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Relationships between the development of numerical abilities and phonological awareness in young age

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Abstract

Background: Previous neuropsychological studies pointed out that amongst the various cognitive skills leading towards the development numeracy; language skills may have an important, while mostly overlooked role. Out of the numerous language skills, phonetic awareness seems to aid the development of arithmetic skills.
Aims: This research aims to explore the relationship between phonetic awareness and the development of numerical skills in young children.
Methods: In this research, children aged 5-6-7-year-old (who were still in kindergarten) were included. We measured their numerical skills using Number Sense Screener and their phonemic awareness using in study.
Results: Regression analysis showed a linear relationship between phonemic awareness and arithmetic skills in children at 6 and 7 years old.
Conclusion: Our results indicate a link between the development of phonemic and arithmetic skills. Furthermore, there is evidence to suggest that the development of these aforementioned skills can predict success in later educational performance.

Keywords: neurophysiology, phonological awareness, numerical skills

Introduction

Development of numerical abilities

The comprehension of numbers, values and amounts is a basic necessity for us. Understanding and solving mathematical problems are part of our everyday life. As such, investigating the development of numerical skills is important in understanding how to help children learn mathematics. Although there is little information on the frequency of dyscalculia, the number of children with learning disabilities tends to increase every year (KSH, 2022). It is unavoidable that we investigate atypical developments and look for ways to mitigate the issues arising from learning disabilities. Exploring developments during kindergarten years is paramount for a better view of how learning disabilities appear in children.

Numerical ability is a multi-component cognitive system. According to the Triple Code Model (TCM, Dehaene, 1992; Dehaene & Cohen, 1995), this cognitive system consists of three closely interconnected mental representations mediated by different brain networks (Figure 1). These three codes are the verbal code (i.e. the word ‘four’), the visual representation (i.e. the Arabic number ‘4’) and an analogue representation of magnitude (i.e. the specific or approximate amount). The verbal code is assumed to be involved in exact counting, and the Arabic code is in written algorithms. The third representation, which supports numerical skills, occurs in numerical activities such as comparisons or approximate arithmetic.

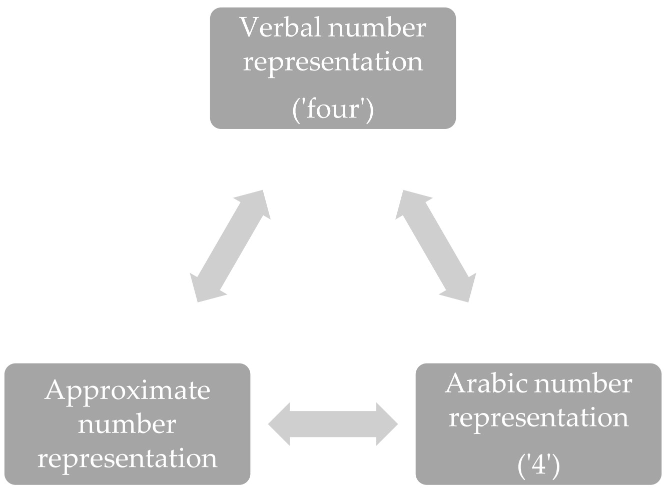

Figure 1. *The Triple Code Model (TCM). The three types of coding of numerical values are verbal (top), visual (bottom right) and abstract (bottom left). These types of coding interact with each other and are involved in different aspects of arithmetic.*

Although the development of early numerical ability is well-known (see discussed in Wynn, 1992), little is known about the development of the overall profile (Passolunghi et al., 2015). Number skills are multi-componen,t and the development of these facets takes years (Dehaene, 1992). For the current topic, it is particularly important that the development of mathematical abilities is influenced by several cognitive factors such as language abilities, both verbal and non-verbal (McCrink & Wynn, 2004; Starr, Libertus & Brannon, 2013; Lourenco et al., 2012). Counting and exact arithmetic rely on language-based representations, whereas the comparison of numbers and estimation of amounts involve approximate quantity-based representations that are already available early in years, before the first stages of language acquisition (Nys, Content & Leybaert 2013).

