = 17.77$). Simply put: $0.09 \times 2.48 =$ regression artifact, a 'pseudo-effect' = 0.223 p.

Figure 8. An example of how to calculate 'regression to the mean'.

If the correlation is $.5$, 50 % of the selected group's results at post-test (the difference between the population mean at post-test and the specific group means at pre-test) it is due to regression to the mean (Trochim & Donnelly, 2006). It is therefore possible to estimate what the gains for a particular group will be at the post-test using a larger group (population) average at post-test, the current group's mean result at pre-tests and the correlation between these two test runs for the population. Figure 8 shows that it is possible to estimate the exact results at a later time using the regression for-

mula. Regression to the mean is calculated above for the boys in the treatment group at T3 in the BNST test.

Table 8 shows that at pre and post-testing each mathematical test is highly correlated while decoding correlates much less. The results in the BNST (T1-T3) show very little regression to the mean, i.e., 9%, whereas reading comprehension regresses 31%, and subtraction 15%.

Table 8
Correlations and Regression to the Mean (%) in the Treatment and Control Groups

Measures	Correlations			% regression to the mean		
	T1 T2	T1 T3	T2 T3	T1T2	T1T3	T2T3
Reading						
comprehension	.70	.69	.69	30	31	31
Decoding	.59	.65	.56	41	35	44
BNST	.93	.91	.92	7	9	8
Addition	.72	.72	.81	28	28	19
Subtraction	.84	.85	.86	16	15	14

Note. n = 57; BNST = Basic Number Screening Test.

3.7.4.1 Skewness is a threat

As aforementioned, calculations can reveal if test results are skewed (have ceiling or floor effects, if the tests are too easy or difficult). It is preferable for groups to perform close to each other and to 0 (see Tables 5, 6 and 7).

3.7.4.2 Pre-test – differences are a threat

Pre-test differences can affect validity. Differences arose when comparing baseline pre-test results of the treatment and control groups in this study, but they were not significant. Even if there are significant differences in pre-tests, it cannot be proved that this will affect the results in any way (Shadish et al., 2002). It can also occur in randomised trials.

Five different scenarios that can occur in post-test compared with pre-test, depending on how the treatment and control groups perform (Shadish et al., 2002; Trochim & Donnelly, 2008), are discussed here.

When the experimental group is at a higher level at the pre-test, the following occurs (Shadish et al., 2002): (1) both groups evolve in the same direction, but the experimental group increases the most; (2) the control group remains at the same level whilst the experimental group increases its gains; and (3) the experimental group impairs its performance at the post-test and approaches the control group. It would be unusual, and a real threat to

validity, if the control group did not evolve at all over time because most students develop in some way over time.

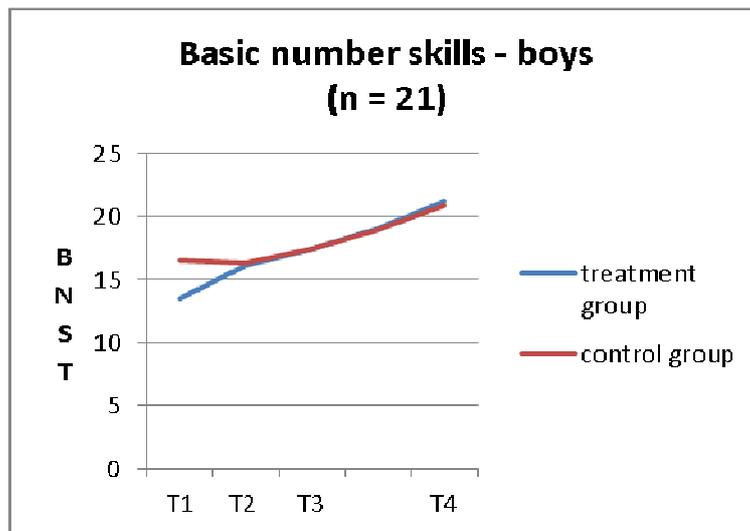


Figure 9. Scenario (4): approaching the control group: basic number skills in boys in the treatment and control groups (n = 27) at T1, T2, T3 and T4.

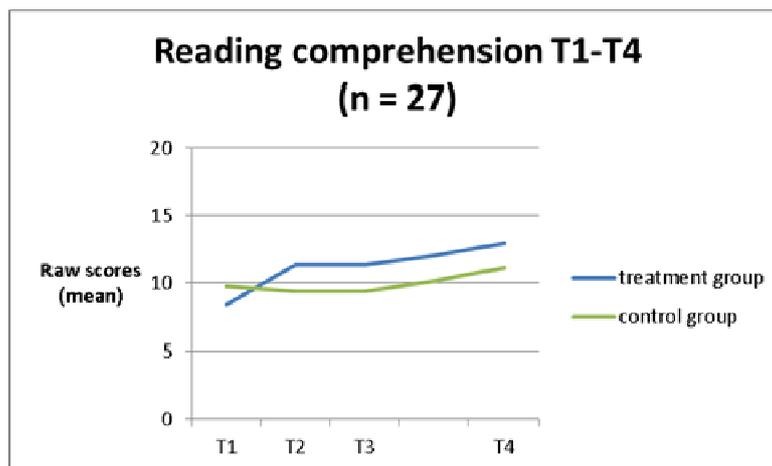


Figure 10. Scenario (5): crossover interaction: reading development in the treatment and control groups at T1, T2, T3, and T4 (n = 27) (Study III, Figure 1).

When the experimental group starts at a lower level, the following occurs:
(4) the experimental group approaches the control group; and finally, (5) the

experimental group ‘surpasses’ the control group, a so-called ‘crossover interaction’ which is not common, but does happen. This is precisely what occurred in this study where mathematics (No 4) (see Figure 9) and reading comprehension (No 5) (see Figure 10) were concerned.

Shadish and colleagues argue that the latter scenarios pose no major threat to validity. Regression is not a likely explanation for this kind of result.

If you happen to find that kind of result, you really have a program effect that beats the odds (Trochim & Donolly, 2008, p. 215).

Positive effects arose in this study, most likely attributed to the effect of the intervention, consistent with the way in which Shadish et al (2002) and Trochim and Donolly (2008) discuss validity and validity threats (Figure 10).

3.7.5 External control group

An external control was used in Study I. Using more than one control group can strengthen the results of a quasi-experimental study (Shadish et al., 2002). However, in this study, the external control group was used to compare the neuropsychological measurements, as the study control group did not take these tests. Both groups of students had attention problems, according to a psychologist’s assessment, or an ADHD diagnosis: one third of the members of the experimental group had a diagnosis, as did all of the members of the external control group. The external control group completed the tests at the same time intervals as our treatment group and its members were in approximately the same age range. Even if this was not the best approach, we placed some value in being able to compare the treatment group's results.

3.7.6 Ethical and economical aspects

The study’s design, which included a detailed account of the intervention, measuring instruments, tests to be conducted, newsletters and consultation with parents, students and school staff, was approved by the Ethical Council, Stockholm, on application: 2003 (Study 1 and II: T1, T2, T3) and 2007 (the longitudinal study: T4).

It can be problematic to conduct an experimental study. In addition to it being costly, the design includes elements that require careful discussion and consideration from an ethical point of view. Is it ethical to induce the students in a control group to work daily, for as many as 20-25 days, on an exercise that is expected to yield no effect?

The design of this study was intended to be experimental with randomisation of the participating groups. In contrast to the programme that the experimental group was offered, the idea was for the control group to work with a

non interactive programme whose difficulty was to be constant throughout the training period.

This did not occur, due in part to economical reasons, but primarily to ethical considerations. Participation in the study, particularly in the control group, could have brought false hopes to students and parents. In addition, the duration of the training was to be five weeks, approximately 40 minutes per day, time that the control group participants could spend in a more constructive way. If the experimental group students and control group students were in the same class, the control group members would most likely soon realise that they belonged to the control group and their data would therefore be less reliable. Students talk to each other and compare data and results. Thus, the value of randomisation in a class would in all probability not be great. The study required substantial financial assistance and this factor contributed to the decision to undertake a study with quasi-experimental design.

4 Results

4.1 Study I – reading results

Study I investigated the relation between WM and reading development. Fifty-seven students participated in the intervention study and an active, external control group ($n = 25$) from a randomised study (Klingberg et al., 2005) was used to compare the neuropsychiatric tests.

Firstly, training effects on neuropsychological tests were evaluated by comparing the results of T2 and T1, and controlling for gender and age (multivariate analysis of variance with repeated measures). The results of four tests improved significantly: Span board forward, Span board back, Digit back and the nonverbal problem solving test (Raven's Progressive Matrices).

Secondly, training effect was analysed by comparing the experimental group's performance on the neuropsychological tests with results from an external control group ($n = 25$). The experimental group's performance improved at T2 (T2-T1) on both Span board forward and back, and both Digit forward and back, but not on Raven. Only Span board forward and Span board back had any lasting significant improvement at the second post-test, T3 (T3-T1).

Having determined that the WM results were affected, trends in the reading-related tests (baseline performance, age and gender were controlled for) were then analysed. This revealed that reading comprehension only improved at T2 (T2-T1) ($p < .01$, $d = 0.88$) and at T3 (T3-T1) ($p < .05$, $d = 0.91$).

Finally, correlation between the reading test and cognitive dimensions, including WM-training performance (start index and max index scores), was examined. At T1, start index correlated with all cognitive measures except the Stroop task (time, seconds). The WM measure Span board correlated with reading comprehension. The conclusion drawn is that WM training appears to affect Span board results, which in turn may affect reading comprehension (Figure 11).

4.2 Study II – basic number skills

Fifty-seven students participated in the intervention study (the same students as in Study I). In Study II, we examined the effects of WM training in basic number skills approximately seven months after WM training. The experimental group's development was compared with that of the control group. In addition, the results for boys only were analysed.

To find out how students in special units perform compared with students in regular classes, baseline results were compared (Figure 1, Study II). Pearson's *t*-test showed that Swedish students in regular classes performed significantly better in all basic number measures compared with the students in special units ($p < .05$). Available basic number scores of regular classes (Grades 3, 4 and 5) and results of special units ($n = 57$) at T1 were converted into Z-scores. Mean Z-scores for the special units and regular classes could then be described and all three basic number test results could be compared in between (Study II, Figure 1).

The treatment effect for basic knowledge in mathematics (BNST), addition and subtraction, was examined using variance analysis (multivariate analysis of variance with repeated measures). This showed that the effect on the BNST was significant at T2, but not at T3. Ten days of additional training before the second post-test with a group of students showed no effect.

The girls were few in number and performed significantly poorer than boys on several tests (number ages, digit span forward, subtraction and the BNST at T1, T2 and T3; and in training scores, i.e., start index and max index). Consequently, all of the analyses were repeated for boys only. The analysis showed significant improvement in the BNST at T2 (treatment effect = $p < .05$, $d = 0.74$) as well as at T3 for the boys (treatment effect = $p < .05$, $d = 0.90$), but not in addition or subtraction. WM tests were not conducted with the control group and, for that reason the experimental group's results from the different test sessions were compared using Cohen's *d*. The effect on WM tests Span board was high (forward, $d = 1.05$, backwards, $d = 0.93$) (see 4.4.1 for further information on the girls' results).

The conclusion drawn is that mathematics and WM are related. Boys aged 9 to 12 years seem to benefit from WM training by improving their performance on both the WM-test and the mathematics test (BNST) (Figure 11).

4.3 Study III – a three-year follow-up

Study III examined how a small number of students ($n = 27$) developed in literacy and basic basic number ability soon after WM training, i.e., approximately six weeks after pre-tests (Time 2, T2), at a seven-month follow-up (Time 3, T3) and over three years later (Time 4, T4), compared with pre-

tests (Time 1, T1). The students (mean age = 14.0) were selected from the original group.

