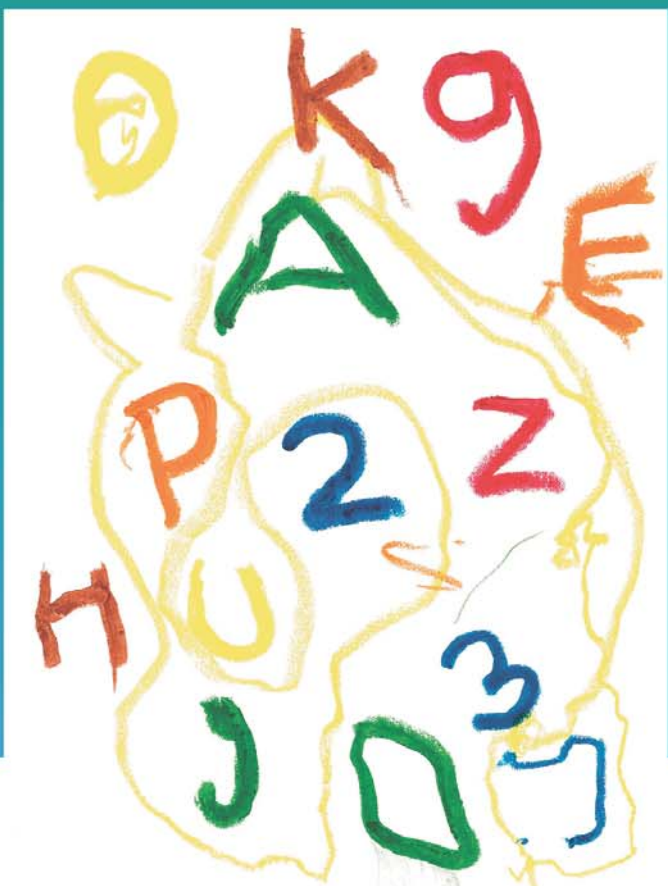
Tuire Koponen

Calculation and Language

Diagnostic and Intervention Studies



JYVÄSKYLÄ STUDIES IN EDUCATION, PSYCHOLOGY AND SOCIAL RESEARCH 340

Tuire Koponen

Calculation and Language

Diagnostic and Intervention Studies

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UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 2008

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ABSTRACT

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The present thesis concerned the impact of language abilities on children's acquisition of numerical skills, in particular single-digit calculation. To better understand the connection between language and numerical skills, three different approaches were used. First, SLI children's numerical skills were compared to those of their educational age-peers and language controls. In addition, the role of cognitive factors (language abilities and non-verbal reasoning) in explaining the variance in these children's numerical skills was examined. Second, a single-case intervention study was used to further examine whether retrieval difficulties in language (i.e. naming speed) are related to learning to retrieve arithmetical facts from long-term memory: Two SLI children with different abilities in naming speed received an arithmetical intervention and differences in their intervention outcomes were related to their different language profiles. Similarly, using a single case approach, it was investigated whether a child with severe naming speed difficulties but intact numerical comprehension would be able to learn arithmetical facts if he is taught to use his conceptual knowledge of numbers and arithmetical operations. Finally, in the fourth study calculation skills were investigated among an unselected sample of 4th graders in order to see whether the cognitive factors earlier found to be related to calculation skill in a clinical group of children with SLI would also be related to the normal development of fluent calculation skill and its co-variation with reading. The results suggest that children with language impairment seem to be in increased risk to having difficulties in several areas of numerical skills. Only one third of the children with SLI showed previously proposed a poor verbal and good non-verbal number skill profile. The results indicated that children with specific language impairment can not be treated as uniform group from the perspective of numerical skills, instead careful assessment is needed. However, most of children with SLI seem to have difficulties in achieving fluent calculation skill despite several years of practice. Moreover, it is suggested that there are at least two cognitive abilities which could work as early indicators of increasing risk for having calculation difficulties as well as have a relation to the development of calculation skill in general: ability to learn and recite verbal number word sequences as well as ability to fluently access long-term memory in order to retrieve verbal labels for visual stimuli (naming speed). Finally, it is suggested that explicit strategy training by integrating conceptual knowledge of numbers and arithmetical operations with declarative and procedural knowledge of arithmetic could be a fruitful intervention approach in order to improve slow and inaccurate calculation, especially when children are weak in the use of counting procedures and have difficulties in direct memory retrieval but show intact number comprehension.

Key words: calculation, language learning impairments, counting, naming speed

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I Koponen, T., Mononen, R., Räsänen, P., & Ahonen, T. (2006). Basic Numeracy in Children with Specific Language Impairment: Heterogeneity and Connections to Language. *Journal of Speech, Language, and Hearing Research, 46*, 1–16.

II Koponen, T., Aro, T., Räsänen, P., & Ahonen, T. (2007). Language-based retrieval difficulties in arithmetic: A single case intervention study comparing two children with SLI. *Educational and Child Psychology, 24*, 98–107.

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IV Koponen, T., Aunola., K., Ahonen, T., & Nurmi., J-E. (2007). Cognitive predictors of single-digit and procedural calculation and their covariation with reading skill. *Journal of Experimental Child Psychology, 97,* 220–241.

1 INTRODUCTION

Achieving a fluent calculation skill during the first three years at school is an important cornerstone for later mathematics. It is important to help the children to achieve fluent calculation skill so that they can manage everyday tasks as well as learn and solve more complicated mathematical problems. Direct memory retrieval has been shown to need fewer working memory resources than other non-retrieval strategies, and thus frequent and efficient use of the fact retrieval strategy might reduce the requirements of the arithmetic task and leave more working resources free for other uses (Imbo & Vandierendonck, 2007). This spare capacity is needed, for example, in monitoring and solving more complex mathematical tasks. Thus, children with fluent single-digit calculation skill are in better position to acquire general computational skills than children with poor calculation fluency.

Although the amount of research and interest in calculation and mathematics has grown during the last few decades, the factors underlying the acquisition of fluent calculation skill remain unclear and the importance of achieving fluent calculation skill continues to be underestimated. These are obstacles to the early identification and provision of educational support for children with calculation difficulties. Too often children are already in the 4th or 5th grade or even at high-school before it becomes evident that they have difficulties in mastering basic arithmetical facts, such as 5+4 or 4x8. By that time they have experienced a lot of failures when trying to solve more complicated mathematical problems.

Fluent calculation skill is one of the basic numerical skills which children with language impairment have difficulty acquiring (Fazio, 1996, 1999). Similarly, language-based reading difficulties have been found to co-occur with arithmetical difficulties (e.g., Ackerman & Dykman, 1995; Räsänen & Ahonen, 1995). These findings raise the question, whether calculation and reading skills share underlying cognitive processes that are language-based. However, the connections between fluent calculation skill and language or calculation and reading are not known and some researchers have proposed that numerical bases rather than other cognitive domains are central in arithmetical fact retrieval deficit (Butterworth, 1999; Jordan, Hanich & Kaplan, 2003a, 2003b; Landerl, Bevan, & Butterworth, 2004). However, although not all children with language impairment or reading difficulties show difficulties in calculation, the rates of co-occurrence (e.g., Badian, 1999; Räsänen & Ahonen, 1995) are too high to be a coincidence. In other words, the possibility of language-based difficulty should also be taken account when examining the cognitive predictors of calculation skill. Thus, theoretically it is interesting to examine further the question whether single-digit calculation is dependent or independent of language abilities. Moreover, for practical reasons, it is important to acquire more knowledge of the relationship between language and calculation in order to identify as early as possible those children who are at risk for calculation difficulties as well as to develop ways of providing them with educational support. Children with specific language impairment have been shown to significantly lag behind their age peers in several number skills, including calculation (Arvedson, 2002; Fazio,1994, 1996, 1999; Tieche Christinat, Conne & Gaillard, 1995), and thus they provide a promising starting point for studies of this kind.

However, there are also indications that, in some numerical tasks, such as number comparison or conceptual knowledge of counting, children with SLI may perform as well as their age peers (Arvedson, 2002; Donlan, 1993; Donlan & Gourlay, 1999; Fazio 1994). This suggest that at least for some basic numerical skills it might be possible to distinguish between verbal and non-verbal number skills (Donlan, 1993; Donlan & Gorlay, 1999). Such a distinction, in turn, could work as a frame to show what specific areas in mathematics need especially to be taken into account when working with children with SLI. However, because previous studies have utilized small sample sizes, and investigated differing age groups, more studies are required to confirm the results. An interesting questions is how well these findings on verbal and non-verbal numerical skills apply to older children who, on the one hand, need to comprehend larger than 2-digit numbers with more complex syntax and, on the other, have had the opportunity to practice counting and simple arithmetic for a longer time.

Previous studies have also found that, even in calculation and approximate magnitude comparison tasks, there are large variations among children with SLI (e.g., Donlan & Gourlay, 1999). Thus, analyses of these within-group differences could help to obtain a better understanding of the relationships between language and calculation. One possible approach is to examine whether some of the children with SLI who have reached a certain level of performance in their numerical skills (e.g., fluent calculation skill and comprehension of multi-digit numbers) differ in their linguistic skills or non-verbal reasoning from those who have not reached the same level despite several years of practice.

Moreover, theoretically based intervention research with carefully diagnosed cases of SLI could provide of value information in developing ways to support the development of calculation skill in children whom normal teaching instructions with textbook-based practice is not enough to provide them with adequate calculation skills. In addition, the results from intervention studies can confirm theories by providing more detailed information on the hypothesised relationship between two abilities, such as the influence of a certain linguistic ability on single digit calculation. This is possible if the participants are carefully matched and provided with focused training, and an adequate pre and post assessment design is used.

