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# Numerical competencies in preschoolers with language difficulties

School children with specific language disorders (SLI) often experience massive learning difficulties that concern not only literacy but also numeracy. Since preschool basic numerical precursor competencies have a great influence on the later development of arithmetic at school, this chapter is interested in potential early difficulties in counting skills, numerical knowledge, understanding of quantities, and early arithmetic skills. Given the close link between learning difficulties and working memory, a second question is whether these potential early difficulties can be associated with functional problems of working memory.

One of early childhood's central developmental tasks lies in the development of language. Yet, not every child achieves the milestones of language development smoothly. Specific language disorders rank among the most frequently occurring developmental dysfunctions during childhood and adolescence, with a total incidence between 5% and 8%. Boys are affected three times as often as girls (Tomblin et al., 1997). The relevant individuals typically display anomalies in language acquisition which do not result from cognitive deficits, physical illness, impaired hearing, or lack of stimuli due to unfavorable or stressful surroundings. SLI is defined by a considerable deviation from normal speech and language development, both in quantity and in quality. Language production as well as language comprehension may be affected (World Health Organization, 2011). The most severe effects manifest themselves in the acquisition of grammatical structures, but also pragmatic competence may be affected (Leonard, 2014). Frequently, articulatory deficits can be detected; however, an isolated functional impairment of articulation does not justify the diagnosis of SLI (Leonard, 2014). Speech anomalies resulting from certain illnesses (i.e., autism) will be excluded from this consideration. These cases are rather referred to as unspecific or secondary language development impairments.

Because of their speech difficulties, children suffering from SLI stand out at an early age. Language delay is a typical sign, along with a relatively small vocabulary and a late usage of phrases of two or more words (Desmarais et al., 2008). This initial deficit in language acquisition will further increase over the developmental course. While affected children show progress in language acquisition to some extent and are capable of understanding and producing simple sentences over the course of their development, they are never going to reach the level of individuals unaffected by SLI. Oftentimes, a number of accompanying

difficulties will develop as a result of the language deficit, especially emotional and social issues (Yew & O'Kearney, 2013); anomalies in the development of motoric abilities (Sanjeevan et al., 2015) and attention deficit hyperactivity disorder (Beitchman et al., 1996, 2001) are characteristic for these children.

## 1 School performance of SLI-affected children

With the onset of schooling, usually extensive learning difficulties arise, since language competence is a prerequisite for the understanding and application of content knowledge. SLI frequently goes hand in hand with an impaired acquisition of reading and writing (Joye et al., 2018). According to estimates, about 25-75% of children affected by SLI will also develop dyslexia (Tomblin et al., 2000; Catts et al., 2005; McArthur et al., 2000). Moreover, the affected children also experience difficulties in the subject of mathematics. In comparison to unaffected children of their age group, they possess significantly lower mathematic capabilities (Durkin et al., 2015). This discrepancy becomes greater as their time in school progresses (Durkin et al., 2013). Children suffering from SLI exhibit considerable problems in counting, both forward and backward, but also in the estimation of quantities and in the comprehension of positional notation (Cowan et al., 2005; Donlan et al., 2007; Fazio, 1996; Nys et al., 2013). Regarding numeracy skills, they are much slower and more prone to mistakes (Cowan et al., 2005). Furthermore, recalling mathematical facts from memory appears to be challenging (Cowan, 2014; Cowan et al., 2005; Fazio, 1996). On the other hand, children with SLI seem to understand mathematical rules and regularities equally well as unaffected children from the same grade (Donlan et al., 2007).

Based on research findings regarding difficulties in the subject of mathematics, this present study poses the central question whether these problems surface in school for the first time, or whether the children have already experienced difficulties with numerical basic skills in the preschool context (cf. Donlan et al., 2007).

#### 2 Preschool-level basic numerical skills

School starters already possess considerable amounts of knowledge of quantities and numbers, which they have acquired during their preschool time (Mähler et al., 2017). This knowledge facilitates a successful performance in their early