Before the sample was drawn, it was decided to include two thirds of the control group students and twice as many from the experimental group. This resulted in a control group of nine students (3 girls / 6 boys), four of whom had an ADHD diagnosis (1 girl/3 boys). Five of these students were now in normal-sized classes and the others (n = 4) were being taught in special units.

Eighteen students (3 girls / 15 boys), nine of whom had an ADHD diagnosis (2 girls/7 boys), formed the experimental group. Twelve of these students were in normal-sized classes and the others (n =6) were still being taught in special units.

Firstly, the performance of the 27 students was compared with that of the students who did not participate in the three-year follow-up, to ensure that the random group was representative of the remainder and of the group as a whole, which proved to be the case. There was no significant difference between the groups on any of the tests (*t*-test), with one exception: those in the experimental group who did not participate at T4 performed better on the Digit forward at T2.

Secondly, the reading and mathematics performances were analysed (variance analysis that controlled for gender and age). The results at T3 were consistent with the results observed in the previous analysis (Study I and II): boys and girls in the experimental group had improved more than those in the control group in reading comprehension at T3, but not in mathematics. These 18 students had also improved in word decoding at T3, which was not the case for all 42 students. The teachers and parents of the treatment group participants rated the students' attention skills (DSM-IV, Questions 1-9). This revealed that the parent rating scores had significantly declined (lower is preferable) at T2 and T3 compared with T1 (*t*-test).

Finally, results at T4 were analysed. There was significant improvement in reading comprehension between T1 and T4 for the entire experimental group.

4.3.1 Results from working memory training

Figure 11 summarizes the results from the working memory training using the second working memory model (see 2.1.4). Figure 11 illustrates enhanced results at T2 and T3 in STM (VS-STM, Span board forward) and WM components i.e., attention (DSM-IV) and VS-WM (Span board back) after training, and in reading, and number skills at T2, T3, and T4 in boys. Improvements appear in white.

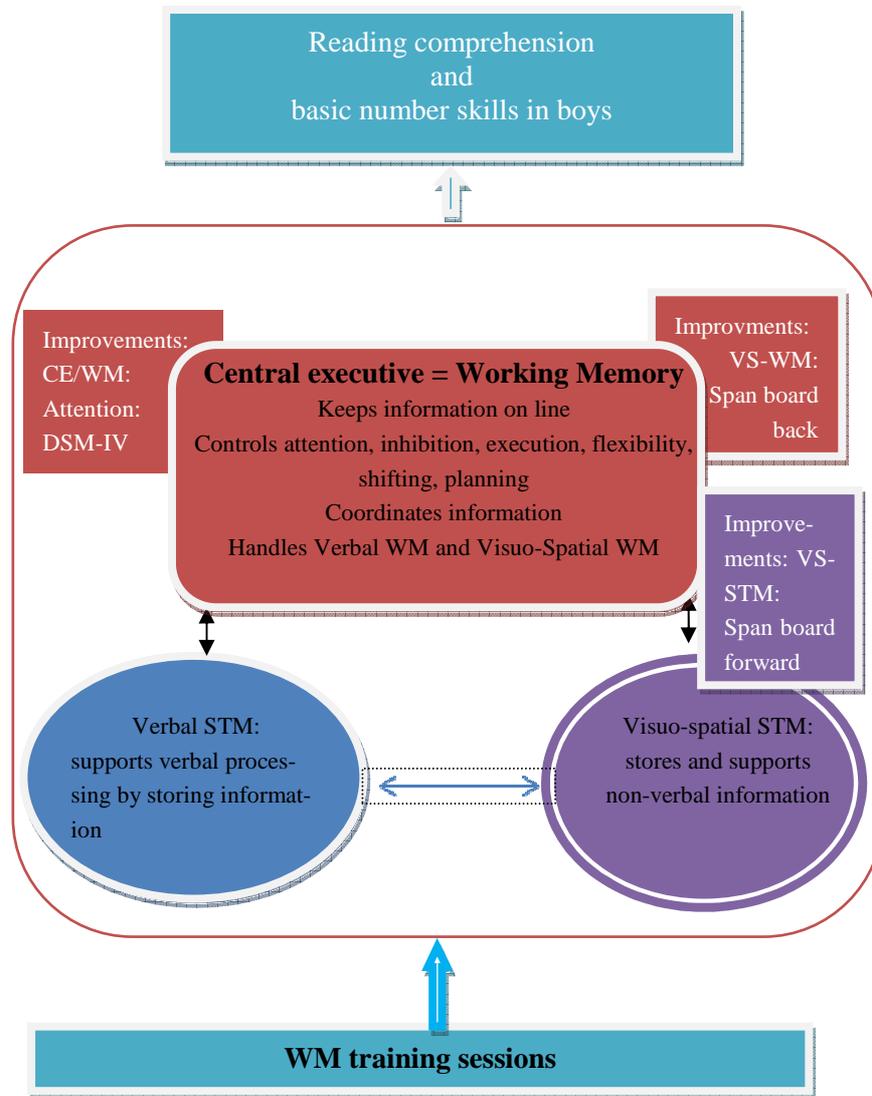


Figure 11. WM model 2 (see Fig. 3). STMs are separate functions. WM-functions = the central executive (Dahlin, 2013; cf. Dehn, 2008; Alloway et al., 2006). Note: VS-STM = visuo-spatial short-term memory; VS-WM = visuo-spatial working memory; DSM-IV = parent and teacher rating scales.

4.4 Additional results

4.4.1 Girls and boys

In relation to the boys, the girls scored significantly lower at baseline in mathematics, Digit forward (STM measure) and start index (training scores at Day 1 of the training session) but not in reading comprehension or word reading. Training scores (max index minus start index) improved as much in girls as in boys.

Table 9
Descriptive Statistics for Girls in the Treatment Group

Measures	T1 <i>mean</i>	SD	T2 <i>Mean</i>	SD	T3 <i>mean</i>	SD	Cohen's <i>d</i>	
							T2-T1	T3-T1
Span board Forward	4.07	1.0	4.93	0.8	5.07	0.8	0.88	1.03
Span board back	3.29	0.9	4.21	2.0	4.50	1.5	0.55	0.91
Digit forward	3.64	0.2	4.14	0.9	3.79	1.0	0.71	0.19
Digit back	2.71	0.6	2.86	0.8	3.00	0.8	0.20	0.38
Raven	27.42	3.1	29.29	2.7	30.29	1.7	0.79	1.07
Addition	14.71	5.9	17.43	4.4	17.14	3.2	- 0.05	0.00
Subtraction	8.86	4.1	10.29	5.6	9.28	4.7	0.27	0.09
Number skills	9.43	5.4	11.28	5.0	12.43	6.6	0.33	0.46
Reading comprehension	7.71	2.1	11.27	1.6	10.00	2.8	1.80	0.87
Word reading	10.86	4.4	12.28	3.8	13.14	5.9	0.32	0.41

Note. $n = 7$; mean age = 10.9 at T1

Table 10
Descriptive Statistics for Boys in the Treatment Group at T1, T2, and T3

Measures	T1		T2		T3		Cohen's <i>d</i>	
	<i>mean</i>	<i>SD</i>	<i>mean</i>	<i>SD</i>	<i>mean</i>	<i>SD</i>	T2-T1	T3-T1
Span board forward	4.60	0.9	5.84	1.0	5.65	1.0	1.25	1.09
Span board Back	4.10	1.1	5.32	1.2	5.09	1.0	1.05	0.93
Digit forward	4.40	0.7	4.83	0.8	4.81	0.8	0.57	0.54
Digit back	3.10	0.8	3.88	1.0	3.47	1.2	0.87	0.36
Raven	27.14	5.3	29.73	5.0	29.82	4.9	0.45	0.52
Addition	17.77	5.2	19.37	5.1	20.60	4.8	0.31	0.56
Subtraction	12.89	5.3	13.43	6.2	14.31	6.0	0.09	0.25
Number skills	15.29	6.2	17.09	6.4	18.83	6.3	0.28	0.56
Reading comprehension	8.60	4.0	11.05	3.3	11.31	3.1	0.67	0.76
Word reading	11.91	3.8	13.00	5.7	13.51	5.2	0.22	0.35

Note. $n = 35$; mean age at Time 1 = 10.7.

No gender differences were noted in the performance of problem solving (Raven), reading measures (*t*-test) or DSM IV at pre and post-tests.

To determine how each group (boys, girls) performed, effect sizes (Cohen's *d*) were conducted. The effect (*d*) was large on Span board in both girls (Table 9) and boys (Table 10). The same pattern occurred in the total group (boys and girls, $n = 42$). For girls, the effect (*d*) was also large in Raven but moderate in number skills (BNST) relative to Time 1, and according to these analyses, the girls showed no improvement whatsoever in addition, subtraction and Digit forward (Table 9).

The boys' results at T4 were investigated. The analysis shows that there were effects for boys at T4 ($n = 15$) in reading comprehension, subtraction and the BNST. Effect sizes (Cohen's *d*) at T4 relative to T1 were: reading comprehension ($d = 1.09$), subtraction ($d = 0.94$) and the basic number test ($d = 0.75$) compared with boys ($n = 6$) in the control group.

4.4.2 Comparison with normal-sized classes

In order to gauge the level of the students' basic knowledge, the average results of the various tests completed by the experimental and control group were compared with the performance of students in regular classes in Grades 3, 4 and 5 (Figure 12).



Figure 12. Descriptive statistics for mathematics and reading results at T1: Z-scores for all available results in reading and basic number skills in regular classes (red, $n = 214$), and in the treatment and control group (blue, $n = 57$). Total mean = 0 ($n = 271$).

Compared with all of the available data ($n = 271$) for Grades 3, 4 and 5, the special units lie on an average of reading and mathematics tests corresponding to the 20th to 30th percentile (basic number skills (BNST), 20th percentile; reading comprehension and addition, 25th percentile; decoding and subtraction, 30th percentile). The students in regular classes performed significantly better in mathematics and reading (Pearson's t -test) than the students in the special units.

It should be noted that the students performed less well on subtraction than addition despite the tests being structured in the same way: they begin

at a very easy level for the first ten problems and the difficulty progressively increases thereafter. This suggests that the subtraction calculations were more difficult for these students to carry out than the addition calculations.

Teachers ($n = 22$; 13 teacher respondents in the experimental group and nine teachers in the control group at T4) shared their perspectives regarding the ability of their students to meet the school's goals in mathematics, English and Swedish. They estimate that approximately half of these students will fail to meet the school's goals in Swedish, English and/or mathematics (mathematics: 9/22; Swedish: 12/22; English: 11/22).

4.4.3 ADHD diagnosis or not

Thirteen students in the experimental group had an ADHD diagnosis. We investigated whether there was any difference in training effect for those with or without a diagnosis. There was not; they developed in almost exactly the same way in both mathematics and reading comprehension.

4.4.4 Correlations in regular classes

Figure 13 shows that reading comprehension and BNST scores are related ($r = .54, p < .01$) in regular classes. Reading comprehension, addition, subtraction and decoding are less related in these students. Figures 13, 14 and 15 summarise correlations in regular classes and the treatment group for reading and BNST.

4.4.5 Correlations in the treatment group

Correlation analyses at T1 show that Raven (nonverbal problem solving) was related to the WM test Span test board and Digit Span. Raven also correlated with mathematics (BNST) and reading comprehension (see Figures 14 and 15).

Correlations between reading and WM measures (see Figure 15): reading comprehension was related to Span board forward, but not to Digit forward or back at pre-test (T1). Span board back had the highest correlations with mathematics through all replicates ($r = .60, p < .01$).