While the TCM model already assumes the involvement of language skills in the development of numerical abilities (i.e. the verbal expression of numbers) (Dehaene, 1992; Dehaene & Cohen, 1995), the identification of the exact language functions involved is yet to be uncovered. Fortunately, some verbal abilities involved with the development of numerical skills are already identified. For example, the verbal representation of numbers is used for the mental manipulation of numbers (Van Rinsveld et al., 2022), arithmetic facts are stored in verbal memory (Otero, Salgado & Moscoso, 2022), and the availability of phonological coding can be.

The relationship between phonological awareness and numerical success

Mathematical and reading skills are correlated, and language skills play a significant role (Korpipää et al., 2017). These results lead to the next hypothetical question if these same language abilities can regulate the numerical success. Previous studies pointed out a potential link between phonetic awareness and mathematical skills (Mazzocco & Myers, 2003, Cowan et al., 2005), but there is a serious lack of research aiming to answer when and how these language skills are linked to the development of numeracy and literacy abilities of young children.

Phonological awareness is an important component of phonological processing (Wagner & Torgesen, 1987) and at least two models showed significant involvement in numerical processes, too. According to the TCM, the verbal code of a number relies on phonological processing when working with numbers (Dehaene et al., 2003). LeFevre et al. (2010) found three cognitive precursors in the early development of numeracy, namely the development of quantitative, linguistic, and spatial attention.

Research questions

1. Could the currently understood developmental progress of number sense to be shown in Hungarian kindergarten-age children?

Previous studies established clearly divided levels of the development of number sense from age five upward (Jordan et al., 2010). However, these levels have not yet been investigated in a Hungarian sample. Furthermore, our understanding of number comparison skill development, which is the best indicator of the atypical development of number sense, is still lacking (Györkő, 2015; Györkő et al., 2020).

2. Is there a difference between phonological awareness of children within very narrow age groups?

The development of phonological awareness is influenced significantly by the process of learning to read. It is well-established that certain phonological abilities are developing during kindergarten, such as vocabulary (Jordanidisz, 2011; Oluette & Haley, 2013). However, it is still unclear if there are significant differences within a narrower age range (i.e. 1 year, resulting in age groups of 5, 6 and 7 years old children).

3. Is there a link between phonological consciousness and numerical sense developments?

Phonological awareness is important for successful language comprehension. It can be assumed that there is also a link between phonological and mathematical abilities, as correlations have been shown between numerical magnitude processing and phonological processing in the Chinese sample (Liu et al., 2022).

Methods and materials

Participants

Data from 367 children were analysed in this study. The children were assigned into three age groups: 5, 6 and 7 years olds (Table 1). Thus, we have covered the sensitive period of the development of phonological awareness (Mayo-Turk; 2005, Nittrouer & Lovewenstein, 2010).

Table 1. *Age patterns of the examined sample*

	N	*Age average/year*	*Minimum age/year*	*Maximum age/year*	*Std*
5 years old	90	5,4	5,1	5,9	,30547
6 years old	237	6,3	5,11	6,9	,32192
7 years old	40	7,1	7	7,9	,19474

Questionnaire

In order to investigate the numerical skills of the children, the Numerical Comparisons and Number combinations subscales of the Number Sense Screener (NSS) were used. The Number Comparisons section assesses understanding of number magnitude when presented in a symbolic form. Numerals corresponding to the numbers in the tasks are presented in the NSS stimulus book, but no physical or pictorial model of the quantities. The Number Combinations items in the story problems subarea assess the child's ability to pull the mathematical data out of a story and perform either an addition or a subtraction problem (Jordan, Glutting & Dyson, 2012).

Phonological awareness was measured by the children's ability to accurately identify the position of specific sounds in a word. During the task, children had to answer if they heard a specific sound at the beginning, middle or the end of the word. The words were given to the children in the forms of pictures.