mathematics instruction. At the point of school enrollment, however, the individual knowledge levels differ substantially (Mähler et al., 2017). While some children manage calculations within the number range up to 100 with ease, other children are unable to count to ten. It can be assumed that SLI-affected children start school with an already disadvantageous learning predisposition in the fields of written language acquisition and numeracy, as a result of their extensive speech and language developmental deficits. Examples of relevant precursor competencies in the context of school numeracy are the ability to comprehend a numerical series, the ability to count, associating numbers to quantities, and the recognition of quantitative relations (Passolunghi et al., 2015). The model of number-quantity connection (Krajewski et al., 2013) describes a developmental progress on three levels: Level (1) comprises the differentiation of easily distinguishable quantities, the recital of numerical series, as well as the imitation of the counting procedure. Subsequently, level (2) establishes the connection between quantities and numbers. Two performances initiate the mental conceptualization of quantity: the internalization of the number's ordinal aspect, as well as the realization of the one-to-one assignment while audibly counting. Distinguishing merely between "little" and "a lot," this notion of quantity is yet a rather unprecise one, but it will further evolve into a precise concept of number (assignment of numbers and their corresponding quantities). Level (2) provides the children with the insight, that quantities can be changed by adding amounts or to subtracting amounts from those (= part-whole concept). If both insights are now combined on level (3), the students will have attained a sophisticated understanding of numerical relations, enabling them to express in numbers both partial quantities and differences in quantity.

# 3 Working memory and numerical competence

Aside from the influential role language skills have, the development of basic numerical competence is also heavily impacted by general cognitive functions. Among these, the operability of working memory is a decisive factor in the development of preschool skills (Friso-van de Bos et al., 2013; Schuchardt et al., 2014). Working memory can be described as a system of short-term storage and simultaneous processing of information, prior to permanent storage in longterm memory. Therefore, working memory is involved in every single instance of information processing and can be construed as a sort of bottleneck of cognitive capacity (Süß, 2001). According to Baddeley (1986), working memory consists of a cross-modal central executive, which comprises two subordinate,

modality-specific components which are limited in capacity. The first component is the phonological loop for verbal and auditory information; the second is the visuo-spatial sketchpad, responsible for visual patterns and spatial layout (see Fig. 1). Following Baddeley's model, the central executive carries out the functions of control, monitoring, and coordination, such as the coordination between subsystems during simultaneous information processing, selection of and switching between different strategies of retrieval, management of selective attention, as well as retrieval and manipulation of long-term memory information. In a further elaboration of his model, Baddeley (2000) postulated the episodic buffer as a fourth component. This instance's purpose lies in combining differently coded information (from perception, from other subsystems of working memory, and from long-term memory) into a coherent whole, before transferring this information to long-term memory. Empirical evidence has not yet been provided for this structural addition; so far, only few studies on this subject have been published.

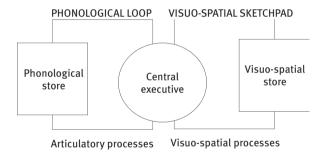


Fig. 1: Working memory model according to Baddeley (1986).

Overall, working memory is regarded as the active memory constituent, which can take in only a limited amount of information. Hence, the operability of working memory constitutes the limiting resource on which an individual's cognitive performance depends. In this context, interindividual differences exist in the size of processed units, and the processing speed of the respective working memories. Both phonological loop and visuo-spatial sketchpad are easily differentiable at an age of four already (Alloway et al., 2006). The differentiation of the central executive cannot be reliably detected before the age of five (Alloway et al., 2006; Michalczyk et al., 2013). For the development of preschool numerical competencies, particularly the visuo-spatial sketchpad has been proven to be a central influencing factor (Krajewski & Schneider, 2009;

Kyttälä et al., 2003; Schuchardt et al., 2014). As Preßler et al. (2013) pointed out in their study, preschool children with an impaired visuo-spatial sketchpad displayed poor mathematical competencies immediately before and three months subsequent to the onset of schooling. This matches the findings on children suffering from dyscalculia, where particularly dysfunctions of working memory's visuo-spatial component have been identified as a decisive causal factor for a reduced numeracy performance (Klesczewski et al., 2018; Schuchardt et al., 2008).

# 4 Working memory and SLI

Working memory difficulties anomalies are also diagnosed in children affected by SLI. Accordingly, a large portion of studies attests a substantial functional deficit of phonological loop and central executive, while impairments of the visuo-spatial sketchpad have been observed rather infrequently (Archibald & Gathercole, 2006; Schuchardt et al., 2013; Marton & Schwartz, 2003; Montgomery & Evans, 2009; Riccio et al., 2007). Schuchardt et al. (2013) examined elementary school children with dyslexia, as well as with a combination of deficits (dyslexia and dyscalculia), focusing on working memory functions. Moreover, half of the test subjects were affected by SLI. Whereas children with a comorbidity of dyslexia and dyscalculia exhibited a functionally impaired visuo-spatial sketchpad, children additionally affected by SLI possessed a properly operating visuo-spatial working memory. Thus, these children's numerical shortcomings appear to be rather a consequence of speech difficulties than attributable to malfunctions of the visuo-spatial sketchpad.