Finally, studies with unselected samples are necessary to examine whether the results of the relationship between language and calculation found in clinical samples also apply to larger groups of children. In other words, are the cognitive factors found to be related to calculation difficulties the same as those associated with the general development of calculation skill? Previous studies of reading and calculation have mainly used combined measures of each skill, such as single-digit calculation, procedural calculation and applied problems in mathematics (Geary, Hamson, & Hoard, 2000; Hanich. Jordan, Kaplan, & Dick, 2001; Hecht, Torgesen, Wagner, & Rashotte, 2000; Jordan et al., 2003a), on the one hand, and word-reading accuracy and reading comprehension in reading (Hanich et al., 2001; Hecht et al., 2000; Jordan et al., 2003a,b), on the other. Because the outcome variables in most of the previous studies have consisted of several subcomponents (Geary et al., 2000; Hanich et al., 2001; Hecht et al., 2000; Jordan et al., 2003a,b), it is difficult to interpret what the comorbidity or covariation found in these studies actually implies, as well as what role the variables underlying them play. Moreover, none of the existing studies have included a reading fluency measure as outcome variable, despite the facts that, reading fluency has been found to be a more critical aspect of reading than accuracy in languages with regular orthographies (e.g., Aro & Wimmer, 2003).

The present thesis concerned the impact of language abilities on the acquisition of numerical skills, in particular single-digit calculation. To better understand the connection between language and calculation, three approaches were used: numerical skills in children with SLI were compared with those of language and educational age-peers, two single-case intervention studies were applied in children with SLI, and hypotheses regarding the relationship between language and calculation were tested in an unselected sample of 4th graders.

1.1 Current models of number processing and calculation

Learning to calculate develops gradually. First, when learning to solve simple arithmetic problems children use calculation strategies based on counting, such as finger counting or verbal counting (Ostad, 1999; Siegler & Shrager, 1984; Siegler, 1987). Initially, in addition tasks children count both numbers presented - counting-all procedure (Fuson, 1982; Geary et al., 2000). Later, children shift to counting on from the cardinal value of the first (counting-on first/max) or larger number (counting-on min) presented, which is a more efficient strategy (Geary et al., 2000). Similarly, in subtraction the most frequently used counting-based strategies among elementary school children are counting-all, countingdown (e.g., 5-2, "four, three") and counting-up (e.g., 5-2, "three, four five") (Ostad, 1999). The frequent successful use of counting strategies is assumed to increase memory representations of arithmetical facts and lead to a strategy of retrieving arithmetical facts from long-term memory (Barrouillet & Fayol, 1998; Siegler & Shrager, 1984). In age-appropriate development of arithmetical skill children usually start using fact retrieval as the main strategy by the age of 9 years (Ashcraft & Fierman, 1982; Brauwer, Verguts, & Fias, 2006; Lemair & Siegler, 1995). However, as found in the study by LeFevre (LeFevre, Sadesky, & Bisanz, 1996), even adults use back-up strategies, such as decomposition into simpler memorized facts or counting. There are also differences between operations. There is a consensus that solving multiplication facts relies to a large extent on memory retrieval (e.g., Brauwer, et al., 2006; Dehaene, Piazza, Pinel, & Cohen, 2003; Roussel, Fayol, & Barrouillet, 2002) whereas in subtraction, the use of reconstructive, strategy-based processing is more common than in either addition or multiplication (Seyler, Kirk, & Ashcraft, 2003; Campbell & Xue, 2001; Ostad, 1999). For example, in the study by Ostad (1999) no more than 40 per cent of the back-up strategies in subtraction were replaced by retrieval strategies among typically developing children from grades 1 to 7, whereas Imbo and Vandierendonck (2005) found that second graders reported the use of retrieval strategy in 60% and fourth graders in 81% of all multiplication trials. Addition, in turn, can be seen as a combination of these two operations in that in small additions (sums below 10) fact retrieval is the most frequently used strategy (e.g., Dehaene et al., 2003; LeFevre et al., 1996) whereas, even among adults, the use of back-up strategies is common in large addition problems (sums larger than 10) (Lefevre et al., 1996).

The existing theoretical models of simple arithmetic calculation (Ashcraft, 1987, 1992; Campbell & Graham, 1985; Siegler & Shrager, 1984) and general models of basic number processing including calculation (Campbell & Clark, 1988; Dehaene, 1992; McCloskey, Caramazza, & Basili, 1985) have mainly been built on findings from normal adults or from adults who have lost certain numerical skills after brain injury and in the case of calculation they mainly focused on modeling fact retrieval. The exception is Siegler's distribution of associations model, which not focuses only on fact retrieval but also accounts for the diversity of children's strategies in addition (Siegler & Shrager, 1984; Siegler & Jenkins, 1989), subtraction (Siegler, 1987) and multiplication (Siegler, 1988).

1.1.1 Theoretical models of simple arithmetic calculation

Models of simple arithmetic calculation (Ashcraft, 1987, 1992; Campbell & Graham, 1985; Siegler & Shrager, 1984) share several basic assumptions and at the same time differ in emphasis and focus (for a review see Ashcraft, 1992). According to Ashcraft, basic addition and multiplication facts are represented in the memory in an organized network of information accessed and retrieved from the network via a process of spreading activation. The strength with which nodes were stored and interconnected is assumed to be a function of frequency of occurrence and practice.

Campbell (1987; Campbell & Craham, 1985) focused on interference as a critical part of the retrieval process. According to Campbell individual multiplication problems activate a network substructure of candidate responses. The level of activation of false candidates affects both the probability of an error and the speed of a correct response. In error priming, response by a prior retrieval promotes errors and slows the correct reaction time of subsequent problems that have a relatively high probability of generating that product as an error. According to this interference model the problem-size effect is also due substantially to a process of associative interference (Campbell, 1987). Small problems (sums smaller than 10) are practised more frequently and thus the strength of the association is greater and less susceptible to interference. Moreover, small problems are learned earlier than larger ones, as they have fewer candidate responses to cause interference.

Siegler's distribution of associations model (Siegler & Shrager, 1984), in turns, emphases the importance of a varied learning history of different problems and answers. Siegler proposes that children associate whatever answer they state with whether it is correct or incorrect, and, thus, erroneous solutions also have an effect on memory representations. When children practice simple arithmetic and solve problem correctly, their representations become more "peaked" in that the association between problem and correct answer becomes stronger than that between problem and incorrect answers. In contrast, frequent errors leads to a flat distribution in which associative strength is dispersed among several answers. The probability of retrieving any correct answer to a problem is proportional to associative strength of that answer relative to the total associative strengths of all answers to the problem. Relative to flat distributions, peaked distribution will elicit a higher percentage of the use of fact retrieval. Once retrieved, an answer is stated if its associative strength exceeds a response threshold (confidence criterion). If not, child can again retrieve an answer, or if an allocated number of searches has been exceeded, the child generates an answer by using a back-up strategy.

According to Siegler, three factors seem to influence the peakedness of the each problem representation: difficulty in correctly executing back-up strategies, exposure to each problem and knowledge of related numerical operations. For example, counting-based back-up strategies operate less accurately when solving large than small problems, and thus the distributions of the associations for large problems are less peaked than for small problems.

To overcome some of the limitations identified in his original model (the assumption of fact retrieval as the default strategy, lack of generalization to other problems, lack of explanation as to how children choose between alternative back-up strategies, and absence of knowledge of item difficulty and usefulness of different strategies), Siegler developed a new Adaptive Strategy Choice Model (ASCM) (Siegler & Shipley, 1995). This model extends the previous one by generalizing to choosing among alternative strategies as well as answers. The ASCM model provides specific predictions about four dimensions of strategic change each of which can yield overall improvements in calculation speed and accuracy: which strategy is used, when each strategy is used, how each strategy is executed and how the strategy is chosen. Improvement in calculation skills can be observed and measured as increased accuracy and speed. Such increases may be due to the more frequent use of the retrieval strategy or more frequent use of the counting-on min instead of counting-on max strategy. Moreover, the increases can be due to more a adequate and faster strategy choice as well as more efficient retrieval process or more efficient execution of a back-up strategy.

Siegler's models can also be used as a frame when examining and describing inadequate development of calculation skill. It has been suggested that the development of calculation in children with mathematical difficulties is different from that observed in normal achievers (Ostad, 1999; but see Torbeyns, Verschaffel, & Ghesquière, 2004), being characterized by predominant use of back-up strategies, use of immature back-up strategies, less adaptive strategy choices, inaccurately executed strategies, and a limited degree of change in the use of strategies from year to year through primary school (e.g., Geary & Brown, 1991; Ostad, 1999).

1.1.2 Calculation in general models of number processing

There are at least two important differences in the way single-digit calculation is presented in the general models of number processing. The first concerns the nature of the mental representations of numbers. McCloskey's model proposes modular and Dehaene's and Campbell's models propose a non-modular architecture. According to McCloskey et al. (1985) arithmetical processing operates upon an abstract representation, and is independent of the format used for the presentation of the problem or production of the response. In Dehaene's model (1992) there are three kinds of representations: verbal, visual-arabic and analogical quantity/ magnitude code. However, Dehaene's model also suggests the absence of format-specific influences, claiming that every type of input is first translated into the verbal code before fact retrieval takes place. In contrast, the encoding complex model of Campbell and Clark (1988) assumes that arithmetical fact retrieval is mediated by format-specific representations, and thus, fact retrieval as well as number processing in general, may differ as a function of the presentation format (e.g., auditory, orthographic, visual, motor codes). Another main difference between these models is related to the role of the semantic system in calculation and in other number processes. For example, Dehaene's triple-code model suggests that arithmetical fact retrieval is possible without semantic activation. This is in contrast with McCloskey's model, in which automatic semantic activation is involved in calculation as well as in other number processing. No specific claims about semantic processing in single-digit calculation are made by Campbell.