Results

Comparing number sense and phonological abilities of age groups

Our tests revealed significant differences between the age groups in several tasks (Table 2). The children were significantly different in their results of arithmetic tasks (Figure 2); however, in number comparison there was only a significant difference between 6- and 7-years old children (Table 3). It can be argued that a potential developmental leap is present between 6 and 7 years of age.

Table 2. *Results of analysis of variance on numerical performance and phonetic awareness by age group*

		MEAN	*STD*	*F*	*P*
MAGNITUDE COMPARISON	5 years old	5,833	1,056		
	6 years old	5,743	1,355	,983	,375
	7 years old	5,966	1,530		
NUMERICAL COMBINATIONS	5 years old	4,111	1,166		
	6 years old	3,682	1,461	6,430	<,002
	7 years old	4,203	1,090		
PHONOLOGICAL AWARENESS	5 years old	4,194	2,936		
	6 years old	4,747	2,763	6,527	<,002
	7 years old	5,712	2,579		

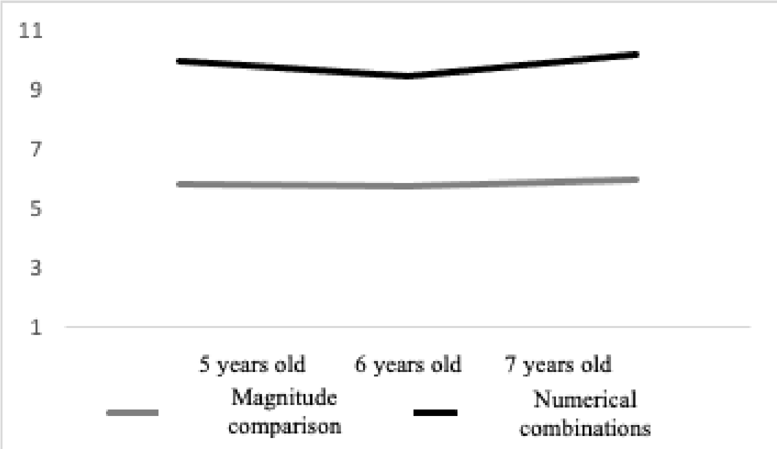

Figure 2. *Results of the judgment of numerical magnitude and the performance of numerical operations by age group*

We used a one-way analysis of variance (ANOVA) to investigate the phonological awareness scores. There was a significant main effect of age group. Post hoc tests revealed significant differences between 5 and 6 and 6- and 7-years old children's results, but there was no difference between 5- and 6-years old children's scores (Figure 3).

Table 3. *Comparing the performance of age groups in numerical magnitude comparison, numerical combinations, and phonological awareness tasks*

		MEAN DIFFERENCE	*STD. ERROR*	*P*
MAGNITUDE COMPARISON	Between 5-6 years old	,09034	,25013	,931
	Between 5-7 years old	-,13277	,26438	,870
	Between 6-7 years old	-,22311	,15921	,341
NUMERICAL COMBINATIONS	Between 5-6 years old	,42887	,23874	,172
	Between 5-7 years old	-,09228	,25233	,929
	Between 6-7 years old	-,52115*	,15196	<,002
PHONOLOGICAL AWARENESS	Between 5-6 years old	-,55322	,49051	,498
	Between 5-7 years old	-1,51742*	,51845	<,010
	Between 6-7 years old	-,96420*	,31222	<,006

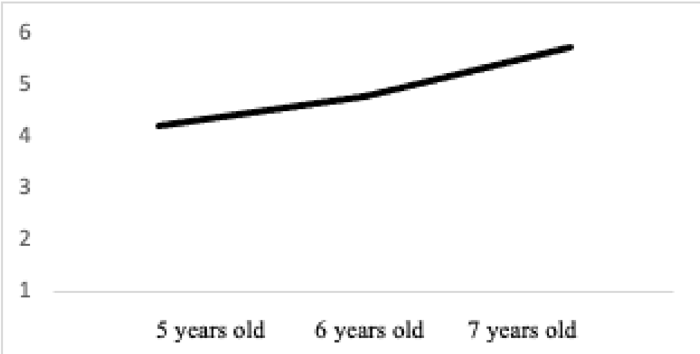

Figure 3. *Changes in the performance of phonetic awareness according to the comparison of age groups*

Investigating the link between phonological and numerical abilities

Linear regression analysis showed a clear link between phonological awareness and number comparison skill, as well as between phonological awareness and arithmetic skills. However, the link is non-significant for 5 years old children and strongly significant for 7 years old children (Table 4). It can be reasoned that 7 years old children rely a lot more on their phonological abilities to solve cognitive problems.