## 5 Research issue

On the basis of research findings on the subject of SLI-affected children experiencing difficulties in mathematics, the principal question (1) arises, whether anomalies regarding preschool basic numeracy competence become apparent prior to schooling? For this, the following categories of competence undergo a closer examination: counting ability, knowledge of numbers, comprehension of quantities, and basic numeracy. It is assumed that preschoolers affected by SLI will, in comparison to their unaffected peers, exhibit a less developed basic numerical competence in all categories.

Moreover, an interesting task (2) lies in exploring the causes of possible developmental deficits in the field of basic numeracy. There are two conceivable explanatory approaches: On the one hand, the study results of Schuchardt et al. (2013) suggest that the present language deficits are responsible for the children's failure to progress at an age-appropriate level in basic numerical learning (language deficit hypothesis). In order to verify this hypothesis, the children affected by SLI will be compared to a group of younger children on the same level of speech development. If the development of basic numerical competencies proceeds analogously to the language level, the performances of these two groups should attain a similar level.

On the other hand, it is also conceivable that, beyond the language deficits, an additional cause in the form of a cognitive working memory deficit exists. In the latter case, the deficit would be attributed to the visuo-spatial sketchpad (working memory deficit hypothesis). Hence, should anomalies of the visuospatial sketchpad appear compared to the control group of the same age, these anomalies could relate to the deficient numeracy development. However, the case of age-appropriate intact visuo-spatial working memory functions would further consolidate the language deficit hypothesis.

#### 6 Method

#### 6.1 Sample and research design

Within the frame of a three-group design, the group of SLI-affected children (n = 25) is contrasted to two control groups: (1) children of the same chronological age without signs of language deficits (CA, n = 25), and (2) a group of children on the same level of language development as the SLI-affected group, that is, of the same language maturity (LA, n = 25). All participating children are native speakers of German and have an IQ of ≥80 (CPM; Bulheller & Häcker, 2002). The children of the SLI group come from two speech therapy kindergartens, the children of both control groups from regular kindergartens. The latter constitute partial random samples from a study on differential developmental courses of cognitive competencies during preschool and elementary school age (Differentielle Entwicklungsverläufe kognitiver Kompetenzen im Vor- und Grundschulalter). The parallelization of language maturity has been conducted on the basis of raw score from the active vocabulary test (AWST-R; Kiese-Himmel, 2005), as well as based on raw score of the subtest morphological rule formation, which is part of the language development test for children (SETK 3-5; Grimm, 2001)

in order to assess grammatical competence. Table 1 contains the sample parameters of all three groups. Here, it becomes apparent that group SLI shows unambiguously substandard performances in the fields of vocabulary and grammar, which would be expected for the age of four.

Tab. 1: Means (SDs) for descriptive characteristics of subgroups.

	SLI (n = 25)	CA (n = 25)	LA (n = 25)
Sex(m/f)	20/05	20/5	14/11
Age (years)	5;4	5;3	4;0
IQ	106.70 (8.01)	105.56 (8.66)	104.32 (7.63)
Vocabulary (RW)	41.09 (8.57)	55.84 (10.09)	40.40 (11.05)
Vocabulary (T-Score)	23.81 (4.45)	52.24 (13.79)	50.28 (9.75)
Grammar (RW)	18.82 (6.56)	26.44 (4.48)	17.04 (7.85)
Grammar (T-Score)	31.79 (4.15)	49.90 (14.77)	50.72 (10.61)

Note: SLI = specific language disorders; CA = chronological age; LA = language age.