In the present thesis Dehaene's model of cognitive and neuroanatomical architectures for number processing is described in more detail for the reason that the theoretical framework of this model provides the best approach to understanding the previous findings on calculation and other number difficulties in children with SLI (see Donlan, 1993; Donlan & Gourlay, 1999).

Dehaene (1992; Dehaene & Cohen, 1995) presented a model of cognitive and neuroanatomical architectures for number processing. According to this triple-code model there are three main representations of numbers and depending on the task, three distinct systems of representation may be recruited. The v*isual Arabic code* subserves multidigit operations and parity judgments. *The analogical quantity or magnitude code* subserves semantic knowledge about the numerical quantities needed, for example, in magnitude comparison. The v*erbal code* subserves rote-learned arithmetical facts and counting sequences.

The model suggests that there are two basic routes through which single-digit arithmetical problems can be solved. In the direct route, the arithmetical problem (2x4, two times four) is converted into an internal verbal representation, which is used to complete this word sequence by using rote verbal memory ("two times four, eight"). In the indirect route, the operands are encoded as quantity representations and semantically meaningful manipulations can then be performed on these quantities. Dehaene and Cohen (1997; Dehaene et al., 2003) have proposed that the direct route is the normal route for over-learned calculations such as single-digit multiplication and simple addition, at least in countries where verbal recitation of multiplication and addition tables is used as a teaching method.

According to this model the neuroanatomically important areas in single-digit addition and multiplication are the left-hemispheric perisylvian area and angular gyrus which are important areas in the verbal coding of numbers, and the left cortico-subcortical loop through the basal ganglia and talamus network, which are assumed to be involved in completing a word sequence by using rote verbal memory ("two times four, eight").

1.2 Specific language impairment – SLI

Children with specific language impairment (SLI) are defined as showing significant deficits in one or more areas of language development in the absence of hearing, non-verbal cognitive, neurological deficits or environmental deprivation (Bishop, 1997; Leonard, 1998). However, despite this definition of specific a disorder, SLI is clearly not limited to language but linguistic impairments have shown to co-occur with several non-linguistic deficits, such as motor (for review see, Hill, 2001) and attention deficits (e.g., Bruce, Thernlund & Nettelbladt, 2006). Studies of working memory have also shown deficits both in phonological (Baddeley, 2003; Gatherole & Baddeley, 1989) and visuo-spatial storage (Hoffman & Gillam, 2004) as well as general executive functions (Baddeley, 2003; Hoffman & Gillam, 2004). SLI has been estimated to affect around 7% of children (Tomblin, Records, Xuyang, Smith, & O'Brien, 1997). More boys than girls are affected (Tomblin et al., 1997) and there is a general consensus that genetic factors have a significant role (e.g., Bishop, 2006). The nature of the language difficulties presented varies substantially between individuals, including different combinations of phonological, grammatical, semantic and pragmatic deficits (Bishop, 1997).

There are several hypotheses relating to the deficit underlying SLI. Some of them are general in nature, such as grammatical deficit (e.g., Rice & Oetting, 1993), rate processing difficulties (e.g., Tallal, 1998; Tallal & Piercy, 1974), general processing deficit (e.g., Kail, 1994; Miller, Kail, Leonard, & Tomblin, 2001) or procedural deficit (Ullman & Pierpont, 2005), and some more specific, like phonological working memory deficit (Gathercole and Baddley, 1990).

1.2.1 Basic numerical skills in children with SLI

Only a few studies have been carried out on the mathematical skills of children with specific language impairment (SLI). The main findings to date on the numerical skills of children with SLI are summarized in Table 1. These studies show that children with SLI lag significantly behind their age peers in several tasks in this academic area (Arvedson, 2002; Fazio, 1999; Tieche Christinat, Conne, & Gaillard, 1995). However, there are indications that, in some mathematical tasks, children with SLI may perform as well as their age peers (Arvedson, 2002; Donlan, 1993; Donlan & Gourlay, 1999).

Of the early numerical skills, the development of counting skill has been shown to be clearly delayed in children with language impairment. Arvedson (2002) found that compared to their age peers, 3,5-to 5-year-old children with SLI retrieved shorter sequences of number words. Likewise, Fazio (1994) found that, in counting, the primary difficulty of 4- to 5-year-old children with SLI was remembering and retrieving the words in the correct order. In her follow-up study two years later (Fazio, 1996), she found that, when the children were 6- to 7-years-old, they had difficulties in retrieving the correct sequence of numbers when counting numbers over twenty. At the age of 9 to 10, the same children with SLI recited significantly shorter sequences of numbers compared to their age peers (Fazio, 1999). Tieche Christinat and colleagues (1995) found that in counting three by three from 1 to 21, 9- to 11-year-old SLI children made more errors than their age peers.

TABLE 1 The research carried out between 1993 – 2004 on the different numerical skills of children with SLI compared to their age peers.

			Verbal skills					Non-verbal skills			
Age years	Study	N	Number transcoding	Counting	Enumeration (set sizes 5 or larger	Calculation		Recognition of Arabic numbers	Conceptual Knowledge (cardinality, conservation of number)	Number comparison	Estimation
						Single-digit numbers	Multi-digit numbers				
4 – 5	Arvedson, 2002	19		–	–				+/-		
	Fazio, 1994	20		–	–				+/-		
6 – 7	Donlan, 1993	13	–		–	–			+/-	+/-	
	Fazio, 1996	14	–	–	–	–		+/-			
7 – 8	Donlan & Gourlay, 1999	13						+/-		+/-	
9 – 11	Tieche Christinat et al., 1999	10	–	–		+/-	–				+/-
	Fazio, 1999	10		–		–	–				

Note.
- = abilities are under the age-appropriate level
+/- = abilities are at least on the age-appropriate level

Later, at school-age, children with SLI have been shown to have difficulties in acquiring a fluent calculation skill, although older children (9 to 11 years) with SLI seem to be able to calculate rather accurately (Tieche Christinat et al., 1995) using slower counting-based calculation strategies more frequently than peers matched for age (Fazio, 1999). Fazio (1999) reported that, compared to their age peers, 9- to 10-year-old children with SLI encountered more problems when fast arithmetical fact retrieval was required.

In contrast, children with SLI have not been found to perform any worse than age-matched controls in number comparison tasks (Donlan 1993; Donlan & Gourlay, 1999). Children aged 6 to 7 years with SLI performed at an age-appropriate level in a comparison task with written Arabic numbers – e.g., which is bigger, 15 or 51? (Donlan, 1993). In his later study with Gourlay (Donlan & Gourlay, 1999), 7- to 8-year-old children with SLI were compared to controls matched for age and language. The children with SLI performed better than their younger language-matched controls and at the same level as their age-matched peers on the number comparison task. Donlan and Gourlay proposed that the ability to relate pairs of numbers to their relative values seems to depend predominantly on nonverbal skills. The only study to investigate the estimation of numbers was carried out by Tieche Christinat and colleagues (1995), who showed that controls had no failures when positioning numbers on a 1-100 scale. Only two out of ten of the children with SLI required lengthy training in the test method and had difficulties in positioning numbers.

In summary, previous findings of group studies in children with SLI suggest that impaired language is strongly associated with difficulties in number processing when the explicit verbal processing and expression of numerals is demanded, as, for example, in verbal counting, retrieving arithmetical facts from memory and number transcoding (going from one numerical code to another, i.e. from Arabic numerals to spoken/written number words, as in 5 → "five" or vice versa, as in "twenty-five"→ 25) (Arvedson, 2002; Donlan, 1993; Donlan & Gourlay, 1999; Fazio, 1994, 1996, 1999; Tieche Christinat, Conne, & Gaillard, 1995). When a more approximate representation of magnitude or numbers is required, as with number comparison and estimation, the performance of individuals with language impairments seems to improve (Donlan, 1993; Donlan & Gourlay, 1999; Tieche Christinat et al., 1995).

However, because these studies have utilized small sample sizes, investigated differing age groups and used different kinds of tasks to measure the skills in question, more studies are required to confirm the results. Furthermore, although considerable heterogeneity has been reported in the numerical skills of children with SLI (Donlan & Gourlay, 1999; Tieche Christinat et. al., 1995), previous studies have not (mostly because of small sample sizes) analyzed whether all children with SLI show the verbal vs. non-verbal dichotomy in their numerical skills. Moreover, the nature of language difficulties also varies substantially between individuals, and thus, it is important to study how different kinds of language abilities are related to certain numerical skills.

1.2.2 Calculation interventions in children with SLI

Previous neuropsychological rehabilitation studies on calculation have mainly been conducted with adults who have lost their fact retrieval skill as a result of brain damage (Girelli, Bartha, & Delazer, 2002; Girelli, Delazer, Semenza, & Denes, 1996; Hittmair-Delazer, Semenza, & Denes, 1994; Whetstone, 1998). Most of these single-case intervention studies have focused on re-teaching the lost knowledge via extensive practice (Girelli et al., 1996; Hittmair-Delazer et al., 1994; Whetstone, 1998). These interventions have produced significant and enduring improvement in the retrieval of arithmetical facts through drill and minimising the opportunity to make errors (for a review see, Girelli & Seron, 2001). In addition to this kind of *restoration* approach, a *reorganisation* approach has been used (Girelli et al., 2002). In this approach efficient back-up strategies are taught instead of trying to re-learn the facts through extensive practice. The intervention focused on the strategic use of patients' residual knowledge and explicit reference to the principles underlying simple arithmetic. Similarly, the findings from educational intervention studies in children suggest that those with mathematical learning difficulties benefit more from strategy instruction than from instruction through drill and practice (Tournaki, 2003). In the study by Tournaki (2003) single-digit addition facts were taught through strategy instruction as well as drill and practice. The results showed that second graders with mathematical learning difficulties benefited more from strategy instruction than from instruction through drill and practice (Tournaki, 2003). However, both of the strategy instructions produced better results than those of the control group, which did not receive any instruction to supplement that of the classroom. Similarly, the results of meta-analysis of mathematical interventions (Kroesbergen & van Luit, 2003) suggest that direct instruction appears to be the most effective approach for the learning basic skills.