The training index outcome scores were significantly related to those of Span board back (T2 – T1, T3 – T1), addition results at T3 and Span board back at T3. The Span board back outcome scores (T3 minus T1) were related to the addition outcome scores ($r = .42, p < .05$).

The relation between reading comprehension and decoding was high in the treatment group but lower in regular classes. This indicates that the treatment group were relying more heavily on decoding than the regular classes were. Firstly, this is further proof that phonological skills are not as important to skilled readers as they are to novice readers. Secondly, it con-

finds that basic number skills are important for reading, as reading and basic skills in mathematics are correlated.

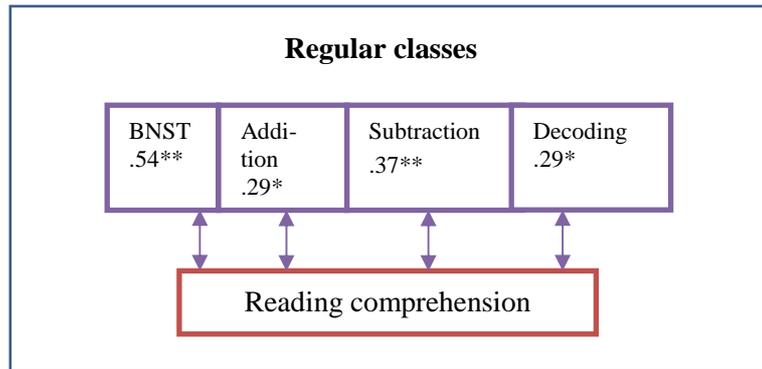


Figure 13. Reading comprehension: correlations in regular classes (n = 100).
Note. * $p < .05$; ** $p < .01$

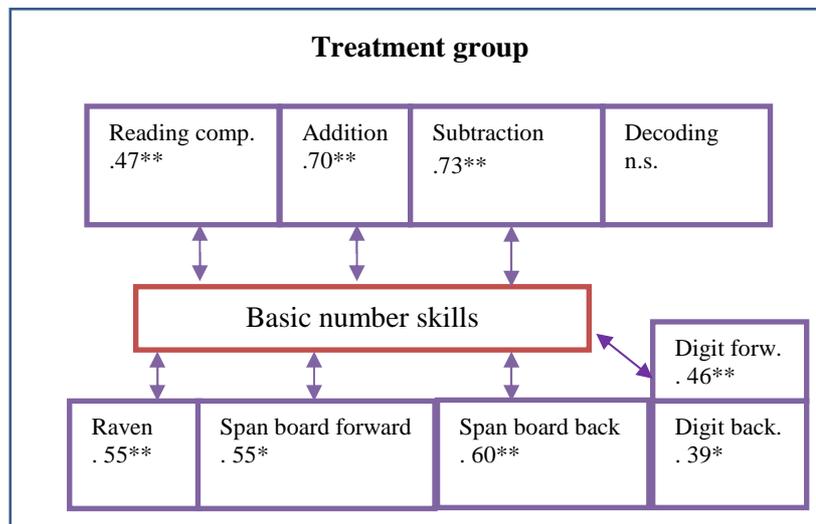


Figure 14. Basic number skills: correlations in the treatment group (n = 42 at T1).
Note. * $p < .05$; ** $p < .01$

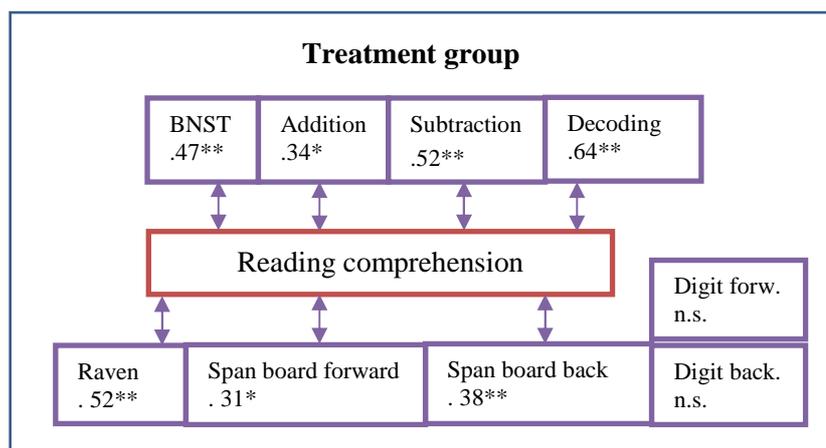


Figure 15. Reading comprehension: correlations in the treatment group (n = 42) at T1.

Note. * $p < .05$; ** $p < .01$

5 Discussion

The overall objective of this thesis was to investigate whether five-week computerised WM training sessions in the school environment would have positive effects on WM-related test results and basic number and reading development in students with attention difficulties. An intervention study featuring an experimental group and a control group was carried out. The participating students were all being educated in special units within or near the ordinary schools and all had attention deficits. Approximately one third of the students had an ADHD diagnosis at project start. The hypothesis posed for this study was that WM measures, reading comprehension and basic number skills are enhanced by the WM training process.

5.1 The whole concept

Reading comprehension and basic number skills in boys improved after working memory training and persisted over the years. The hypothesis posed for this study was proved to be partially true. The study shows that WM training resulted in enhanced reading comprehension scores. It is reasonable to assume that other factors may have also contributed to the results. Effects in WM experimental studies depend on the specified definition of WM, the types of tests conducted, the statistical analyses and the study's design. How we define and measure attention and WM skills is clearly fundamental as it affects the conclusions we draw.

One explanation for the enhanced results may be that the 'concept as a whole' (e.g. training, training situations, increased attention from adults, rewards, motivation and a feeling of succeeding) may have influenced the results. Some studies find correlation between positive experiences and increased activity in the prefrontal cortex (Light et al., 2009). Increased activity after WM training in this particular area has been documented (Takeuchi et al., 2010; Olesen et al., 2004). While others may disagree (see 2.10.4), on the basis of this study, I believe that the WM training sessions may have "set something in motion", as discussed by Logie (2012). Logie highlights the development of specific strategies that may be applied to other learning situations, together with enhanced motivation. Wellbeing and positive experiences affect learning (Light et al., 2009). The discovery and development of strategies occurs during training, students experience a positive feeling from

the adults' participation and positive attitudes, and the combined effect of these elements increases their willingness to apply themselves better in other contexts as well.

Particular attention was paid in the planning stages of this study to the training schedule, the participating adult being on positive terms with each child, the information presented, and the involvement of parents from the very beginning and throughout the training (e.g., meetings at school, telephone interviews, the daily provision of training protocols).

Moreover, all of the students who participated in the present study had attention deficits. WM problems lead to both poorer planning and attention skills (St Clair-Thompson, 2011), which is important to consider. It may be an additional cue. This study shows improvements in attention, as measured by rating scales, and visuo-spatial WM results.

Studies show that both WM and attention abilities contribute to WM capacity differences in individuals, but no theory has been able to explain why this is the case, according to Gibson et al. (2012). Ideally, training programmes would be able to affect both attention and WM.

Finally, the link between LTM and WM is important (e.g., Nyberg & Bäckman, 2007). Dopamine was found to be enhanced after WM training (McNab et al., 2009), facilitating memory recall and the collection and storage of knowledge in LTM, which along with other enhancements might strengthen the effect. Certain aspects of WM, attention and school subjects are discussed below.

5.2 Working memory, reading and basic number skills

5.2.1 Reading comprehension

Reading comprehension was the only reading test in which results improved across the entire training group after WM training. The results of the other reading measures were not expected to improve. The hypothesis was that reading comprehension would improve because most of the exercises in the training conducted loaded on WM abilities (i.e., visuo-spatial-WM) and not on STM. Other reading tests (decoding/phonological ability and orthographic skills) were included more as 'control measures', with a view to verifying or ruling out the kinds of abilities influenced by the training programme.

The results show that working memory capacity is related to reading. Improvements were made in reading comprehension at T2, T3 and T4 (Study I and III). The improvements observed at T3 in reading for the entire group are still in evidence three years later when compared with the control group and the results at T1, and have not diminished.

Enhancements in WM measures, as shown in the Span board (visual, non-verbal), and Digit span (verbal) may be linked to the positive development of reading comprehension. Shah and Miyake (1996) found that reading and visuo-spatial skills were related and that they influenced reading comprehension results.

Cooperation between verbal and visual features and attention, which are managed by CE, is highlighted as being significant in reading comprehension (e.g., Baddeley, 1992; Gathercole & Pickering, 2001). Swanson et al. (2006) emphasise the importance of the central executive (CE) function in reading comprehension. Further, attention (rating-scales) was, for instance, improved after WM training in a study by Gibson et al., (2012). Efficient WM processes, including attention, appear to be essential in reading comprehension. In the context of this discussion, I believe that the CE function may have improved (Span board back improvement) (Figure 11, 16), possibly by enhanced attention ability (DSM-IV), which is necessary in order to be able to process information (e.g., Cowan, 2005).

Decoding skills did not improve after WM training. However, decoding problems are not always the reason behind severe reading difficulties. Those who have difficulty understanding text do not generally differ from those without this problem where performance on phonological memory tests (STM) is concerned. Rather, if information processing (WM) is problematic, reading comprehension can be affected (Hulme & Snowling, 2009). Melby-Lervåg, Lyster, and Hulme (2012) found that phonemic skills varied in children with dyslexia in relation to children of the same age without reading problems. However, it requires probably a more varied explanation for dyslexia. (Smith-Spark & Fisk, 2007).

Most reading comprehension tests are designed differently from this. To avoid poor writing ability affecting reading comprehension results, oral answers to the open-ended questions were written down by the adult carrying out the test. It was probably easier for the students to reply verbally to an adult than to write their answers independently. As a result, the students possibly felt more confident and they may have increased their own efforts to focus on these particular tasks.

The experimental group performed lower on both mathematics and reading tests at T1 than the control group, but the differences were not significant. In the case of reading comprehension, the experimental group passed the control group at T2 and developed at a similar rate to the control group, but at a higher level. No other measure showed this pattern. This type of development, when a treatment group that is lower than the control group at pre-tests but develops so much that it crosses the control group's curve, is referred to as a so-called 'crossover' (Trochim & Donnelly, 2006) and provides strength to a quasi-experimental study. Crossover is positive and increases the reliability of a study because it decreases the risk that the changes could be due to an artefact (a regression to the mean) and increases the prob-

ability that the changes are ‘real effects’ (Trochim & Donnelly, 2006; Shadish et al., 2002) (Figure 10).

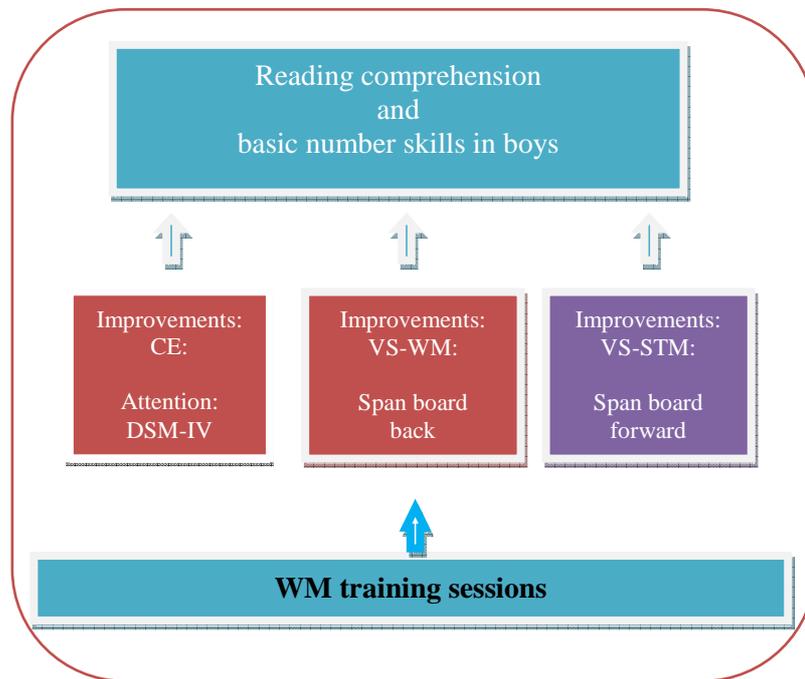


Figure 16. This figure summarises the results: attention, STM and WM components were enhanced after training, at T2 and T3; and reading and number skills showed improvements at T2, T3, and T4. These advances appear in white (see Figure 11 also).