#### 6.2 Instruments

#### 6.2.1 Numerical competencies

The implicated battery of tasks has been developed for the age group between three and six years (retest-reliability rtt = .95). Computers have been used as interface for all tasks. Counting abilities have been tested via two subtests. For audible counting (Cronbach's alpha = .95), the child is instructed to count a sequence of numbers up to 25. In a further step, the child is asked to count from 58 to 72. The latter sequence is meant to test the child's ability to start counting from any given point within the numerical series. In *counting objects* (Cronbach's alpha = .83), the child is instructed to count 11 given quantities, which are being visually presented (yellow stars on a blue background) in succession. The child is asked to point a finger at the individual objects while audible counting them. The number of stars varies between three and twenty-one. The task assesses the degree to which the child already masters basic counting principles, such as one-to-one correspondence, stable order, and cardinality. For the survey regarding *numeral knowledge*, the two following tasks have been designed. For the denomination of Arabic numerals (Cronbach's alpha = .93), a task with 17 items captures the ability of transferring Arabic numerals into words. The numerals (1 to 12, 15, 18, 19, 100, and 116) are presented along with additional objects to be named (e.g., mouse, apple, tree, ball, moon) on a computer display. In the second task, transcoding (Cronbach's alpha = .65), three Arabic numerals are visually displayed; the child is subsequently asked to point out a verbally indicated number within this number range (number range: 1 to 150). The comprehension of quantity has been assessed with the task *quantity comparison* (Cronbach's alpha = .73). On a screen, two rectangular shapes are displayed, each filled with different amounts of objects (circles, squares, bars). The child is to name the square containing the largest number of objects. The objects vary in size, shape, and arrangement. At the same time, the quantitative proportions differ greatly (e.g., 15:3, respectively 7:6). Early numerical competence has been examined in two tasks. For the addition of two visualized quantities (Cronbach's alpha = .66), two circles, each containing blocks which indicate quantities, are displayed. The task now is to determine the sum of both quantities. In the task mental operations involving objects (Cronbach's alpha = .77), the computer shows either a garage or a rabbit's burrow, into which successively two differing numbers of cars, respectively of rabbits, enter and disappear. Following this presentation, the child is asked to report the number of objects inside the structures. Also, this task assesses primary addition skills, whereby the first subset must be represented mentally in order to add the second subset.

As dependent variables, the children's individual raw points have been divided by the corresponding total of items for every single subtest; resultingly, the values are in the range of 0 to 1.

#### 6.2.2 Working memory

Here, children worked on two tasks from the working memory test battery for children between ages 5 and 12 (AGTB 5-12; Hasselhorn et al., 2012). For the examination of the visuo-static component of the visuo-spatial sketchpad, the matrix span has been implicated (retest-reliability rtt = .51; split-half-reliability r = .98). Patterns of black-and-white sections of a four-by-four matrix are visualized on the display, starting with two sections and increasing up to a maximum of eight black sections. Immediately following this presentation, the children are to reproduce the black sections by pressing the corresponding areas on the empty display matrix. A *corsi-block-span* (retest-reliability rtt = .60; split-half-reliability r = .97) serves to assess the visuo-spatial sketchpad's spatial-dynamical component. The child is exposed to a touchscreen monitor showing nine arbitrarily arranged white squares, in which for moments little smiley faces appear consecutively. Subsequently, the child is instructed to touch those display areas in which the smiley faces had been visible, in order of their appearance. As the dependent variable, the longest sequence attained in both tasks is being determined.

## 7 Results

The performances for the entirety of tasks examined of three groups can be obtained from Tab. 2. Initially, the performances in the field of numerical competence have been analyzed via individual univariate analyses of variance (ANOVA). Through this, as presumed, a significant group effect manifested itself for all tasks (Tab. 2). Further post hoc tests (Tukey) for the explanation of group effects illustrated that children of the CA group achieved significantly

Tab. 2: Means (SDs) for numerical competencies and working memory of subgroups.

	SLI	CA	LA	ANOVA		Post hoc comparison	
				F(2,72)	р	$\eta_p^2$	
Numerical competencies							
Counting abilities							
Audibly counting	0.32 (0.14)	0.50 (0.18)	0.33 (0.18)	9.73	.000	.213	SLI = LA < CA
Counting objects	0.53 (0.26)	0.81 (0.22)	0.50 (0.26)	11.70	.000	.245	SLI = LA < CA
Numeral knowledge							
Denomination of Arabic numerals	0.32 (0.20)	0.52 (0.23)	0.20 (0.24)	9.94	.000	.216	LA < SLI < CA
Transcoding	0.64 (0.24)	0.76 (0.20)	0.49 (0.26)	8.48	.000	.191	LA < SLI < CA
Comprehension of quantity							
Quantity comparison	0.72 (0.09)	0.82 (0.10)	0.63 (0.13)	19.21	.000	.348	LA < SLI < CA
Early numerical competence							
Addition of two visualized quantities	0.54 (0.24)	0.77 (0.28)	0.57 (0.26)	5.77	.005	.138	SLI = LA < CA
Mental operations involving objects	0.41 (0.24)	0.57 (0.24)	0.40 (0.22)	4.08	.021	.102	SLI = LA < CA
Visuo-spatial working memory							
Matrix-span	3.28 (0.84)	3.28 (0.74)	2.29 (0.64)	14.40	.000	.289	LA < SLI = CA
Corsi-block-span	3.28 (0.74)	2.96 (0.79)	2.54 (0.59)	6.62	.002	.157	LA < SLI = CA