To my knowledge, there are no previous intervention studies which have had the aim of enhancing calculation skill in children with language impairment, despite the fact that calculation difficulties are very common among these children. Children with language impairment have been found to have severe difficulties in counting (Donlan et al., 2006; Fazio, 1994, 1996,1999), which in turn could explain their delayed development in calculation: a fluent and accurate counting procedure is demanded in order to form the correct associations in the long-term memory between the problem presented and the answer and so to shift from counting-based strategies to fact retrieval, which is the fastest calculation strategy. Moreover, it can be hypothesized that both counting and calculation skills share common underlying processes which would explain the strong association found between these two skills (Donlan et al., 2006; Fazio, 1999). When planning an intervention for children with both language and calculation difficulties, either plain drill and practice type of arithmetical fact training or counting-based back-up strategy training may not be the most optimal as these strategies seems to rely on processes which are usually found to be severely impaired in children with language impairment. In contrast the numbers of facts to be memorized should be restricted and an alternative strategy to slow and error-prone counting procedures should be provided. This could be done by using the child's conceptual knowledge of numbers and arithmetical principles, which are found to be better preserved in children with SLI, and integrating that knowledge with the child's declarative and procedural knowledge of arithmetical operations.

1.3 Calculation, reading and language

In recent studies the same cognitive factors have been found to predict both calculation and reading skills. It has been suggested that phonological processing, especially phonological awareness, an ability to identify and manipulate phonological segments of various size (e.g., phoneme, syllable, rhyme), is related to the acquisition of word reading skill (e.g.,Wagner et al., 1997) and to be a core deficit underlying reading difficulties (e.g., Pennington, Cardoso-Martins, Green, & Lefly, 2001; Stanovich, Siegel, & Gottardo, 1997). In studies with Finnish-speaking children phonological awareness has been related to the early stages of reading (Aro, Aro, Ahonen, Räsänen, Hietala, & Lyytinen 1999; Holopainen, Ahonen, & Lyytinen, 2002; Lepola, Poskiparta, Laakkonen, & Niemi, 2005; Leppänen, Aunola, Niemi, & Nurmi, 2006). In a study of mathematical skills Hecht and colleagues (Hecht et al., 2000) found that phonological awareness was uniquely associated with growth in general computation skills, and together with naming speed and phonological memory, almost completely accounted for the associations between reading and single-digit calculation efficiency.

In order to combine findings from phonological difficulties associated with both reading and calculation skills, Robinson and colleagues (Robinson, Menchetti, & Torgesen, 2002) proposed a two-factor theory. According to this theory, phonological processing abilities underlie the learning difficulties of MD/RD children and weak number sense is a causal factor in math-fact learning difficulties of MD-only and some MD/RD children. Robinson suggests that in phonological deficit auditory, phonological features associated both with individual numbers and with number facts in their entirety are weakly connected and encoded, and thus have less distinct memory representations which to retrieve. Similarly, Geary (1993; Geary et al., 2001) have suggested that representing and retrieving phonological information from the long-term memory may underlie the problems in learning arithmetical facts as well as co-morbidity with reading difficulty.

During the last decades growing interest has been shown in naming-speed deficit and its relationship with reading difficulties. Several studies of reading skill have shown that rapid automatized naming (RAN), the ability to name continuously presented familiar symbols (e.g., objects, letters or digits) accounts for a significant amount of the variance in reading above and beyond what is explained by phonological awareness (e.g., Filippo et al., 2005; Georgiou, Parrila, & Kirby, 2006; Lepola et al., 2005) and both children and adults with reading disabilities have also exhibited pronounced difficulties in naming speed tasks (Wolf, Barry, & Morris, 1986; Wolf &Bowers, 1999; Wolf et al., 2002). Naming speed has been shown to be associated in particular with reading fluency (Lepola et al., 2005; Wolf et al., 2002), which in turn, has been shown to be a more critical aspect of reading than accuracy in transparent languages with consistent grapheme-to-phoneme correspondences (e.g., Aro & Wimmer, 2003). Studies of the relationship between different subcomponents of RAN and reading have shown that pause times and not articulation speed (Neuhaus, Foorman, Francis, &Carlson, 2001; Georgiou et al., 2006) is related to reading ability. Similarly, in the study by Filippo and colleagues (Filippo et al., 2005) performance on the naming test, but not on the visual scanning and stimulus identification test or articulation test, predicted speed and accuracy in reading. Moreover, Georgiou and colleagues (2006) found that the predictive power of pause time and total time did not differ markedly and thus they concluded that for most purposes obtaining the total time will suffice. This is an important finding, thus most of the studies examining the relationship between naming speed and reading have used total time as a variable. Interestingly, an association has also been found between calculation efficiency and naming speed (Hecht, et al., 2000; Bull & Johnston, 1997). Moreover, in the study by Hecht and colleagues, the correlations between calculation efficiency and speed of naming isolated letters or digits in the fourth and fifth grades varied from .43 to.56 ($p<.05$), which was almost as high the similar correlations of up to .57 ($p<.05$) between calculation efficiency and general computation skills.

According to Misra and colleagues (Misra, Katzir, Wolf, & Poldrack, 2004) rapid naming would compose a large subset of the same processes engaged during the fluent reading of words in continuous text by a skilled reader. For each behavior a symbolic form (letters and numbers) or picture would be mapped onto both the phonological form and the semantic representation of it quickly and accurately, while allowing for a rapid shift of attention to the next stimulus. These could also be seen close to the subset of processes needed in fluent calculation when solving simple problems presented in numerical format on the same layout. Rapid access from visual symbol either to phonological or semantic representation or both are required, while at the same time allowing for a rapid shift of attention to the next problem.

A third ability which has been found to be associated both with calculation (Johansson, 2005; Secada, Fuson, & Hall, 1983) and reading (Leppänen et al., 2006) is counting - the ability to recite number-word sequences correctly. A fluent and accurate counting procedure is demanded in order to form the associations in the long-term memory between the problem presented and the answer, and to help in shifting from counting-based strategies to fact retrieval, which is the fastest calculation strategy. In addition, it is also possible that both the counting and fact retrieval skills share common cognitive processes (e.g., (Donlan et al., 2007) and are supported by the same system in the brain (e.g., Dehaene & Cohen, 1997). More surprisingly, in the study by

Leppänen and colleagues (Leppänen et al., 2006a) counting ability was the most powerful predictor of word chain and text reading performance in grade 4, despite the inclusion of phonological awareness and letter knowledge in the same analysis. The authors suggested that one possible factor underlying this association between reading and counting could be working memory. Working memory, in turn, is also needed in single-digit calculation, especially when using counting-based back-up strategies (Imbo & Vandierendonck, 2006).

The associations found between naming speed, phonological awareness or counting and reading or calculation come mainly from separate studies and, although various hypotheses have been presented, only very few studies have empirically examined to what extent these factors would explain the covariance found between calculation and reading when presented in the same model.

2 OVERVIEW OF ORGINAL STUDIES

2.1 Aims

The present thesis was concerned the impact of language abilities on the acquisition of numerical skills, in particular calculation skill. To better understand the connection between language and numerical skills, three different approaches were used. First, in order to examine the influence of language impairment on various numerical skills, SLI children's numerical skills were compared to those of their educational age-peers and language controls. In addition, it was examined how well cognitive factors (e.g. language abilities and non-verbal reasoning) explain the variance in these children's numerical skills, in particular in calculation and understanding numbers (e.g., comparison and estimation). Second, by means of a single-case intervention study it was further examined whether retrieval difficulties in language are related to learning to retrieve arithmetical facts from long-term memory: Two SLI children with different abilities in verbal retrieval received an arithmetical intervention and the differences in their intervention outcomes were related to differences in their language profiles. Similarly, using a single case approach, it was investigated whether a child who is weak in the use of counting procedures and who has difficulties in direct memory retrieval but shows intact number comprehension, could improve his calculation efficiency. In this case an instructional approach was applied which decreases the amount of facts to be memorised and provides an alternative, conceptual-based strategy to slow and error-prone counting procedures.

Finally, in the fourth study single-digit and procedural calculation skills in Grade 4 were investigated among an unselected sample in order to see whether the cognitive factors previously found to be related to calculation skill in a clinical group of children with SLI would also be related to the normal development of fluent calculation skill and its co-variation with reading.

TABLE 2 Summary of the methods used in the orginal studies (I-IV)

Study	Participants	Procedure	Main measures	Main statistical analyses
Study I	SLI= 9-to 11-year-old children with SLI; n=29 LC=6-year-old pre-schoolers; n=20 EC=1st-3rd graders; n= 47, 40 and 33	-cross-sectional	verbal number skills non-verbal number skills linguistic skills non-verbal reasoning	ANCOVA, MANOVA, ANOVA and Fisher Least Significant Difference Non-parametric Kruskal-Wallis test Non-parametric Mann-Whitney test
Study II	- Two 10-year-old children with SLI	-intervention design	single-digit calculation non-verbal number skills linguistic skills non-verbal reasoning	Non-parametric Friedman Test Non-parametric Cochran Test
Study III	- One 11-year-old child with SLI	-intervention design	single-digit calculation	Non-parametric Friedman Test Non-parametric Cochran Test Non-parametric Wilcoxon signed-rank test Non-parametric McNemar
Study IV	-The children (N=178) were examined in kindergarten and in the 4th grade	-longitudinal	single-digit calculation procedural calculation text reading cognitive antacedents mother's education	Path analyses and Structural Equation modelling were carried out using the Mplus statistical package

2.2 Methods

A summary of the methods used in present thesis are reported in table 2.