The WM training sessions seem to have influenced the results of the measurements used in this study. It can be assumed that if the students had not taken part in the intervention study, they might have remained at the same, lower level relative to the control group: at T3 and T4 as at T1. As it has been noted that the development of WM is linear and related to reading comprehension, there is significant risk of a ‘rich-get-richer’ effect emerging (Stanovich, 2000), i.e., the able students perform progressively better while those performing lower from the outset find it difficult to reach the same level as their peers without WM problems.

Neither orthographic skills nor decoding were improved by the intervention, with one exception: improved decoding at T3 was observed in the boys. However, it is not possible to draw any conclusions from this. Melby-Lervåg and colleagues argue that phonemic skills are the very foundation of reading.

However, they discuss neither reading comprehension nor the higher cognitive processes involved in inference making, i.e., WM abilities. It is probably necessary to consider both bottom-up and top-down processes as discussed by Verhoeven, Reitsma and Siegel (2011). Consequently, it is necessary to consider more than phonetic skills alone as a basis for reading development. In this study, reading comprehension improved but decoding ability did not.

5.2.2 Basic number skills

Overall, basic number ability (BNST) improved at T2, but not at T3 (Study II). However, analysis of the performance of the boys in the treatment group alone reveals that they had improved significantly at both T3 and T4 compared with the boys in the control group. In the case of basic number skills, the treatment group approaches the control group but their development curves do not intersect. Nevertheless, the trend is considered as positive [see scenario (4), Figure 9] (Trochim & Donnelly, 2006). In the treatment group, the BNST and subtraction were related to reading comprehension. Training outcome scores were related to those of Span board back at T3.

The enhancement in the BNST results may be due to skills in processing (WM), and linking and recoding information (LTM). For example, it was found that students who perform poorly on mathematical tasks do not necessarily have difficulty storing information (Passolunghi & Siegel, 2004). Furthermore, according to Hulme and Snowling (2009), the ability to process information differs from one individual to another.

5.2.2.1 Subtraction skills

Another measure that shows improvement on only one occasion (cf. decoding for boys at T3) is subtraction for boys at T4 (the girls were excluded from the analysis as they were too few in number and did not improve at all at addition, subtraction or Digit forward). It can be noted that the students in this study performed less well on subtraction than addition, despite the tests being structured in the same way, i.e., starting at a very easy level for the first ten tasks before progressively increasing in difficulty.

It is more difficult to count backwards than forwards (cf. Study II, Table 2: Digit forward and back: raw scores are lower on Digit back). Subtraction is more difficult for these students to calculate than addition (Study II: Table 1, 2: raw scores are lower on subtraction). Some of the students in this study identified subtraction as a difficult aspect of basic mathematics. The use of addition and subtraction tests, which are easy to administer, could be one way of identifying students at risk of developing difficulties in mathematics.

Addition and subtraction calculations are dependent on stored knowledge in LTM (from experience and training) and on the ability to retrieve factual knowledge from LTM rapidly as the tests only last for a few minutes. These processes do not draw much on WM capacity, i.e., if they are automatized.

Subtraction is in that case a purely STM task (cf. Klingberg, 2007). However, if the assignments to be made are not automatised, it burdens WM. It follows that if students with WM difficulties are obliged to perform the calculations manually, they will have insufficient time in which to solve many of the problems, as their WM will be continuously overloaded (Clark et al., 2006).

5.2.2.2 WM and mathematics

The Span board back (visuo-spatial WM; VS-WM) results improved and had the highest correlation with basic number skills. This may explain why the boys improved in basic number skills.

In sum, the Basic Number Screening Test contains a variety of questions, some of which call for logical thinking (adding a series of numbers) and has no set time limit. Out of the two tests in which the boys improved, one was time-limited (subtraction, T4) and other was not (BNST, T2, T3, T4).

Deficiencies in WM capacity can cause difficulties in mathematics. Gersten et al. (2005) conclude that reading difficulties are related to the speed with which mathematical problems can be solved. However, as with poor reading skills, the reasons behind the varying degrees of difficulties may be a combination of factors such as a lack of basic knowledge and/or vocabulary, behavioural problems, personality-related issues, impaired cognitive ability other than WM, poor teaching skills, teacher personality issues or the environment (e.g., Goswami, 2008a; Snow & Polselli Sweet, 2003). It is therefore unwise to consider simply one or two of these elements in isolation; it is more complex than that.

WM is important to performance in both basic number skills (Lemaire et al., 1996) and reading comprehension. It can predict the mathematical development of students with normal reading development, regardless of ability in the phonological loop, inhibition and reading (Swanson, 2006).

Mathematics draws on many different abilities. I do not believe that it is possible to generalise ‘difficulties in mathematics’. A person may have specific difficulties with subtraction, but not with addition, or find it hard to understand written problems, conversion or the like. It is important to analyse each student’s difficulties carefully and provide assistance in their respective problem areas as the difficulties arise.

5.2.3 The effect on visuo-spatial abilities

This study shows that a relationship exists between reading and number skills and working memory and reveals a correlation between particular visuo-spatial STM and WM, reading and mathematics at pre-tests in these students. WM training scores correlated with improvements in Span board, both at T2 and T3. Previous studies have found that a low visuo-spatial WM in students is an indicator of reading and mathematics difficulties (Pickering

& Gathercole, 2004) and that CE function ability differed between those with good and poor reading comprehension (Swanson et al., 2006).

Analyses (Study I) reveal that Span board forward (visuo-spatial STM), Span board back (visuo-spatial WM) and Digit span forward (verbal STM) and back (verbal WM) all improved immediately after training compared with the results of an external control group. However, only Span board was significantly enhanced at T3. The WM training intervention seems to generate improvements in non-trained abilities, i.e., reading comprehension, which could be due in part to the enhanced visuo-spatial STM and WM (Span board).

5.2.4 Attention deficits may mask other problems

Teachers and parents in the treatment group rated the students' attention skills (DSM-IV, Questions 1-9). This showed that the score had diminished (lower is preferable) significantly at T2 and T3 compared with T1 (*t*-test).

It may be that the five-week training increased concentration abilities and awareness that making an effort in learning situations can be worthwhile, and that it can result in increased motivation and interest. Attention is necessary in order for learning to take place (e.g., Verhoeven et al., 2011; Cowan, 2005), and it is important to be able to control and direct it (Figure 1).

Attention difficulties may be overlooked in students with reading and basic number difficulties. It is important to understand where the weaknesses lie and not to simply dismiss a student with an attention deficit as “forgetful”, “lazy” or someone who “never listens”, thereby denying the child appropriate assistance and the education that he or she warrants (Alloway & Gathercole, 2006). Some students with a diagnosis in attention deficits (ADHD-I) do not receive help with additional problems they may have such as difficulties in reading and or mathematics. Focus is often fixed solely on issues relating to conduct (Tannock & Martinusson, 2001). Addressing this failure could involve restructuring and planning education in a completely different way (Clark et al., 2006) and providing specific support in mathematics and in reading and writing.

Wåhlstedt (2009) found that certain EFs and academic achievement are not related to hyperactivity or impulse control deficits, but to inattention. She highlights, as do many others (e.g., McLeod et al., 2012; Nigg, 2006), the diversity in children with attention problems and the importance of investigating each child's profile in order to confirm if they have attention, hyperactivity and/or comorbid problems.

The students who participated in this study were being taught in special units, primarily due to their attention difficulties and not because of mathematics or reading disabilities. Only three had been investigated for dyslexia at T1. Nevertheless, they performed significantly lower than the regular clas-

ses. They were in the 25th percentile in reading comprehension and in the 20th percentile in basic number skills (the BNST) at pre-tests.

5.2.5 Motivation and the feeling of succeeding

Several students in this study expressed anxiety and doubt about failing to learn or a particular kind of teaching, both of which almost certainly affect motivation.

This could be an important focus area. Students in this study were able to clearly express how they feel when they cannot or do not understand.

One girl in this study said that her confidence falters at every mathematics lesson:

Every time we have maths...I am disappointed in myself because I cannot...I lose confidence (Grade 6, difficulties in mathematics).

One of the boys said that he walks around the classroom when he does not understand and that there is no point in even trying.

It has been noted that students in Grade 1 withdrew from lessons (Poskiparta et al., 2003) despite the fact that no significant differences had been recognised between the students at preschool level. Some of these students may have been exposed to curriculum content that was too advanced before having the opportunity to acquire the prerequisite knowledge and as a result lost their desire to learn. A number of them may have had difficulty following instructions, leading them to withdraw. Perhaps it is characteristic of students with WM-deficits and/or attention difficulties to frequently withdraw in this way. Positive learning situations are essential. The fact that low WM capacity may generate low self-esteem (Alloway & Gathercole, 2006), 2006) and that self-esteem may affect the way in which problems are solved (Naglieri & Johnson, 2000) could be valuable knowledge for teachers.

The opposite situation may prevail if one is motivated. A girl in this study who likes mathematics said that “maths is fun, it's exciting”. She also expresses the importance of experience to learning.

... when you experience that, you learn ... know how, that's good. Then ... it feels pretty good.

Success has an impact on learning (Light et al., 2009). Some of the students' improvements on the tests carried out may be due to them experiencing a feeling of succeeding during the training programme sessions, an understanding that it is possible to influence their own learning situation. During the study, students in the treatment group received extra encouragement and affirmation and together with successful training (all students completed

the stipulated amount of exercise: 20-25 days, which may indicate the involvement of both students and adults) improved their performance on both WM-test reading and basic number tests.

They probably discovered that the ability to focus provided the opportunity to solve a task; it 'paid off'. Some students remarked that they were able to concentrate better after practice. They now have greater insight into what 'concentration' means and involves. As a result, they have a strategy in learning situations: to make their best efforts to concentrate on a task, which in turn produces positive results and wellbeing. Success creates the desire to learn more (Light, et al., 2009; Timperley, 2011). A boy (Grade 7) who participated in this study explains succinctly what he does best in school and why: "Math. I've been practicing a lot, then it's easy!"

However, all measures did not improve. This suggests that the training effects were not a general improvement in motivation.

5.2.6 Early efforts

Students with attention deficits could be considered at risk of underachieving in school: the students in this study performed significantly lower at T1 compared with students in regular classes. Students in the study were in Grades 3 to 5. Possibly the focus should be on earlier efforts to train WM and support the acquisition of basic skills. Together with motivation and the pleasure attached to fulfilling different kinds of tasks, it might affect the development of knowledge and WM, as positive emotions are beneficial in this context. In order to prevent students from 'hiding' and losing motivation, students with difficulties in mathematics should be identified and stimulated as early as in preschool and Grade 1 (Lepola et al., 2005), an approach that I believe should also apply to students with reading-related difficulties.

Perhaps it is difficult to compensate at a later stage for the slow development of skills in young students with significant WM deficits. Years of stimulation and learning are lost in later grades. Stanovich (2001) underlines the importance of basic knowledge in building new knowledge. Basic knowledge acquisition may be hindered by task avoidance strategies, which may result in further conflict with teachers (Henricsson & Rydell, 2004), and a lower level of intuition than peers (McLeod et al, 2012).