Table 4. *Distribution of the relationship between phonetic awareness and numerical success by age group*

		Phonological awareness			
		R	F	t	p
Magnitude comparison	5 years old	,304	3,163	1,778	,085
	6 years old	,191	9,530	3,087	<,002
	7 years old	,549*	33,996	13,246	<,001
Numerical combinations	5 years old	,242	1,926	1,388	,175
	6 years old	,317	28,114	5,302	<,001
	7 years old	,317	8,847	2,974	<,004

Conclusions

Here, we investigated the relationship between two cognitive abilities' development. Within number sense, we focused on number comparison and combination skills, while within phonological skills, we investigated phonological awareness. Additionally, we have investigated the relationships between the aforementioned cognitive abilities in three narrow age groups (5, 6 and 7 years old).

We have identified significant developmental leaps from 6 to 7 years old children (which is the age just before or at starting elementary school in Hungary), which is in line with previous findings (Jordan et al., 2012). This was expected, as previous studies already pointed out significant developments in number sense (e.g. arithmetic skills, and number comparisons skills) at this age range (Györkő, 2015; Györkő et al., 2020). Numerical comparison skills are described as having a predictive effect on number sense (Schneider et al., 2017; Schwenk et al., 2017), as well as success in elementary school (Jordan et al., 2007; Jordan et al., 2009). Based on our previous findings, it can be argued that older children (7 years old) are more successful as they accumulate more and more experience (Yilmaz, 2017).

Several novel paradigms stepped over the evaluation of developmental patterns and priorities tasks aimed at developing cognitive abilities. For instance, the view on the development of arithmetic and mathematical skills of children shifted significantly (see discussed in Baroody, Lai, Mix, 2006; Kermani, 2017, Aragón-Mendizábal et al., 2017; Thomas, et al., 2021). It is more widespread to investigate typical and atypical developmental patterns, as well as give suggestions on modernising our way of teaching mathematics. For example, Baroody, Eiland and Thompson (2009) reported significant development of mathematical knowledge in high-risk kindergarten-aged children following a 9 months long training.

It is important to stress our findings about the strong link between phonological awareness and number sense for children at the end of their kindergarten years. We suggest a supporting role of language skills for accurate mathematical problem-solving as well as text comprehension (De Smedt, 2018). This link has been found in young atypical children as well: There was a strong link between phonological awareness and number sense in young children with dyscalculia (Peters, De Beeck & De Smedt, 2020). However, other studies suggest that this correlation between phonological and numerical skills is present in older children as well. Hecht et al. (2001) investigated nearly 200 8 years old children's phonological memory, awareness and access to phonological codes up until they turned 11 years old. All three abilities (phonological memory, awareness and access to phonological codes) correlated with their mathematical computation skills throughout the study. Furthermore, they showed that phonological processing skill predicts the level of numerical abilities.

In sum, our findings, together with the results reported in the literature, suggest that there are sensitive periods of numerical skill development. These sensitive periods are strongly linked with phonological abilities, such as phonological awareness. We can also link our findings to the previously suggested link between phonological representation and cognitive development (Simmons & Singleton, 2008).

Limitations and future plans

Our study had limitations and gave us insight for future research ideas. First, we worked with an unbalanced sample (90, 237 and 40 for age groups 5, 6 and 7 respectively), making it difficult to account for individual variability. Second, we only studied phonological awareness. We suggest including the measurements of verbal memory, as well as other linguistic aspects, such as syntactic comprehension in future investigations. By adding these aspects, we can paint a more accurate picture of cognitive development, thus better explaining early signs of atypical development in children.

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