Study I

This study examined basic numerical skills in children with specific language impairment (SLI) and how well linguistic factors explain the variance in these children's numerical skills.

The performance of children with SLI (N=29) was compared to that of typically developing children along a continuum ranging from pre-school to third grade (N= 20, 47, 40 and 33). This facilitated both linguistic and educational age comparisons. To study numerical skills within the SLI group more closely, this group was divided into subgroups on the basis of their performance in verbal and nonverbal numerical skills. As a result, three subgroups, out of the four possible, were found: twelve children showed difficulties in both verbal and non-verbal numerical skills, 8 children showed difficulties in verbal numerical skills only, and 9 children showed no difficulties in either verbal or nonverbal numerical skills. No child experienced difficulties solely in nonverbal numerical skills. The performance of the different SLI subgroups in the linguistic and non-verbal reasoning task was analyzed.

Results

As a single group, the children with SLI lagged behind their educational age controls in both verbal and non-verbal numerical skills, performing on average at the level of first graders in single-digit calculation and nonverbal number tasks. However, consistent with previous studies most of the children with SLI (69%) had difficulties in calculating simple additions and subtractions fluently but understood the structure and meaning of numbers rather well. Moreover, the children with SLI did not differ in verbal counting skills from their 6-year-old language controls. The subgroup analyses revealed that the ability to retrieve arithmetic facts from the memory was connected to naming speed, whereas the differences between the subgroups in non-verbal numerical skills were not explained by the cognitive skills measurd (non-verbal reasoning skill, verbal short-term memory, vocabulary, comprehension and naming speed).

Discussion

Previous research has shown that on average, children with SLI are dysfluent in single-digit calculation but show strengths in nonverbal numerical skills, such as number comparison. This study found that children with SLI showed a more heterogeneous profile of strengths and weakness which could not be fully explained solely by reference to their language abilities or to theories of number-specific processing. We propose that some language factors are associated with the development of numerical skills but that instead of studying the influence of language impairment as such on numerical skills, more specific hypotheses concerning the influence of linguistic deficits on the development of numerical skills are required. The results obtained from this study suggest that the development of calculation fluency seems to share some of the underlying processing abilities required for accessing the long-term memory in order to recall the names of objects or colors rapidly.

Study II

The aim of this single-case intervention study was to examine whether difficulties in fluent language-based retrieval are related to learning to retrieve arithmetical facts from long-term memory. Two 10-year-old Finnish-speaking children considered to have SLI were trained individually twice a week for two months using computerised game-like addition tasks. The participants were matched for non-verbal reasoning and non-verbal numerical skills as well as linguistic skills (verbal short-term memory, comprehension and vocabulary). The key cognitive difference between the participants was in naming speed. Child A had difficulties in fluently retrieving language-based material while child B's performance on the same task was close to the age mean. A multiple baseline across-subjects design was used, with three baseline assessments and three follow-up assessments.

Results
Before the intervention both children used finger-counting strategies only. During the intervention child B progressed from finger-counting strategies to fact retrieval, while child A continued to use finger counting only. Both children were able to learn the counting on-min strategy starting the counting on process from the larger addend and thus ignoring the order of presentation the terms.

Discussion
The results suggest that through intensive practice with immediate feedback and a large amounts of repetition even a rather short but focused intervention may improve calculation skill in children with SLI. However, the particular nature of the language impairment seems to have a major impact. That is, specific difficulties in verbal retrieval and in forming verbal associations seems to be connected to the ability to learn arithmetical facts. In addition to lending support to earlier findings, indicating that children with language impairment have a specific problem in fact retrieval, the present thesis shows the importance of defining in detail the particular SLI phenotype when trying to understand the role played by language in arithmetical difficulties.

Study III

The aim of this single-case intervention study was to examine whether a conceptual knowledge-based intervention would improve the efficiency of single-digit arithmetical calculation in a child with naming speed difficulties but intact number comprehension. The intervention concerned an 11-year-old Finnish-speaking child with specific language impairment who had difficulties in single-digit calculation. He was trained individually once a week for three months. The aim was to help him to acquire more efficient calculation skill by training calculation strategies integrating his existing conceptual knowledge of numbers (e.g., 10 is one larger than 9) and arithmetical operations (e.g., 6+5=5+6) with his declarative (e.g., 5+5=10, 8+8=16) and procedural (e.g., 9+x= 10+x –1 or x-10= x-9+1) knowledge of arithmetical operations. On the basis of his baseline performance single-digit arithmetical problems were divided into "well-known arithmetical problems" and "error-prone arithmetical problems". Instead of training the arithmetical facts by rote learning, the goal was to construct decomposition strategies based on meaningful relationships between the arithmetical facts. An intervention design was used consisting of six pre-intervention and three post-intervention assessments.

Results
The results show that the child calculated additions, subtractions and multiplications more accurately after the intervention was applied. In subtraction he also used more retrieval-based strategies after than before the intervention.

Discussion
The results suggest that an intervention program focusing on the meaningful learning of arithmetical problems can be beneficial, especially when children are weak in the use of counting procedures and have difficulties in direct memory retrieval but show intact number comprehension. Children with language impairment, particularly those with naming speed difficulties, have been found to have problems in fluent single-digit calculation more often than their normal age- or educational-matched peers and thus could benefit from an instructional approach which decreases the amount of facts to be memorised and provides an alternative strategy to slow and error-prone counting procedures.

Study IV

This study examined to what extent children's cognitive abilities in kindergarten, and their mother's education, predict their single-digit and procedural calculation skills, and the covariance of these with reading in Grade

4. The children (N=178) were first examined in kindergarten according to their basic numerical skills, linguistic skills and visual attention, and later in the 4th grade according their calculation and reading skills. Data on the children's cognitive ability at age 5 and mother's level of education were also collected.

Results

The results showed that each of the two core components of calculation, single-digit and procedural calculation, as well as their covariance with reading, were predicted by unique cognitive factors: In addition to counting ability, single-digit calculation, as well as its covariation with text reading, was predicted by naming speed. In contrast, procedural calculation was predicted by number concept skill and mother's education after controlling for single-digit calculation.

Discussion

The results of this study support the claim that the multicomponental approach is a fruitful one in seeking to understand the development of mathematical skill and its covariation with other skills, such as reading. The study showed that two core components of calculation, single-digit and procedural calculation, each have unique cognitive antecedents: single-digit calculation, as well as its covariation with text reading, were predicted by the ability to learn and retrieve verbal sequences as well as ability to form visual-verbal associations and rapidly retrieve verbal labels for visual stimuli. This result suggests that, although single-digit calculation is a numerical skill, it is also connected to linguistic abilities and, thus, linguistic difficulties may restrict children's acquisition of calculation skill. Also of importance is the hierarchical relationship between the components. Procedural calculation has been shown to be a skill distinct from knowledge of arithmetical facts. However, single-digit calculation (memory-based retrieval or counting strategies) is required to obtain intermediate answers when performing multi-step calculations. This has to be taken into account when examining procedural calculation and the cognitive factors underlying it as well as its covariance with other skills. After controlling for single-digit calculation, procedural calculation was predicted by number concept skill and mother's education, and its covariance with reading was best predicted by counting ability. All these skills, text reading, procedural calculation and counting, can be seen as multi-step procedures demanding good monitoring, error detection and self-correction skills, and thus engaging the working memory. Moreover, counting ability and procedural calculation skill demand sequencing skill in order to learn the correct order of number words and calculation procedures.

3 GENERAL DISCUSSION

The present thesis concerned the impact of language abilities on the acquisition of numerical skills, in particular single-digit calculation. The main findings of the present thesis and its theoretical and practical implications are discussed below.

3.1 Summary and discussion of main findings

3.1.1 Numerical skills and SLI

The first study examined the influence of language impairment on various numerical skills. As a group, the children with SLI lagged behind their educational age controls in both verbal and non-verbal numerical skills. As expected, children with SLI performed at the level of their language-matched controls in counting and at the level of first graders in calculation. In contrast to the expectations based on previous findings, the children with language impairment lagged behind their educational controls and performed at the level of first graders also in number comparison and other non-verbal number tasks. However, the results also demonstrated that children with SLI can not be treated as uniform group from the perspective of numerical skills, because of the large variance in both verbal and non-verbal numerical skills. The subgroup analyses revealed that less than one-third of the children with SLI clearly showed a "poor verbal – better non-verbal" numerical skills profile, having difficulties in fluent calculation but performing well in number comparison and estimation. Another third of the children showed no difficulties in either verbal or non-verbal numerical skills, and the rest of the children showed difficulties in both verbal and non-verbal numerical skills. No child experienced difficulties solely in non-verbal number skills.