Since preschool students are especially sensitive to assimilating ways of regulating their own emotions and behaviour, it might be worthwhile training EF, which could produce a positive outcome with lifelong benefits (Center on the Developing Child at Harvard University, 2011). A recent study found that students with the poorest EFs before intervention (i.e., WM training, classroom interventions and physical exercise) targeting the improvement of WM, social interaction and emotional control improved the most (Diamond & Lee, 2011).

While it may be common to focus efforts solely on phonology and reading intervention at an early age, this appears somewhat ill-considered. I believe that early efforts should encompass all areas of possible shortcomings, i.e., to teach and provide strategies in order to compensate for weak abilities in WM, early numeracy, problem solving and executive functions, along with reading-related fields such as phonological awareness, word recognition, listening comprehension and reading comprehension. Meeting students' needs demands indeed knowledge, experience and ongoing research.

5.2.7 Differences in performance

Differences between the boys' and girls' results appeared in the present study, in the sense that the girls started at a significantly lower level at baseline in mathematics, Digit forward (STM measure) and start index (training scores at Day 1 of the training sessions) but not in reading comprehension or word reading. They improved on one WM test (i.e., Span board back, Study II) while the boys also performed better on the Digit span. The girls improved as much in training scores, but their progress remained equidistant to that of the boys at post-tests.

This particular case could be due to chance alone, but could also mirror general gender differences that may occur among students, i.e., a higher prevalence of reading disabilities in boys (Rutter et al., 2004). Rutter and colleagues found in four independent studies that reading disabilities were significantly higher in boys. Since girls generally appear more attentive than boys, they may not receive the specific help that they need in order to cope positively (Gathercole & Alloway, 2008). However, the sample size for girls in this study was not large enough to draw any conclusions. It would therefore be desirable if future research on attention deficits focused specifically on the needs of girls, which appear to differ compared with boys.

The fact that more boys than girls have an ADHD diagnosis may contribute to less research being devoted to girls. It may also be that girls respond differently to interventions or that their problems are of a different nature, but this remains unclear (Hinshaw, 2002). In a recent study, it was found that poor EF abilities in childhood predict low mathematics achievement in girls. The girls with both EF deficits and ADHD developed at a lower level than the girls without these problems (Miller & Hinshaw, 2010).

These findings are important because the girls in this study improved as much in Span board, training scores and reading as the boys relative to pre-test, despite starting at a lower level than the boys. However, they improved moderately in the BNST and did not improve at all in Digit forward, addition or subtraction (at T3 relative to T1). It may be that a low level of WM at start influences development in mathematics. Previous studies show that the development of WM is dependent on 'start level': those who start low develop at a lower level over the years compared with peers (Baddeley, 2006).

Differences in performance can be attributed to a number of variables. Firstly, students can be differentiated from one another by the way in which their brains function (Goswami, 2008a). For example, there may be differences in the use of prior knowledge from LTM (Ericsson & Kintch, 1995) which may result in limitations in linking information from different sources (Alloway & Gathercole, 2006).

Secondly, Goswami (2008a) highlights the importance of considering the interaction between biological and environmental influences which occurs constantly in cognitive development. It is reasonable to assume from what is discussed here, that it is important to pay early attention to WM ability and to reading and number skills because WM capacity seems to be related to the development of these abilities. Having an understanding of this area is highly relevant in education because the brain is still the ‘main organ of learning’ (Goswami, 2008a, p. 381). This knowledge can be helpful in developing better teaching environments.

5.3 Methodological issues

5.3.1 Limitations

The present study is a quasi-experimental study, so-called because the treatment and control groups were not randomly selected. The control group received no placebo. Errors due to statistical analyses (regression to the mean) test correlation over time and pre-test results can affect the outcome later in different ways and affect a quasi-experimental study in a positive or negative sense. In systematic reviews, some believe that an experimental study with placebo and randomisation is the only design worth considering.

The possibility of conducting a randomised study was debated, i.e., to allow one randomly selected group of students to work with the interactive WM-training programme while inducing another group to practice with ‘game software’. Morrison and Chein (2011) highlight the dilemma of control groups losing motivation and interest. Furthermore, the research team was not entirely satisfied with a situation requiring students to spend many hours training with a programme unlikely to have a positive effect, all the while raising the expectations of the students and parents concerned. Therefore, on ethical grounds, we allowed the control group to participate uniquely by completing tests with the same frequency as the treatment group. All of these discussions and decisions were obviously made prior to project start and prior to submitting an ethics application. The design was approved by the Ethical Council.

An experimental study with randomised assignment is regarded as the most reliable model for conducting studies that are able to prove the causal

effects of treatments. The results of a study with quasi-experimental design can nevertheless provide valuable knowledge (Shadish et al., 2002). Many factors can affect the results of a study, whether it is randomised or not. Even in a randomised trial, the validity of an experiment is never certain (Shadish et al., 2002). All studies require accuracy and the appropriate analyses, but the choice of design can have a range of consequences. Randomisation does not automatically provide a reliability study. In every kind of study, the participants' awareness of being part of a study influences the results, as does the test design, implementation, group composition and accuracy in analysis (Shadish et al., 2002).

In terms of evidence of causal relationships in quasi-experimental studies, I believe that ruling out studies as a matter of course based on design carries the risk of overlooking vital information and failing to notice an aspect of a much broader perspective (Shadish et al., 2002). It is difficult to achieve and guarantee perfect experimental situations within educational settings, especially in longitudinal studies where the participants are in any case exposed to influences of variables that may be difficult to control.

5.3.2 Strengths

First, let us consider pre-tests. There were differences in baseline performance between the experimental group and control group, but they were not significant. They can be controlled by using, as was the case here, the baseline results, ages, differences in schools and sex as covariates (Mertens, 2005). However, various types of precipitation influence the final results, such as how basic number skill development in boys from the treatment group approaches the control group. Reading comprehension shows a positive development, a crossover effect, which is highly encouraging according to Shadish et al. (2002) and Trochim and Donnelly (2006), and gives weight to the results of a quasi-experimental study.

Some might argue that the results depend on inferior, unstandardised tests, but we found it necessary to design our own test because of the unsuitability of the available designs (commencing at too high a level, generally designed for students in regular-sized classes) and the lack of parallel versions.

The measurements are judged to be reliable because the tests were evaluated and corrected by the researcher, both before and during test execution and when different versions were tested (at weekly intervals), and because most tests were carried out by that same researcher. However, this person knew who belonged to the treatment and control group, as it was not a "double blind" study.

Also reported are correlations between test sessions, the way in which actual impact is calculated and the results of the statistical calculations. Training was organised and carried out consistently for all participants. Precise

and accurate information was given to teachers and parents orally, during personal meetings and by mail.

It is worth mentioning that we also employed well-proven and standardised tests in addition to the tests that we designed: besides WM (WISC III, WAICE-NI) and problem solving tests (Raven), a mathematics test (the BNST) that has two parallel versions and table norms (standardised on 3,042 students in the middle of the school year). The results of the BNST show that only the boys in the treatment group improved in the BNST, but did so at T2, T3 and three years later compared with the boys in the control group.

5.4 Conclusions

This study presents five key findings:

(1) The treatment group seems to have gained from the working memory training, (2) reading comprehension and basic number skills are related to WM measures, (3) WM training sessions and positive experiences alone are insufficient to help these students develop in line with their peers in school subjects such as reading and mathematics, (4) WM ability can vary among groups, and (5) more research is needed to substantiate the efficacy of the WM training program.

Firstly, the treatment group seems to have gained from the cognitive training of working memory with the computer assisted program. The gains were observed on reading comprehension, and visuo-spatial WM and STM measures, and on basic number skills in boys both directly after training, after six months and at the three year follow-up. Attention ability in terms of DSM-IV (parent rating scales) increased after WM training. It is reasonable to assume that several factors may have contributed to the results.

Secondly, the conclusions drawn are that WM ability is related to reading and basic number skills and for that reason, it is important to take WM capacity into account in the classroom.

Thirdly, this study shows that students are still experiencing difficulties in certain subjects three years after the training. Far from all students will meet the school's goals in Swedish, English and/or mathematics, according to teachers. Probably, students' mathematics and reading skills should have been strengthened at earlier ages, regardless of whether they had a diagnosis of any kind. The students' development seems to have been affected to such an extent in the early years that it could be difficult to repair. Still, my own view is that being part of this intervention study and completing the training sessions was in some way meaningful for the treatment group participants.

Next, this study shows that WM-capacity can vary among different students. Boys and girls in the treatment group performed differently.

Finally, the study has methodological limitations. The results have limited value when it comes to causal relations.

5.4.1 Implications for teaching children with special educational needs

Five principal implications have arisen from this study that should be considered in education:

(1) the assessment of children's cognitive profiles, (2) educators being research-informed, i.e., able to recognise variables and underlying cognitive function in the classroom, (3) the provision of systematic education according to each individual's profile and proximal zone, (4) the evaluation of instructional effects and long-term follow-up, and (5) educators being aware of differences in individuals' cognitive profiles, not only in children with ADHD diagnoses but also in those with 'only' attention related problems.

It was found that WM ability is related to reading and basic skills. Accessing knowledge (stored in LTM), not only for mathematics but also for reading, probably charge resources such as WM and attention and activate various other cognitive resources, depending on how easy or difficult it is for the individual to pick up information from the LTM. We should therefore pay attention to the way in which students are stimulated at preschool and later in school.

The girls who participated in this study started at a lower level than the boys. They improved as much in training, but their progress remained equidistant to that of the boys at post-tests. It is noteworthy that individuals may differ in WM subsystems, affecting school results in different ways (Baddeley, 2006). It is quite possibly the quiet, sedate boys and girls who seldom ask for help to whom we should be paying particular attention. I believe that practice in whatever form (proven to be highly productive in the case of reading) is conducive to development, but it is crucial to begin interventions at early ages.

In sum, I believe that WM difficulties should be taken into account in schools from an early age, along with reading and mathematics, as these abilities appear to be related. For this reason, I believe in creating stimulating, meaningful and evidence-based education drawing on educators' knowledge and experience. I also believe that students' development should be continuously evaluated and mapped, thus providing teachers with the knowledge of *what* to focus on and *how* during the school years. If work in the classroom is not evaluated, it is unclear whether or not new inputs produce better outputs.

In my opinion, the field of special education should be at the forefront when it comes to evaluating and gaining knowledge about research and the best use of findings in school contexts, so as to facilitate learning for all students. Special education should be designed to ensure that learning and development are able to take place with accuracy via prevention, support and alleviation. I hope that this study makes a valid contribution to research literature devoted to relieving problems caused specifically by weak WM capacity. I also hope that this study provides valuable information and insights that will prove beneficial to future research and policy development for students with special educational needs.

5.5 Continued research

I see high value in conducting a working memory study in for example Grade 2, with students who have WM problems and/or difficulties in reading or mathematics. Immediately after WM training, they would train (daily for approximately half an hour over a few weeks) both their phonological, reading and basic number skills. Students would complete self-ratings at all measurement points. There would need to be an equal ratio of girls and boys in each group.

Mathematics receives less research attention than reading and should be investigated further to reach a better understanding of the relevant underlying cognitive processes and how to best implement experience with number symbols and counting in young children.

It is also my opinion that classroom research that focuses on cognitive overload should be investigated further.

Finally, every effort should be made to recruit an adequate number of girls in intervention studies, particularly in studies whose participants are selected from populations where girls tend to be underrepresented. Girls' difficulties and the ways in which they respond to interventions could therefore be analysed and the results compared with other girls.