Note: SLI = specific language disorders; CA = chronological age; LA = language age.

better results in all tasks than children affected by SLI. The comparison with group LA is used to answer the question whether these poor numerical performances of children exhibiting language development anomalies can be attributed to their low level of language development. Here, the results show a heterogeneous pattern. While group SLI yields comparable results in the fields of counting ability and numeracy, they deliver better results than group LA in tasks regarding numeral knowledge and quantity comparison.

As a second step, the performances for working memory's visuo-spatial sketchpad have been examined employing once more univariate analysis of variance (ANOVA) for both tasks separately. Again, substantial group effects appeared (Tab. 2). Yet, subsequent post hoc comparisons uncovered a different result pattern. In both tasks, the SLI and the CA groups yielded similar results, which were significantly higher than those of group LA children.

## 8 Discussion

The present study closely examined the development of basic numerical preschool competence of SLI-affected children prior to schooling. It became apparent that these individuals showed weaker performances than their peers without language impairments in all fields. In this context, counting ability and first numerical operation skills are comparable to the results of the younger control group. Thus, it appears that the exhibited developmental delay corresponds to the deficit in language competence. However, different result patterns come into view in the examination of quantity comprehension and numeral knowledge. Here, the SLI-affected children's performances rank between those of the two control groups. These findings might be interpreted as evidence for general numerical knowledge of quantity and numerals is not as strongly affected as the specific numerical operations of counting and calculating (cf. Donlan et al., 2007). Presumably, operations of counting and calculating are related to language proficiency more closely than knowledge of quantity and numerals.

Furthermore, it becomes clear that anomalies of numeracy development cannot be associated with a diminished capacity of working memory's visuo-spatial sketchpad. Despite the fundamental role visuo-spatial working memory plays in building up numerical preschool competencies, the children with deficient preschool competence partaking in this survey did not exhibit shortcomings regarding visuo-spatial working memory. Beyond that, functional anomalies of the visuospatial sketchpad can be assessed to have a clear connection with a developing dyscalculia (Schuchardt et al., 2008). Asked for a cautious estimate, one can derive

from the findings that the SLI-affected children examined here do not possess a significant risk of developing a dyscalculia, since they are unaffected by working memory problems, which frequently are the underlying cause.

Results of the present study rather give evidence for the language deficit hypotheses, according to which language development anomalies represent an obstacle to age-appropriate numeracy development. This obstacle becomes apparent already at preschool age in counting and calculation tasks. Therefore, one can conclude that age-appropriate language competence is not only of central importance in its role as a prerequisite of literacy, but that it is also crucial for the acquisition of preschool numerical competence. For this reason, SLIaffected children after all are particularly prone to developing learning dysfunctions. Since the acquisition of knowledge and the transfer of educational content happen via speech and language, language development deficits constitute a considerable risk for achieving academic success, to which affected children are exposed during preschool and schooling ages.

The results described must be considered in the light of the limitations of the study. It should be noted, for example, that the sample size is rather small. A replication on a larger sample would therefore be desirable. Moreover, only a few working memory tasks were included. A comprehensive battery of tasks that include a wider range of working memory functions would be desirable here. Furthermore, we should be aware of the fact that a diagnosis of SLI is less stable at early ages, and therefore, predictions should be made carefully.

To counteract the emergence and consolidation of numeracy acquisition problems within the context of school education, special tuition is mandatory from early on. As it is the case for all combined developmental deficits (in this case preschool language and numeracy competence), there is a lack of academic studies to recommend an appropriate, evidence-based strategy of support: Would a specific language tuition result in an improvement of numerical competence? Or, as an alternative approach: Is the training of numerical competence the more appropriate intervention, considering the reduced level of speech development?

Possibly, children with language impairments require simplified teaching instructions tailored to their needs, ideally realized via visualization, in order to facilitate the comprehension of numerical concepts. The same problem presents itself during the first years of schooling, even in specialized language learning groups, or in an inclusive learning group offering special language tuition. While both pedagogical environments obviously focus on improving language competence, a methodically and didactically differentiated form of tuition may still be requisite, which explicitly takes into consideration the children's individual learning progress.

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