Consistent with previous studies (Fazio,1996, 1999) and with recent findings by Donlan and colleagues (Cowan et al., 2005; Donlan et al., 2007) most of the children with SLI had difficulties in calculating simple additions and subtractions fluently (69%), suggesting that calculation skill is somehow related to language processing. This suggestion was supported by the finding that naming speed differentiated those children with SLI who after several years of practice still depended on slow calculation strategies in single-digit additions and subtractions from those who had learnt to retrieve answers to the same problems from memory. The SLI subgroups did not differ in other linguistic skills or non-verbal reasoning skill. Moreover, due to the fact that children with SLI also had severe difficulties in counting, which is strong predictor of fluent calculation skill, and that in the recent study by Donlan (Donlan et al., 2007) the group difference between SLI children and age-controls in calculation was abolished after controlling for counting ability, the data in this first study were re-examined. The results showed that, the SLI subgroups did not differ significantly in counting ability. There are several possible reasons for the difference between the findings. One possible explanation is the difference in the systems of verbalising number word sequences in Finnish and English. In Finnish the numbers 10-20 are represented in a structurally more consistent manner, equivalent to "one from the second(ten)" two from the second… nine from the second, two ten (partitive)" (in English "eleven, twelve, thirteen.. nineteen, twenty"). Thus, it is possible that in Finnish learning to recite number words relies to a lesser extent on rote verbal learning and may not be associated with calculation as strongly as in English. However, as the results from the fourth study showed, counting ability measured in kindergarten was strongly associated with later calculation skill in an unselected sample. In addition, preliminary findings based on unselected data on 5-year-old Finnish and English children (Aunio, Aubrey, Godfrey, YeuJuan, & Yan Liu, submitted) indicated that there were no differences between the two groups in frequency of mastering the counting sequence from 1 to 20. About half of the children in each country (46% of Finnish and 49% of English) were able to recite the number word sequence correctly. Another explanation could be that measuring accuracy in counting is not sensitive enough to detect whether calculation skill is automatized or not, at least among older SLI children, because it does not discriminate between children according their counting fluency, which is another critical aspect of counting ability and related to the development of calculation skill.

Also, the finding that more than half of the children with SLI (59%) seemed to understand the meaning and/or structure of single- and multi-digit numbers can be seen as lending support to the previous proposal that, despite language impairment, children with SLI can acquire numerical information related to the magnitude of Arabic numerals and the quantitative relations between them (Donlan & Gourlay, 1999). However, there was also a rather large group of SLI children (41%) whose understanding of numbers was weak. It is assumed that the brain has a domain-specific area for quantity processing which is activated whenever a comparative operation that needs access to a numerical scale is called for (Dehaene, 1992; Dehaene & Cohen, 1995; Dehaene, Piazza, Philippe, & Cohen, 2003). The differences in findings may partially be due to the fact that previous studies have only been carried out with single and double-digit numbers and that the influence of syntactic complexity (e.g.; three and four-digit numbers) on the identification process and on the whole comparison process has not been studied. As Arabic numerals advance in magnitude, it becomes increasingly difficult to process quantity using only the visuo-spatial structure of the printed number; hence using verbal decoding may serve as an aid in the process of number comparison. The question is, can this finding be explained by the influence of a more general deficit in processing syntax? The finding of a small but significant correlation between the number comprehension task and the sentence comprehension task partly supports this suggestion, although the general deficit in processing syntax did not fully explain the children's performance in the number comparison task in the present thesis.

The influence of the complexity of number structure on SLI children's performance in number comparison was also found in the studies by Donlan and colleagues. Earlier they found that 8-year-old children with SLI did not differ from age controls in comparison tasks with double-digit numbers (Donlan & Gourlay, 1999). However, in their recent studies using larger numbers they found that 8-year-old children with SLI lagged behind their age peers in a number comparison task in which numbers with up to five digits were included (Cowan et al., 2005; Donlan et al., 2007). Moreover, they found that counting skill was a significant predictor of multi-digit magnitude comparison, abolishing the group difference between the SLI children and age controls. Also in cross-national studies the development of number word sequence skills have been related to the understanding of numbers and the ten-base structure (for a review see Miller, Kelly, & Zhou, 2005). Many of these studies have traced the contrastive developmental trajectories of rote count knowledge in American English and Chinese speakers, noting in particular the obstacle set by the English –teen words. A systematic and transparent number word system, as in Chinese, is thought to facilitate children's understanding of numbers, counting and the underlying ten-base structure, providing one explanation for the finding that East Asian children outperform their American age-peers in number skills. If the language-related differences between systematic (e.g. Chinese) and unsystematic (English and Finnish) number word systems could pose obstacles among an unselected sample of typically developing children, it could be assumed that among SLI children the influence of such differences on acquiring understanding of the structure of numbers is even greater. However, although, the finding that most of the SLI children have major difficulties in counting yet have average understanding of numbers does not lend support to this hypothesis, it is nevertheless worthy of empirical investigation.

Johansson (2005) suggested that counting on the number-word sequence may be an early solution procedure and that, with increasing counting skill, the child may detect regularities in the number-word sequence that can be used to form new and more accurate strategies in calculation. Similarly, it could be that with fluent counting skill, the child may detect regularities in the number-word sequence that can be used to grasp the logical rules underlying the ten-base and place value system needed in multi-digit comparison tasks.

Moreover, it is also possible that “grasping logical rules” in different contexts, such as when learning the number-word sequence, the ten-base system, grammar in language, relies on the same sequential process, as abstract structure. Abstract structure is one type of processing in sequential cognition and it is defined in terms of generative rules that describe the relations between elements repeated within a sequence (Dominey, Hoen, Blanc, & Lelekov-Boissard, 2003). However, so far empirical studies have been restricted to the association between abstract structure processing and grammatical skills in adults with language impairment, and thus further studies are needed in order to find out whether sequential cognition, such as in serial and abstract structure processing (see e.g., Dominey, et al., 2003) could also play an important role in the development of the number word sequence and ten-base system as well as calculation.

3.1.2 Calculation skill and specific language processes

The first study of this thesis suggested that the development of calculation fluency seems to share some of the underlying processing abilities required for accessing the long-term memory in order to retrieve the names of objects or colors rapidly (naming speed). The aim of the second study was to explore this hypothesis further. The primary focus of the study was to examine the effect of an intensive intervention on the calculation skill of two participants with SLI: one had difficulties in both fluent calculation and naming speed while the other had difficulties only in calculation. Two SLI children with different abilities in naming speed but matched in all other linguistic and non-verbal reasoning skills received an arithmetical intervention in order to examine whether the capacity to learn arithmetical facts is related to language-based retrieving ability.

The results suggest that even a rather short but focused and intensive intervention may improve calculation skill in children with SLI. However, the particular nature of the language impairment seem to have a major impact. That is, a specific difficulty in fluently retrieving verbal labels for visual stimuli (naming speed) and in forming verbal associations seems to be connected to the ability to learn arithmetical facts but not to the ability to learn more efficient counting-based strategies, such as counting on the larger number. In addition to lending support to earlier findings, indicating that a significant proportion of children with language impairment have a specific problem in fact retrieval, the present thesis shows the importance of defining in detail the particular SLI phenotype when trying to understand the role played by language in arithmetical difficulties.

The second study also shows the importance of the individual assessment of calculation strategies, including observation and interview with the child, as well as need of explicit strategy instruction in order to help children to overcome specific problems in calculation, such as use of immature calculation strategies. Use of poor finger counting strategies leads to many calculation errors and makes calculation slow, which in turn, prevents or delays the shift to the use of a fact retrieval strategy and thus development of fluent calculation skill. As indicated in this study, even a rather short but intensive intervention may be helpful, if it is focused, includes explicit strategy instructions, and provides immediate feedback and a well motivated learning context. Computer programs could function as good intervention tools, especially as they enable immediate feedback to be given and can be used to provide game-type practice in situations where teachers can not do it by themselves.

The results of this study indicate that achieving fluent calculation skill is especially hard for children with SLI who have naming speed deficit. However, it is not assumed that these children would be unable to learn to use faster memory-based strategies. But, at least, it takes more time and effort than with typically developing children or children with SLI but without naming speed deficit. Further interventions studies are needed in order to examine whether longer intervention, including training of conceptual knowledge of numbers and arithmetic and integration of that knowledge with declarative and procedural knowledge, could help these children to achieve more efficient calculation skill.

3.1.3 Conceptual knowledge-based training in single-digit calculation

Third, it was examined whether a child with severe naming speed difficulties but intact numerical comprehension is able to learn arithmetical facts if he is taught to use his conceptual understanding of numbers and arithmetical operations. Previous studies in children with SLI have suggested that despite severe difficulties in learning the correct order of counting words as well as difficulties in fluent calculation, children with language impairment seem to be as capable as typically developing peers of grasping the logical principles underlying counting (Adverson, 2002; Donlan, 1993; Fazio, 1994) and arithmetic (Donlan et al., 2007). Also, as found in the present thesis and the studies by Donlan and colleagues (Donlan, 1993; Donlan & Gourlay, 1999; Donlan et al., 2007), most, but not all, of children with language impairment seem to have rather a good understanding of the magnitude of numbers. These strengths, where they exist, suggest one approach to an intervention for children with language impairment in aimed at achieving more fluent and accurate calculation skill. The results of this intervention study suggested that an intervention program focusing on the meaningful learning of arithmetical problems can be beneficial, especially when children are weak in the use of counting procedures and have difficulties in direct memory retrieval. The intervention provided alternative strategies to slow and error-prone counting procedures and error-prone fact retrieval strategy by integrating the child's existing conceptual knowledge of numbers and arithmetical operations with declarative and procedural knowledge of arithmetic. Moreover, the number of facts to be memorized was restricted and the intervention was focused on the specific arithmetical problems to which the child was error-prone. However, despite the importance of single-case studies in developing and testing intervention methods on a level of detail not reached by using group designs, we have to acknowledge the need for further studies with larger samples before drawing more general conclusions.