References

- Adams, J., and Hitch, G. (1998). Children's mental arithmetic and working memory. In C. Donlan (ed.) *The development of mathematical skills*. Hove, Psychological Press, 153-73.
- Alloway T. P., Gathercole, S. E., Adams, A-M., Willis, C., Eaglen, R. & Lamont, E. (2005a). Working memory and phonological awareness as predictors of progress towards early learning goals at school entry. *British Journal of Developmental Psychology*, 23, 417-426.
- Alloway T. P., Gathercole, S. E., Adams, A-M., & Willis, C. (2005b). Working memory abilities in children with special educational needs. *Educational & Child Psychology*, 22(4), 56-67.
- Alloway, T.P. & Gathercole, S.E. (2006). How does working memory work in the classroom? *Educational Research and Reviews*, 1 (4), 134-139.
- Alloway, T. P., Gathercole, S. E., & Pickering, S. J. (2006). Verbal and visuospatial short-term memory and working memory in children. Are they separable? *Child Development*, 77(6), 1698-1716.
- Alloway, T. P., Gathercole, S. E., Kirkwood, H., & Elliott, J. (2009a). The cognitive and behavioural characteristics of children with low working memory. *Child Development*, 80(2), 606-621.
- Alloway, T. P., Gathercole, S. E., Holmes, Place, Elliot & Hilton. (2009b). The diagnostic utility of behavioural checklists in identifying children with working memory deficits. *Child Psychiatry Human Development*, 40, 353-366.
- Alloway, T. P., & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology*, 106, 20-29.
- Alloway, T. P., Banner, G. E., & Smith, P. (2010). Working memory and cognitive styles in adolescents' attainment. *British Journal of Educational Psychology*, 80, 567-581.
- Alloway, T. P., & Passolunghi, M. C. (2011). The relationship between working memory, IQ, and mathematical skills in children. *Learning and Individual Differences*, 21, 133-137.
- American Educational and Research Association, American Psychological Association and National Council on Measurement in Education (2002). *Standards for educational and psychological testing*. Washington, DC: Psychological Association.
- Andersson, U. (2008). Working memory as a predictor of written arithmetical skills in children: The importance of central executive functions. *British Journal of Educational Psychology*, 78(2), 181-203.

- Apter, B. J. B. (2012) Do computerised training programmes designed to improve working memory work? *Educational Psychology in Practice: theory, research and practice in educational psychology*, 28(3), 257-272.
- Baddeley, A. (1992). Working memory. *Science*, 225(5044), 556-600.
- Baddeley, A. B. (1996). Exploring the central executive. *The Quarterly Journal of Experimental Psychology*, 49A(1), 5-28.
- Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Science*, 4(11), 417-423.
- Baddeley, A. D. (2006). Working memory: an overview. In S. J. Pickering (Ed.). *Working memory and education*, pp. 3-31. London: Academic Press.
- Baddeley, A. D. (2007). *Working memory, thought and action*. Oxford: University Press.
- Barkley, R. A. (1997). Behavioural inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin*, 121(1), 65-94.
- Barkley, R. A. (1998). Attention-deficit hyperactivity disorder. *Scientific American*, 279 (3), 66- 72.
- Biederman, J., Petty, C. R., Doyle, A. E., Spencer, T., Henderson, C. S., Mar- ion, B., Fried, B., & Faraone, S. V. (2008). Stability of executive function deficits in girls with ADHD: A prospective longitudinal follow up study into adolescence. *Developmental Neuropsychology*, 33(1), 44–61.
- Bilartz, T. D., Bruhn, R. A., & Olson, J. E. (2000). The effect of early music training on child cognitive development. *Journal of Applied Developmental Psychology*, 20(4), 615-636.
- Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology*, 19(3), 273-293.
- Bull, R. & Espy, K.A. (2006). Working memory, executive functioning, and children's mathematics. In S.J. Pickering (Ed), *Working Memory and Education*. Educational Psychology, Academic Press, pp. 94-125.
- Bull, R., Espy Andrews, K., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology*, 33(3), 205–228.
- Burton, C., & Daneman, M. (2007). Compensating for a limited working memory capacity during reading: Evidence from eye movements. *Reading Psychology*, 28, 163-186.
- Cain, K., Oakhill, J., & Bryant, P. (2004). Children's reading comprehension ability: concurrent prediction by working memory, verbal ability, and component skills. *Journal of Educational Psychology*, 96(1), 31-42.
- Cain, K. & Oakhill, J. (2006). Profiles of children with specific reading comprehension difficulties. *British Journal of Educational Psychology*, 76, 683-696.
- Cain, K. (2006). Children's reading comprehension: the role of working memory in normal and impaired development. In S. Pickering (Ed.), *Working memory and education*, pp. 62-91.
- Caretti, B., Borella, E., & De Beni, R. (2007). Does strategic memory training improve the working memory performance of younger and older adults? *Experimental Psychology*, 54(4), 311–320.
- Carroll, D. W. (1994). *Psychology of Language*. California: Brooks/Cole Publishing Company.

- Cartwright, K. B. (2012): Insights from cognitive neuroscience: The importance of executive function for early reading development and education. *Early Education & Development*, 23(1), 24-36.
- Castellanos, X. F., & Tannock, R. (2002). Neuroscience of attention-deficit/hyperactivity disorder: The search for endophenotypes. *Nature Reviews Neuroscience*, 3, 617-628.
- Cefai, C., & Cooper, P. (2010). Students without voices: The unheard accounts of secondary school students with social, emotional and behaviour difficulties. *European Journal of Special Needs Education*, 25(2), 183-198.
- Center on the Developing Child at Harvard University (2011). Building the Brain's "Air Traffic Control" System: How early experiences shape the development of executive function: working paper No.11. <http://www.developingchild.harvard.edu>
- Chein, J. & Morrison, A. (2010). Expanding the mind's workspace: training and transfer effects with a complex working memory span task. *Psychonomic Bulletin & Review*, 17(2), 193-199.
- Cherkes-Julkowski, M., Sharp, S & Stolzenberg, J. (1997). *Rethinking attention deficit disorders*. USA: Brookline Books.
- Chinn, S. (2004). *The trouble with maths*. London: RoutledgeFalmer.
- Clark, R., Nguyen, F., & Sweller, J. (2006). *Efficiency in Learning: Evidence-Based Guidelines to Manage Cognitive Load*. San Fransisco: John Wiley & Sons, Inc.
- Cogmed training, Cogmed Working Memory Training, Sweden. Pearson Assessment.
- Conway, A. R. A., & Getz, S. J. (2012). Cognitive ability: Does working memory training enhance intelligence? *Current Biology*, 20(8), R362-R364.
- Cowan, N. (2005). *Working memory capacity*. New York and Hove: Psychology Press.
- D'Amico, A. (2006). Training of working memory for preventing mathematical difficulties. *Etá Evolutiva*, 83, 90-99.
- Dahlin, Erica., Bäckman, L., Neely Stigsdotter, A., & Nyberg, L. (2009). Training of the executive component of working memory: Subcortical areas mediate transfer effects. *Restorative Neurology and Neuroscience*, 27, 405-419.
- Das, J. R., & Naglieri, J. A. (1995). Individual differences in cognitive processes of planning: A personality variable? *Psychological Record*, 00332933, 45(3), 1-13.
- de Jong, P. T. (2006). Understanding normal and impaired reading development: A working memory perspective. I S. Pickering (Ed.), *Working memory and education*, pp. 33-60. London: Elsevier Inc.
- Dehaene, S. (2004). Evolution of human cortical circuits for reading and arithmetic: "The neuronal recycling" hypothesis. In S. Dehaene, J. R. Duhamel, M. Hauser & G. Rizzolatti (Eds.), *From monkey brain to human brain*. Cambridge, Massachusetts: MIT Press.
- Dehene, S. (2009). *Reading in the brain: the science and evolution of a human invention*. United States of America: Penguin Books Ltd.
- Dehn, M. J. (2008). Working memory and academic learning: Assessment and intervention. New Jersey: John Wiley & Sons.

- DeStefano, D., & LeFevre, J-A. (2004). The role of working memory in mental arithmetic. *European Journal of Cognitive Psychology*, 16(3), 353-386.
- Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4–12 years old. *Science*, 333(6045), 959–964. doi:10.1126/science.1204529.
- DSM-IV. (1994). *Diagnostic and statistical manual of mental disorders* (4th ed.). Washington, DC: American Psychiatric Association.
- Duff, S. C., & Logie, R. H. (2001). Processing and storage in working memory span. *The Quarterly Journal of Experimental Psychology*, 54A(1), 31-48.
- Dufva, M., Niemi, P., & Voeten, M. J. M. (2001). The role of phonological memory, word recognition, and comprehension skills in reading development: from preschool to grade 2. *Reading and Writing*, 14, 91-117.
- DuPaul, G. J., Eckert, T. L., & McGoey, K.E. (1997). Interventions for students with attention-deficit/hyperactivity disorder: One size does not fit all. *School Psychology Review*, 26, 369-381.
- Ehrenstein, A., Schweickert, R., Choi, S., & Proctor, R., W. (1997). Scheduling processes in working memory: Instructions control the order of memory search and mental arithmetic. *The Quarterly Journal of Experimental Psychology*, 50A(4), 766-802.
- Ek, U., Westerlund, J., Holmberg, K., & K. Fernell, E. (2010). Academic performance of adolescents with ADHD and other behavioural and learning problems — a population-based longitudinal study. *Foundation Acta Paediatrica*, 100, 402-406.
- Ek, U., Westerlund, J., & Fernell, E. (2013). General versus executive cognitive ability in pupils with ADHD and with milder attention problems. *Neuropsychiatric Disease and Treatment*, 9, 1-6.
- Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General*, 128 (3), 309-331.
- Ericsson, A. K., & Kintsch, W. (1995). Long-term working memory. *Psychological Review*, 102(2), 211–245.
- Fayol, M., Abdi, H. & Gombert, J-E. (1987). Arithmetic problems formulation and working memory Load. *Cognition and Instruction*, 4(3), 187–202.
- Gathercole, S., & Pickering, S. (2001). Working memory deficits in children with special educational needs. *British Journal of Special Education*, 28(2), 89-97.
- Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. (2004a). Working memory skills and educational attainment: Evidence from National Curriculum assessments at 7 and 14 years of age. *Allied Cognitive Psychology*, 18, 1-16.
- Gathercole, S. E. Pickering, S. J. Ambridge, B., & Wearing, H. (2004b). The structure of working memory from 4 to 15 years of age. *Developmental Psychology*, 40, 177-190.
- Gathercole, S. E., Lamont, E., & Alloway, T. P. (2006). Working memory in the classroom. In S. Pickering (Ed.), *Working memory and education*, pp. 219–240. USA: Academic Press.
- Gathercole, S. E., Durling, E., Evans, M. Jeffock, S., & Stone, S. (2008). Working memory abilities and children’s performance in laboratory ana-