3.1.4 Predictors of covariance between calculation and reading

A clinical sample provides one possibility to study the mechanism of co-morbidity, such as found between language impairment and calculation, or reading and calculation. However, clinical samples are always biased, and thus, replications with unselected sample are needed in order to see whether the results found in children with SLI could also provide information about the factors underlying the normal development of calculation and reading skills. Similarly, a better understanding of the factors related to normal development of calculation skill could also help in understanding the possible factors underlying difficulties in calculation. In the fourth study, the relationship between language, reading and calculation was studied in an unselected sample. It was examined whether the cognitive factors found to be related to calculation difficulties in the clinical sample of children with severe impairments in language are the same as those associated with the general development of calculation skill. It was found that the same factors that were related to calculation skills, as well as to the co-variation between calculation skills and reading in Grade 4, were the same among the unselected sample as found in studies of children with SLI. The result showed that single-digit calculation, as well as its covariation with text reading, were associated with counting ability and naming speed. In addition, letter knowledge was related to covariation between calculation and reading. It is suggested that the ability to learn and retrieve verbal sequences as well as the ability to form visual-verbal associations and rapidly retrieve verbal labels for visual stimuli are related to the development of fluent calculation skill as well as its covariation with reading.

3.2 Theoretical implications

The present thesis suggests that there are at least two cognitive abilities, which could work as early indicators of increasing risk for calculation difficulties both in children with SLI as well as among typically developing children: the ability to learn and recite verbal number word sequences as well as the ability to fluently access long-term memory in order to retrieve verbal labels for visual stimuli (naming speed).

The theoretical models of calculation skill and language provide an interesting framework within with to discuss the theoretical implication of the findings in the present thesis.

3.2.1 Counting ability and calculation

Siegler's model of calculation skill helps us to understand how weakness in counting, which is often found in children with language impairment, may influence their later calculation skill. Siegler's distribution of associations model emphasis the importance of a varied learning history to different problems and answers. As the findings of this study as well as others in children with SLI (Adverson, 2002; Fazio, 1994, 1996, 1999; Cowan et al., 2005) have shown, these children have great difficulties in learning to recite number word sequences in the correct order and in fluently counting backwards or by certain steps. In calculation children with SLI have been found to use more counting-based backup strategies and commit more errors when using backup strategies than their age-peers (Cowan, et al., 2005; Fazio, 1996, 1999). In Siegler's distribution of associations model this kind of history of miscounting leads to a flat distribution in which associative strength is dispersed among several answers, and thus direct memory retrieval is not possible or it may produce incorrect answers. In the present thesis, fluency of single-digit calculation in the 4th grade, and its covariation with text reading, was best predicted by counting ability in kindergarten. In addition to the fact that in calculation the use of memory-based retrieval strategies is preceded by the use of counting-based strategies, and thus accurate and fluent retrieval of the number-word sequence is required in order to be able to shift from counting-based strategies to fact retrieval, there are at least three other factors that could partially explain the strong associations between these two skills.

First, it is possible that counting and calculation share common processes (and neural mechanism) (Dehaene & Cohen, 1997). According to Dehaene's triple-code model (Dehaene & Cohen, 1997) the normal route for over-learned calculations such as single-digit multiplication and simple addition is the direct route, in which the arithmetical problem (2x4, two times four) is converted into an internal verbal representation, which is then used to complete this word sequence by using rote verbal memory ("two times four, eight"). The results from studies in children with SLI suggest that the rote retrieval of memorized material, such as a poem or sequence of number words, is particularly difficult for these children (Fazio, 1994, 1996, 1997). Recently, Ullman (Ullman & Pierpont, 2005) proposed that SLI can largely be explained by abnormal development of the brain structures that constitute the procedural memory system. This system involves the frontal/basal-ganglia circuits subserving the learning and execution of motor and cognitive skills, and is particularly important for acquiring and performing skills involving sequences.

Additionally, by using the theoretical concept of working memory, counting and calculation skills may rely on the same cognitive ability (Cowan et al., 2005; Geary, Hoard, Byrd-Craven, & DeSoto, 2004). Working memory has been found to be related to single-digit calculation, especially when strategies other than retrieval are involved, such as counting-based strategies (Cowan et al., 2005; Geary et al., 2004; Imbo & Vandierendonck, 2007). However, working memory did not emerge as a significant factor in the present thesis among older SLI children: In the first study, performance in the digit span tasks did not differentiate those children with SLI who, after several years of practice, still depended on slow calculation strategies in single-digit additions and subtractions from those who had learnt to retrieve those same calculations from memory. Additionally in the second study children had exactly same span in recalling digits forward and backward, and thus working memory did not account for the different benefits they derived from the intervention. In the third study, the child had language impairment and showed calculation difficulties but performed rather well in the digit span tasks as in any other memory task. In general, working memory resources are needed when learning new skills. This may provide one explanation for the results. These children with SLI had practised counting and basic calculation for several years, and although they did not calculate fluently they were accurate. This means that the counting list from 1 to 20 had been accurately established and that they managed to monitor the use of counting-based strategies well enough to obtain correct answers, and thus, the demands on working memory were not as high as in the early phase when learning to recite number words in the correct order or practising the use of counting-based strategies. However, as suggested by Cowan (Cowan et al., 2005), in order to better understand the relationship between counting, calculation and working memory, counting range (novel or familiar), direction (forward or backward) and steps (by one or two steps) as well as calculation strategies (retrieval or counting-based strategy) should be taken into account.

Third, it is also possible that counting and calculation share a common representational system (Donlan et al., 2007; Geary et al., 2001; Robinson et al., 2002). The phonological processing hypothesis suggests that phonological features associated both with individual numbers and with number facts in their entirety are weakly connected and encoded, and thus have less distinct memory representations available for retrieval.

However, it seems that although the accuracy of counting in kindergarten seems to be a very strong predictor of later calculation fluency in an unselected sample and explains the group differences in calculation between the SLI and the control group in 7- to 9-year-old children (Donlan et al., 2007), among older SLI children it is not sensitive enough to detect whether calculation skill is automatized or not. In contrast, the rapid accessing of long-term memory in order to retrieve the names of objects or colors fluently seems to be better index of whether calculation skill is automatized or not among SLI children.

3.2.2 Naming speed and calculation

Naming speed has earlier been found to be a good predictor of reading skill and in the present thesis was found to be associated with calculation skill both in a clinical sample of children with SLI as well as in an unselected sample of typically developing children. One way to interpret rapid naming is as an index of the speed with which phonological information can be accessed (Wagner & Torgesen, 1987). However, it has also been proposed that naming speed index processes which are, at least in part, independent of phonology (e.g., Wolf & Bowers, 1999) and that naming speed accounts for a significant amount of the variance in reading above and beyond what is explained by phonological awareness (e.g., Filippo et al., 2005; Georgiou, Parrila, & Kirby, 2006; Lepola et al., 2005; Powell, Stainthorp, Stuart, Garwood, & Quinlan, 2007). In reading research, there are ongoing studies that are trying to clarify the question of which sub processes in rapid serial naming are the most critical when predicting reading skill. For example, by manipulating the number of different stimuli to be named, it might be possible to clarify whether mapping onto the phonological form or, perhaps, the inhibition of previous responses in a sequence are more critical aspect of rapid serial naming. Once that is established, we can ask whether the critical sub processes that are related to acquiring fluent reading skill are the same as those related to the acquisition of calculation skill. At least, that could be possible in the sense that in the fourth study naming speed contributed significantly to the covariance between single-digit calculation and reading skill and that no unique impacts of the naming speed on reading or calculation were found after taking account the shared variance of these two variables. However, it is also possible that the critical part of the predictive value of naming speed is more complicated, such as rapid, parallel activation and processing of different types of representations (visual, phonological, semantic). According to Misra and colleagues (Misra, Katzir, Wolf, & Poldrack, 2004) rapid naming would compose a large subset of the same processes engaged during the fluent reading of words in continuous text by a skilled reader. For each behavior a symbolic form (letters and numbers) or picture would be mapped onto both the phonological form and the semantic representation of it quickly and accurately while allowing for a rapid shift of attention to the next stimulus. These could also be seen as close to the subset of processes needed in fluent calculation when solving simple problems presented in numerical format on the same layout. Rapid access from visual symbol either to phonological or semantic representation or both are required while at the same time allowing for a rapid shift of attention to the next problem.

3.2.3 Counting ability, naming speed and models of calculation

The present thesis suggests that naming speed and counting ability are two cognitive abilities which are related to fluent calculation skill both in children with SLI as well as among typically developing children. The findings accords well with Dehaene's description of the calculation process, in which "the problem is first converted into an internal verbal representation, which is used to complete this word sequence by using rote verbal memory". In other words, the ability fluently to access long-term memory in order to retrieve the verbal labels for a visual stimulus (naming speed) could tap the same processes as needed in calculation when converting arithmetical problems into an internal verbal representation. The ability to learn and to recite a verbal number word sequence, in turn, could share the same underlying cognitive processes needed in learning arithmetical facts and in fact retrieval when completing word sequence that consists of the terms presented in the problem. The description of procedural memory deficit (Ullman & Pierpont, 2005) also accords with findings of difficulties in verbal retrieval (naming speed) and verbal sequence learning and production (counting) in children with SLI. However, further studies are needed in order to confirm these suggestions. Counting and naming are multi-componential skills, and the specific relationship between counting and calculation or naming speed and calculation was not examined in more detail in the present studies. Thus, it is suggested that the different sub components of counting ability and their relationship to the development of language and calculation should be further studied as well as the factors underlying the slow accessing of long-term memory in order to retrieve verbal labels for visual stimuli. Longitudinal studies are needed in order to better understand what is a cause and what is a consequence and how the relationship between numerical skills and cognitive abilities changes during development.