- logues of classroom activities. *Applied Cognitive Psychology*, 22, 1019-1037.
- Gathercole, S., & Alloway, T. P. (2008). *Working memory and learning*. London: SAGE Publication Ltd.
- Geary, D. C. (2011). Cognitive predictors of achievement growth in mathematics: A 5-year longitudinal study. *Developmental Psychology*, 47(6), 1539-1552.
- Gersten, R., Jordan, N. C., & Flojo, J. R. (2005). Early identification and interventions for students with mathematics difficulties. *Journal of Learning Disabilities*, 38(4), 293-394.
- Gibson, B. S., Gondoli, D. M., Johnson, A. C., Steeger, C. M., & Morrissey, R. A. (2012). The future promise of Cogmed training. *Journal of Applied Research in Memory and Cognition*, 1, 214-216.
- Gillham, B., & Hesse, K. (2001). *Basic number screening test*. Great Britain: Hodder and Stoughton Educational.
- Goldstein, S., & Naglieri, J. (2008). The school neuropsychology of ADHD: Theory and assessment, and intervention. *Psychology in the Schools*, 45(9), 859-874.
- Goswami, U. (2008a). Principles of learning, implications for teaching: A cognitive neuroscience perspective. *Journal of Philosophy of Education*, 42(3-4), 381-399.
- Goswami, U. (2008b). *Cognitive development. The learning brain*. UK and USA, New York: Psychology Press.
- Greene, (2003, 2009). *Explosiva barn*. Stockholm: Cura Bokförlag och Utbildning AB.
- Gropper, R. J., & Tannock, R. (2009). A pilot study of working memory and academic achievement in college student with ADHD. *Journal of Attention Disorders*, 12(6), 574-581.
- Halperin, J. M., & Healey, D. M. (2011). The influences of environmental enrichment, cognitive enhancement, and physical exercise on brain development: Can we alter the developmental trajectories of ADHD? *Neuroscience and Biobehavioral Reviews*, 35, 621-634.
- Hardy, K K, Willard, VW, & Bonner, M J. (2011). Computerized cognitive training in survivors of childhood cancer: a pilot study, *Journal of Pediatric Oncology Nurses*, 28(1), 27-33.
- Haskell, S.H. (2000). The determinants of arithmetic skills in young children: Some observations. *European Child & Adolescent Psychiatry*, 9, II/77-II/86.
- Hattie, J. (2009). *Visible learning. A synthesis of over 800 meta-analyses relating to achievement*. New York: Routledge.
- Heiervang, E., & Hugdahl, K. (2003). Impaired visual attention in children with dyslexia. *Journal of Learning Disabilities*, 36(1), 68-73.
- Hempel, A., Giesel, F. L., Nohazarahit, M., Caraballo, G., Amann, M., Meyer, H., et al. (2004). Plasticity of cortical activation related to working memory during training. *American Journal of Psychiatry*, 161(4), 745-747.
- Henricsson, L., & Rydell, A-M. (2004). Elementary school children with behavior problems: Teacher-child relations and self-perception. A prospective study. *Merrill-Palmer Quarterly*, 50(2), 111-138.
- Hinshaw, S. P. (2002). Preadolescent girls with attention-deficits/hyperactivity disorder: Background characteristics, comorbidity,

- cognitive and social functioning, and parenting practices. *Journal of Consulting and Clinical Psychology*, 70, 1086-1098.
- Holmes, J., & Adams, W. (2006). Working memory and children's mathematical skills: Implications for mathematical development and mathematics curricula. *Educational Psychology*, 26(3), 339-366.
- Holmes, J., Gathercole, S. E., & Dunning, D. L. (2009). Adaptive training leads to sustained enhancement of poor working memory in children. *Developmental Science*, <http://dx.doi.org/10.1111/j.1467-7687.200900848.x>
- Holmes, J., Gathercole, S. E., Place, M., Dunning, D. L., Hilton, K. A., & Elliott, J. G. (2010). Working memory deficits can be overcome: Impacts of training and medication on working memory in children with ADHD. *Applied Cognitive Psychology*, 24, 827-836.
- Hulme, C., & Snowling, M. J. (2009). *Developmental disorders of language learning and cognition*. UK: Wiley- Blackwell.
- Hulme, C., & Melby-Lervåg, M. (2012) Current evidence does not support the claims made for CogMed working memory training. *Journal of Applied Research in Memory and Cognition*, 1, 197-200.
- Iuculano, T., Moro, R., & Butterworth, B. (2011). Updating working memory and arithmetical attainment in school. *Learning and Individual Differences*, 21, 655-661
- Ingvar, M. (2007). *Hjärnbarkens funktion*. In K. Österberg (Ed.), *Hjärnan*. Stockholm: Karolinska Institutet, University press.
- Jaeggi, S. M., Buschkuhl, M., Jonides, J., & Shah, P. (2012). Cogmed and working memory training – current challenges and the search for underlying mechanisms. *Journal of Applied Research in Memory and Cognition*, 1(3), 211-213.
- Jaušovec, N., & Jaušovec, K. (2012). Working memory training: Improving intelligence – changing brain activity. *Brain and Cognition*, 79, 96-106.
- Jiménez, J. E., Siegel, L. O'Shanahan, I., & Ford, L. (2009). The relative roles of IQ and cognitive processes in reading disability, *Educational Psychology*, 29(1), 27-43.
- Johansson, B., & Tornmalm, M. (2012). Working memory training for patient with acquired brain injury: effects in daily life. *Scandinavian Journal of Occupational Therapy*, 19, 176-183.
- Jolles, D.D., Grol, M. J., Van Buchem, M. A., Rombouts, S. A.R.B., & Crone, E. A. (2010). Practice effects in the brain: Changes in cerebral activation after working memory practice depend on task demands. *NeuroImage*, 52, 658-668.
- Kane, M. J., Brown, L. H., Mc Vay, J. C., Silvia, P. J., Myin-Germeys, I., & Kwapil, T. R. (2007). For whom the mind wanders, and when. *Psychological Science*, 18(7), 614-621.
- Kazdin, A. E. (1998). Conduct disorder. In R.J. Morris and T.R. Kratochwill (Eds.), *The practice of child therapy* (3rd ed.), pp. 199-230). Boston: Allyn Bacon.
- Keeler, M. L., & Swanson, H. L. (2001). Does strategy knowledge influence working memory in children with mathematical disabilities? *Journal of Learning Disabilities*, 34(5), 418-435.
- Klingberg, T., Forssberg, H., & Westerberg, H. (2002) Training of Working Memory in Children with ADHD. *Journal of Clinical and Experimental Neuropsychology*, 24(6), 781-791.
- Klingberg, T., Fernell, E., Olesen, P. J, Johnson, M., Gustafsson, P., Dahlström, K., et al. (2005). Computerized training of working memory in

- children with ADHD - a randomized controlled trial. *Journal of the American Academy of Child & Adolescent Psychiatry*, 44(2), 177–186.
- Klingberg, T. (2007). Den översvämmade hjärnan. Stockholm: Natur och Kultur.
- Knivsberg, A-M., Reichelt, K-L., & Nødland, M. (1999). Comorbidity, or co-existence, between dyslexia and attention deficit hyperactivity disorder. *British Journal of Special Education*, 26(1), 42- 47.
- Krumm, S., Ziegler, M., & Buehner, M. (2008). Reasoning and working memory as predictors of school grades. *Learning and Individual Differences*, 18, 248-257.
- Lagercrantz, H., & Olson, L. (2007). *Fostrets och barnets hjärna*. In K. Österberg (Ed.), *Hjärnan*. Stockholm: Karolinska Institutet, University Press.
- Lee, Y., Lu, M., & Ko, H. (2007). Effects of skill training on working memory capacity. *Learning and Instruction*, 17, 336-344.
- LeFevre, J-A., & Bisanz, J. (1987). Cognitive Arithmetic: Evidence for the Development of Automaticity. Paper presented at the Biennial Meeting of the Society for Research in Child Development (Baltimore, April, 1987).
- Lemaire, P., Abdi, H., & Fayol, M. (1996). The role of working memory resources in simple cognitive arithmetic. *European Journal of Cognitive Psychology*, 8, 73-105.
- Lepola, J., Niemi, P., Kuikka, M., & Hannula, M. M. (2005). Cognitive-linguistic skills and motivation as longitudinal predictors of reading and arithmetic achievement: A follow up study from kindergarten to grade 2. *International Journal of Educational Research* 43, 250-271.
- Lezak, M. (1995). *Neuropsychological Assessment*. New York: Oxford University Press.
- Light, S. N., Coan, J. A., Zahn-Waxler, C., Frye, C., Goldsmith, H. H., & Davidson, R. J. (2009). Empathy is associated with dynamic change in prefrontal brain electrical activity during positive emotion in children. *Child Development, Volume 80*(4), 1210–1231.
- Locuniak, M. N., & Jordan, N. C. (2008). Using kindergarten number sense to predict calculation fluency in second grade. *Journal of Learning Disabilities*, 4, (5), 451–459.
- Logan, G. D. (1997). Automaticity and reading: Perspectives from the instance theory of automatization. *Reading & Writing Quarterly*, 13(2), 123-147.
- Logie, R. (2012). Cognitive training: Strategies and the multicomponent cognitive system. *Journal of Applied Research in Memory and Cognition*, 1(3), 206-207.
- Løhaugen, G. C. C., Antonsen, I., Håberg, A., Gramstad, A., Vik, T. Brubakk, A-M. et al. (2011). Computerized working memory training improves function in adolescents born at extremely low birth weight. *The Journal of Pediatrics*, 158, 555-561.
- Loosli, S.V., Buschkuehl, M., Perrig, W.J., & Jaeggi, S.M. (2012). Working memory training improves reading processes in typically developing children. *Child Neuropsychology*, 18(1), 62-78.
- Lundberg, I., & Sterner, G. (2006). Reading, arithmetic, and task orientation – How are they related? *Annals of Dyslexia*, 56(2), 361–377.

- Lyttinen, S., & Lehto, J. E. (1998). Hierarchy rating as a measure of text macroprocessing: relationship with working memory and school achievement. *Educational Psychology, 18*(2), 157-169
- Martel, M. M. (2009). Research review: A new perspective on attention-deficit/hyperactivity disorder: emotion dysregulation and trait models. *Journal of Child Psychology and Psychiatry, 50*(9), 1042-1051.
- Masten, A. S. et al. (2012). Executive function skills and school success in young children experiencing homelessness. *Educational Researcher, 41*(9), 375-384.
- Mayes, S. D., & Calhoun, S. L. (2006). Frequency of reading, math, and writing disabilities in children with clinical disorders. *Learning and Individual Differences, 16*, 15-157.
- Mayes, S. D., Calhoun, S. L., & Crowell, E. W. (2000). Learning Disabilities and ADHD: Overlapping Disorders. *Journal of Learning Disabilities, 33*(5), 417-425.
- McLeod, J. M., Uemara, R., & Rohrman, S. (2012). Adolescent mental health, behavior problems, and academic achievement. *Journal of Health and Social Behavior, 53*(4), 482-497.
- McNab, F., Varrone, A., Farde, L. Jucaite, A., Bystritsky, P., Forsberg, H. et al. (2009). Changes in cortical dopamine D1 receptor binding associated with cognitive training. *Science, 323* (6), 799-801.
- McMillan, J. H. (2004). *Educational research*. USA: Pearson Education, Inc.
- Melby-Lervåg, M. (2012). The relative predictive contribution and causal role of phoneme awareness, rhyme awareness and verbal short-term memory in reading skills: A review. *Scandinavian Journal of Educational Research, 56*(4), 363-380.
- Melby-Lervåg, M., Lyster, H. S-A., & Hulme, C. (2012). Phonological skills and their role in learning to read: A meta-analytic review. *Phonological Bulletin, 138*(2), 322-352.
- Mertens, D. M. (2005). *Research methods in education and psychology. Integrating diversity with quantitative & qualitative approaches*. London: Sage Publications.
- Mezzacappa, E., & Buckner, J. C. (2010). Working memory training for children with attention problems or hyperactivity: a school-based pilot study. *School Mental Health*. DOI 10.1007/s12310-010-9030-9.
- Miller, M., & Hinshaw, S. P. (2010). Does childhood executive function predict adolescent functional outcomes in girls with ADHD? *Journal of Abnormal Child Psychology, 38*, 315-326.
- Milne, D. (2005). *Teaching the brain to read*. Australia: Smart Kids Ltd.
- Miner, M., & Shah, P. (2006). Sources of working memory deficits in children and possibilities for remediation. I S. J. Pickering (Ed.), *Working memory and education*, pp. 273-307. London: Elsevier Inc.
- Morrison, A. B., & Chein, J. M. (2011). Does working memory work? The promise and challenges of enhancing cognition by training working memory. *Psychonomic Bulletin & Review, 18*, 46-60.
- Morrison, A. B., & Chein, J. M. (2012). The controversy over Cogmed. *Journal of Applied Research in memory and Cognition, 1*, 208-210.
- Naglieri, J. A., & Johnson, D. (2000). Effectiveness of a cognitive strategy intervention in improving arithmetic computation based on the PASS theory. *Journal of Learning Disabilities, 33*(6), 591-597.