3.3 Practical implications

The research results reported here strongly indicate that children with language impairment are at increased risk for having difficulties in several areas of numerical skills, and thus more attention should be paid to this issue. Secondly, it is also very important to take into account that children with specific language impairment can not be treated as uniform group from the perspective of numerical skills. For these reason their calculation and other numerical skills need to be carefully assessed in order to plan relevant education and support.

However, there are some basic skills that seem to be more at risk if children have language impairment, such as counting and calculation. Most of the children with SLI seemed to have difficulties in achieving fluent calculation skill despite several years of practice. These difficulties may partially be due to weak counting skills, but in addition to that SLI children, in particular those with naming speed deficit, seemed to be at increased risk for having difficulties in single-digit calculation. It is suggested that there are at least two cognitive abilities; which could work as early indicators of increasing risk for calculation difficulties both in children with SLI and in typically developing children: the ability to learn and recite verbal number word sequences and the ability to fluently access long-term memory in order to retrieve verbal labels for visual stimuli (naming speed).

Third, despite severe difficulties in calculation there are, as far as I know, no previous intervention studies which have focused on calculation skill in children with language impairment. In this thesis it is suggested that explicit strategy training by integrating conceptual knowledge of numbers and arithmetical operations with knowledge of arithmetical facts and with knowledge and use of counting-based procedures could be a fruitful approach in seeking to improve calculation skill in children with language impairment. It would allow a restriction on the amount of facts to be memorized, and would thus decreases the rote-verbal learning load, which has usually been found to be particularly poor in children with language impairment. In contrast, it relies on the child's conceptual knowledge of numbers and of arithmetical operations and principles, which are more often found to be preserved in children with SLI (Donlan et al., 2007). This approach seemed of especial benefit when child was weak in the use of counting procedures and had difficulties in direct memory retrieval but nevertheless showed intact number comprehension.

3.4 Concluding Remarks

In summary, different theoretical frameworks suggest that there are multiple routes to solving simple arithmetical problems, some which rely more on verbal processing and others with the emphasis on the semantic processing of numbers (e.g., Dehaene et al., 2003, Robinson et al., 2002). The present findings suggest that, although the understanding of quantitative and number symbols is very important, difficulties in the cognitive processes that support the fluent naming and learning of verbal sequences are at least as important factors underlying difficulties in fluent calculation. One interesting and important question related to this issue is why children with severe difficulties in those processes but with average or good numerical understanding not use their numerical knowledge when trying to learn arithmetical facts. Dehaene and Cohen (1997) have proposed that the direct route is the normal route for over learned calculations such as single-digit multiplication and simple addition, at least in countries where verbal recitation of multiplication and addition tables is used as a teaching method. On the basis of this proposal, it can be asked whether this association of calculation with language skills is partially due to the instruction given at school. Are children guided to use verbal rehearsal as a study method to compensate for the lack of sufficient conceptual-based instruction? Instead of paying attention only to issues such as whether child solved all the arithmetical problems required and whether the answers were correct, more attention should be paid to how child solved the problems and whether she or he calculated fluently and used appropriate strategies. It has been shown that when teaching children with difficulties in language or in learning in general, we can not count on the premise that their strategies will change as a result of practice per se; instead explicit instruction is needed in order to teach these children use more efficient strategies. In children with learning difficulties in particular the instruction should move more towards the explicit teaching of conceptual based strategies instead of drill and practice type of training. It can not be assumed that children who are able to solve simple arithmetical problem also think of it as a numerical problem and not simply as a procedural activity, such as "lift two fingers first and then three" or as a single fact that has been learned like any other rote verbal sequence e.g. "two times four is eight vs. eeny, meeny, miny". More practice supporting children's understanding of how different arithmetical problems are related (e.g., 5+5 and 5+6 or 7-4 and 3+4) is needed.

TIIVISTELMÄ

Tässä tutkimuksessa tarkasteltiin kielellisten taitojen yhteyttä matemaattisten perustaitojen, erityisesti peruslaskutaidon, kehittymiseen. Ensimmäisessä osatutkimuksessa vertailtiin 9-11-vuotiaiden kielihäiriöisten (dysfasia) lasten matematiikan perustaitoja opetustasoverrokkeihin ja kieliverrokkeihin. Lisäksi tarkasteltiin, kuinka hyvin erilaiset kielelliset tekijät ja ei-kielellinen päättelykyky selittävät dysfaattisten lasten matematiikan taitoja. Toisessa osatutkimuksessa yksilökuntoutustutkimus asetelman avulla tutkittiin tarkemmin, ovatko nopean nimeämisen ongelmat yhteydessä vaikeuteen hakea aritmeettisia faktoja pitkäkestoisesta muistista: Kaksi dysfaattista lasta, jotka erosivat taidoiltaan nopeassa nimeämisessä mutta joilla molemmilla oli selkeitä vaikeuksia sujuvassa laskemisessa, osallistuivat laskutaitoa harjoittavaan kuntoutukseen. Tutkimuksessa tarkasteltiin, onko nimeämisen vaikeudella yhteyttä kuntoutuksen vaikutukseen, eli laskunopeuteen, tarkkuuteen sekä muutoksiin laskustrategioissa, eli onnistuuko vastauksen haku muistista. Kolmannessa osatutkimuksessa käytettiin myös yksilötutkimus asetelmaa, jonka avulla pyrittiin selvittämään, pystytäänkö laskutaidon tarkkuutta ja varmuutta kehittämään harjoittelemalla käsitteelliseen tietoon pohjaavia laskustrategioita. Strategiat rakentuivat lukumäärien, lukujen ja laskutoimitusten käsitteelliseen ymmärtämiseen sekä lukujen välisten suuruussuhteiden ymmärtämiseen. Lapsen hyvin hallitsemia aritmeettisia faktoja (esim. 5+5=10) harjoiteltiin käyttämään apuna muiden, heikommin automatisoituneiden ja virheille alttiimpien laskujen ratkaisemisessa (esim. 5+5=10, 5+6=?). Neljännessä osatutkimuksessa tutkittiin neljäsluokkalaisilla lapsilla, ovatko samat kognitiiviset tekijät yhteydessä laskutaidon sujuvuuteen valikoimattomassa otoksessa kuin vakavasti kielihäiriöisten lasten ryhmässä. Lisäksi tarkasteltiin, ovatko nämä tekijät selittämässä laskemisen ja lukemisen yhteistä vaihtelua.

Tulokset osoittavat, että opetustasoverrokkeihin nähden 9-11-vuotiailla dysfaattisilla lapsilla on selvästi enemmän vaikeuksia useammalla eri alueella matematiikan perustaidoissa. Samalla tärkeä havainto oli, että lapset, joilla on dysfasia, eivät muodosta yhtenäistä ryhmää matemaattisten perustaitojen suhteen, vaan yksilöllistä arviointia tarvitaan kunkin kielihäiriöisen lapsen taitojen ja tuen tarpeen selvittämiseksi. Kuitenkin aikaisempien tutkimushavaintojen kanssa yhtenevästi näyttäisi siltä, että erityisesti sujuvan laskutaidon kehittyminen on vuosien harjoittelusta huolimatta vaikeaa suurimmalle osalle kielihäiriöisistä lapsista. Eri osatutkimusten tulokset viittaisivat siihen, että lukujen luettelutaito ja nopea nimeäminen ovat kaksi varhaisemmin arvioitavissa olevaa ennusmerkkiä, jotka ovat yhteydessä sujuvaan laskutaitoon. Esikoulussa mitattu lukujen luettelutaito näyttäisi olevan paras ennustaja niin neljännen luokan peruslaskutaidon sujuvuudelle kuin laskutaidon ja lukutaidon yhteiselle vaihtelulle. Vastaavasti nimeämisen nopeus erotteli kielihäiriöisten lasten ryhmässä sujuvat ja ei-sujuvat laskijat. Lisätukea nopean nimeämisen yhteydestä sujuvaan laskutaitoon, saatiin toisessa osatutkimuksessa, jossa kuntoutuksen vaiku-

tus oli erilainen laskutaidoltaan ja muilta kielellisiltä lähtötaidoilta vastaavilla kahdella dysfaattisella lapsella, mutta jotka erosivat nopean nimeämisen taidoiltaan. Ennen kuntoutusta molemmat lapsista käyttivät sormilla luettelua ainoana laskustrategiana ja lähtivät luettelemaan aina ensimmäisestä luvusta eteenpäin. Kuntoutuksen aikana molemmat lapsista oppivat ottamaan isomman luvun alkutekijäksi, mutta vain nopean nimeämisen taidoiltaan ikätasoinen kielihäiriöinen lapsi pystyi kuntoutuksen päätyttyä hakemaan vastauksia suoraan pitkäkestoisesta muistista.

Käsitteelliseen tietoon pohjautuva harjoittelu näyttäisi kuitenkin tukevan laskutarkkuuden ja varmuuden kehittymistä myös nimeämisen vaikeuksista huolimatta. Kolmannessa osatutkimuksessa tutkittavana oli 11-vuotias kielihäiriöinen lapsi, jolla oli nopean nimeämisen vaikeuksia mutta hyvä ymmärrys luvuista. Lapsen laskutaito kehittyi kuntoutuksen aikana hänen oppiessaan käyttämään hyvin hallitsemiaan aritmeettisia faktoja heikommin automatisoituneiden ja virheille alttiimpien laskujen ratkaisemisessa. Kuntoutuksessa aritmeettisia laskuja opeteltiin merkityksellisessä suhteessa toisiinsa, eikä irrallisina faktoina tai toimintasarjoina. Näin pystyttiin myös rajoittamaan ulkoa muistettavien faktojen määrää ja tarjoamaan luotettavampi ja tarkempi strategia virhealttiin luettelemalla laskemisen sijaan.

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