- Nation, K. (2006). Children's reading comprehension difficulties. In M. J. Snowling & C. Hulme (Eds.), *The Science of reading*, 248-271. UK, Oxford: Blackwell Publishing Ltd.
- Niaz, M., & Logie, R. H. (1993). Working memory, mental capacity and science education: Towards an understanding of the 'working memory overload hypothesis'. *Oxford Review of Education*, 19(4), 511-525.
- Niemi, P., Nurmi, J.-E., Lyyra, A.-L., Lerkkanen, M.-J., Lepola, J., Poskiparta, E. et al. (2011). Task avoidance, number skills and parental learning difficulties as predictors of poor response to instruction. *Journal of Learning Disabilities*, 44, 459-471.
- Nigg, J. T. (2006). *What causes ADHD?* New York: Guilford Press.
- Norrelgen, F. (2002). *Development of Working memory, Speech perception and Auditory Temporal Resolution in Children with attention deficit Hyperactivity Disorder and Language Impairment*. Stockholm: Repro print AB. Thesis. Department of Woman and Child Health Neuropediatric Research Unit, Karolinska Institutet.
- Nyberg, L., & Bäckman, L. (2007). *Det episodiska minnet*. In K. Österberg (Ed.), *Hjärnan*. Stockholm: Karolinska Institutet, University press.
- Olesen, P. J., Westerberg, H., & Klingberg, T. (2004). Increased prefrontal and parietal activity after training of working memory. *Nature Neuroscience*, 7(1), 75-79.
- Paas, F., van Gog, T. & Sweller, J. (2010). Cognitive Load Theory: New conceptualizations, specifications, and integrated research perspectives. *Educational Psychology Review*, 22, 115-121.
- Passolunghi, C. M., & Siegel, L. S. (2004). Working memory and access to numerical information in children with disability in mathematics. *Journal of Experimental Child Psychology*, 88, 348-369.
- Pickering, S., & Gathercole, S. (2004). Distinctive working memory profiles in children with special educational needs. *Educational Psychology*, 24 (3).
- PIRLS 2001. (2003) *PIRLS Technical Report*. USA: International Study Center, Lynch School of Education, Boston College.
- Poskiparta, E., Niemi, P., Lepola, J., Ahtola, A., & Laine, P. (2003). Motivational-emotional vulnerability and difficulties in learning to read and spell. *British Journal of Educational Psychology*, 73, 187-206.
- Raven, J.C. (1995). *Coloured Progressive Matrices*. Oxford, United Kingdom: Oxford Psychologists Press.
- Reuhkala, M. (2001). Mathematical skills in ninth-graders: Relationship with visuo-spatial abilities and working memory. *Educational Psychology*, 21(4) 387-398.
- Roodenrys, S., Koloski, N., & Grainger, J. (2001). Working memory function in attention deficit hyperactivity disorder and reading disabled children. *British Journal of Developmental Psychology*, 19, 325-337.
- Rose, T. L., & Rouhani, P. (2012). Influence of verbal working memory depends on vocabulary: oral reading fluency in adolescents with dyslexia. *Mind, Brain, and Education*, 6(1), 1-9.
- Roughan, L., & Hadwin, J. A. (2011). The impact of working memory training in young people with social, emotional and behavioural difficulties. *Learning and Individual Differences* 21, 759-764.
- Rutter, M., Caspi, A., Fergusson, D., Horwood, L.J., Goodman, R., Maughan, B., et al. (2004). Sex differences in developmental reading disability: new

- findings from 4 epidemiological studies. *Journal of the American Medical Association*, 291(16), 2007-2012.
- SAS Institute Inc. (2004). *SAS/STAT® 9.1 User's Guide*. Cary, NC: SAS Institute Inc.
- SBU (Swedish Council on Health Technology Assessment). (2009). Datorstödd träning för barn med ADHD. *SBU-Alert Rapport*, 2009-05.
- Seigneuric, A., & Ehrlich, M-F. (2005). Contribution of working memory capacity to children's reading comprehension: A longitudinal investigation. *Reading and Writing*, 18, 617-656.
- Shadish, W.R., Cook, T. D., & Campbell, D. T. (2002). *Experimental and quasi-experimental designs for generalized causal inference*. USA: Houghton Mifflin Company.
- Shah, P. & Miyake, A. (1996). The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *Journal of Experimental Psychology: General*, 125(1), 4-27.
- Shah, P., Buschkuhl, M., Jaeggi, S., & Jonides, J. (2012). Cognitive training for ADHD: The importance of individual differences. *Journal of Applied Research in Memory and Cognition*, 1, 204-205.
- Shaywitz, S. E., & Shaywitz, B. A. (2004). Reading disability and the brain. *Educational Leadership*, 61(6), 6-11.
- Shipstead, Z., Redick, T. S., & Engle, R. W. (2012). Is working memory training effective? *American Psychological Association*, 138, (4), 628-654.
- Siegel, L., & Ryan, E. (1989). The development of working memory in normally achieving and subtypes of learning disabled children. *Child Development*, 60, 973-980.
- Smith-Spark, J. H., & Fisk, J. E. (2007). Working memory functioning in developmental dyslexia. *Memory*, 15(1), 34-56.
- Snow, C., Burns, M. & Griffin, P. (1998). *Preventing reading difficulties in young children*. Washington, DC: National Academy Press.
- Snow, C. E., & Polsell Sweet, A. (2003). Reading for comprehension. In A. Polsell Sweet & C. E. Snow (Eds.), *Rethinking reading comprehension*, pp. 1-11. New York: The Guilford Press.
- Snow, C., Griffin, P., & Burns, M. (2005). *Knowledge to support the teaching of reading*. San Francisco, USA: John Wiley & Sons, Inc.
- Snowling, M. (2000/2006). *Dyslexia*. Oxford: Basil Blackwell.
- Sonuga-Barke, E. J. S., Oades, R. D., Psychogiou, L., Chen, W., Franke, B., Buitelaar, J. et al. (2009). Dopamine and serotonin transporter genotypes moderate sensitivity to maternal expressed emotion: the case of conduct and emotional problems in attention deficit/hyperactivity disorder. *Journal of Child Psychology and Psychiatry*, 50(9), 1052-1063.
- St Clair-Thompson, H. L., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *The Quarterly Journal of Experimental Psychology*, 59(4), 745-759.
- St Clair-Thompson, H., Stevens, R., Hunt, A., & Bolder, E. (2010). Improving children's working memory and classroom performance. *Educational Psychology*, 30(2), 203-219.
- St Clair-Thompson, H. L. (2011). Executive functions and working memory behaviours in children with a poor working memory. *Learning and Individual Difference*, 21, 409-414.
- Stanovich, K. E. (2000). *Progress in understanding reading*. New York: Guilford Press.

- Swanson, H. L., & Ramalgia, J. M. (1992). The relationship between phonological codes on memory and spelling tasks for student with and without learning disabilities. *Journal of Learning Disabilities*, 25(6), 396-407.
- Swanson, H.L., & Berninger, V.W. (1996). Individual differences in children's working memory and writing skill. *Journal of Experimental Child Psychology*, 63, 358-385.
- Swanson, H. L., & Siegel, L. (2001). Learning disabilities as a working memory deficit. *Issues in Education*, 7(1), 1-48.
- Swanson, H. L. (2006). Cognitive processes that underlie mathematical precociousness in young children. *Journal of Experimental Child Psychology*, 93, 239-264.
- Swanson, H. L., Howard, C.B., & Sáez, L. (2006). Do different components of working memory underlie different subgroups of reading disabilities? *Journal of Learning Disabilities*, 39(3), 252-269.
- Swanson, H. L. (2011). Working memory, attention, and mathematical problem solving: A longitudinal study of elementary school children. *Journal of Educational Psychology*, 103(4), 821-837.
- Takeuchi, H., Sekiguchi, A., Taki, Y., Yokoyama, S., Yomogida, Y., Komuro, N. et al. (2010). Training of working memory impacts structural connectivity. *The Journal of Neuroscience*, 30(9), 3297-3303.
- Tannock, R. & Martinusson, R. (2001). Reconceptualizing ADHD. *Educational Leadership*, 59(3), 20-25.
- Thevenot, C., Barrouillet, P., & Fayol, M. (2001). Algorithmic solution of arithmetic problems and operands-answer associations in long-term memory. *Quarterly Journal of Experimental Psychology, Section A*, 54(2), 599-611.
- Tillman, C., Eninger, L., Forssman, L., & Bohlin, G. (2011): The relation between working memory components and ADHD symptoms from a developmental perspective. *Developmental Neuropsychology*, 36(2), 181-198.
- Timperley, H. (2011). *Realizing the power of professional learning*. England: Open University press.
- Trochim, W., & Donnelly, J. (2006). *The research methods knowledge base*. USA: Atomic Dog.
- Vellutino, F.R. (2003). Individual differences as sources of variability in reading comprehension in elementary school children. In A. P. Polzella Sweet & C. E. Snow (Eds.), *Rethinking reading comprehension*, pp 51-81. New York: The Guilford Press.
- Verhoeven, L. Reitsma, P. & Siegel, L. (2011). Cognitive and linguistic factors in reading comprehension. *Reading and Writing*, 24, 387-394.
- Verhoeven, L., Schnotz, W, & Paas, F. (2009). Cognitive load in interactive knowledge construction. *Learning and Instruction*, 19, 369-375.
- Vredeveldt, A., Hitch, G. J., & Baddeley, A. D. (2011). Eyeclosure helps memory by reducing cognitive load and enhancing visualisation. *Memory and Cognition*, 39, 1253-1263.
- Vucovic, R. K. (2012). Mathematics difficulty with and without reading difficulty: Findings and implications from a four-year longitudinal study. *Exceptional children*, 78(3), 280-300.
- Vucovic, R. K., Lesaux, N. K., & Siegel, L. S. (2010). The mathematics skill of children with reading difficulties. *Learning and Individual Differences*, 20, 639-643.
- Walberg, H.J., & Tsai, S-L. (1983). Matthew effects in education. *Educational Research Quarterly*, 20(3) 359-373.

- Westerberg, H., & Klingberg, T. (2007). Changes in cortical activity after training of working memory – a single-subject analysis. *Psychology & Behaviour*, 92, 186-192.
- Willcutt, E. G., Doyle, A. E., Nigg, J. T., Faraone, S. V., & Pennington, B. F. (2005). Validity of the executive function theory of attention deficit/hyperactivity disorder: A meta-analytic review. *Biological Psychiatry*, 57, 1336–1346.
- Wilson, K. M., & Swanson, H. L. (2001). Are mathematics disabilities due to a domain-general or a domain-specific working memory deficit? *Journal of Learning Disabilities*, 34(3), 237-249.
- Witt, M. (2011). School based working memory training: Preliminary finding of improvement in children's mathematical performance. *Advances in Cognitive Psychology*, 7, 7-15.
- Worden, J. M., Hinton, C., & Fischer, K. W. (2011). What does the brain have to do with learning? *Kappan Magazine*, 8, 8-13.
- Wählstedt, C. (2009). *Specifying the heterogeneity in children with adhd. Symptom domains, neuropsychological processes, and comorbidity*. Uppsala: the Faculty of Social Sciences 47. Dissertation.

