School-entry Sensorimotor and Cognitive Profile and Success in Mathematics

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Abstract:	In our research, we are following primary school first-graders, tracking their progress over time in diverse areas. The Sensorimotor and Cognitive Profile Test is a tool for teachers to obtain information on the developmental profile of children so that they can plan their personalized methods of mathematics learning based on the results. We have assessed 415 first-graders' sensorimotor and cognitive abilities and compared these profiles with the level of academic math success based on teachers' evaluation. The results indicate that 20% of the children do not have the matured sensorimotor and cognitive functions vital for learning mathematics and only 53% of the first-graders could master the curriculum well. The groups of first-graders who failed or were very poor in mathematics in the first months of schooling differed from the better-achieving groups in all monitored variables. However, the most critical area, apart from abstract thinking and quantity concept, seems to be working memory. Several sensorimotor areas, such as body scheme and spatial orientation, sensorimotor efficiency, seriality, and even sense of balance are also among the areas to be improved for a chance at acceptable achievements in mathematics.

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Abstract

In our research, we are following primary school first-graders, tracking their progress over time in diverse areas. The Sensorimotor and Cognitive Profile Test is a tool for teachers to obtain information on the developmental profile of children so that they can plan their personalized methods of mathematics learning based on the results. We have assessed 415 first-graders' sensorimotor and cognitive abilities and compared these profiles with the level of academic math success based on teachers' evaluation. The results indicate that 20% of the children do not have the matured sensorimotor and cognitive functions vital for learning mathematics and only 53% of the first-graders could master the curriculum well. The groups of first-graders who failed or were very poor in mathematics in the first months of schooling differed from the better-achieving groups in all monitored variables. However, the most critical area, apart from abstract thinking and quantity concept, seems to be working memory. Several sensorimotor areas, such as body scheme and spatial orientation, sensorimotor efficiency, seriality, and even sense of balance are also among the areas to be improved for a chance at acceptable achievements in mathematics.

Keywords: sensorimotor and cognitive profile, mathematics, school-entry

1. Introduction

Mathematical thinking influences individuals' experiences of the environment, contributing to their perception and meaning-making about the world. (Tall, 1995) However, in education, mathematics teaching still focuses mainly on numeracy (Linder and Simpson, 2018), and the school measures children's mathematical knowledge through counting operations. Numbers are part of the language of mathematics that children have to master, but the emphasis in school is so much on learning to count that those who perform less well in this end up excluded from mathematical thinking through their initial failure (Carpenter. Fennema & Franke, 1996). Significant changes should be

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carried out in teaching mathematics to first graders in at least two respects: numeracy should be linked much more to mathematical thinking and the teaching of mathematics should progress in line with children's neurological maturation. (Bobis et al., 2005) The first task involves reconsidering the teaching materials used for mathematics instruction. The second task is much more complex, because the development of children's nervous system is extremely diverse not in small part due to the recently expanded information space, as a consequence of which the development of a wide range of basic sensorimotor functions has become necessary. Piaget (1955) cautioned that children may need to learn physical rules before learning abstract representations. Since individuals may have different ability structures, they are likely to take different learning paths. Laja and Hijirian (2022) observed gender-based differences in cognitive development among university students that affected their learning of mathematics. They argue that these differences should be taken as opportunities for improving teaching approaches to suit individual learners' needs. We argue that it is important to know the ability profiles that are beneficial and work well in learning mathematics, as well as the characteristics representing obstacles to the learning progress. However, research shows that attention seems to have been directed to the first challenges since the majority of teacher training is focused on improving teaching materials and strategies (Gosztonyi, 2020, 2023). Therefore, the second challenge is worth being considered in research.

2. Learning basic mathematics

Research findings have repeatedly suggested that information processing speed, visuospatial abilities, working memory, number sense, and fluid intelligence contribute significantly to school performance (Rohde & Thompson, 2007; Tikhomirova, Malykh & Malykh, 2020). Cueli and colleagues (2020) found that attention is highly important in young children's numeracy skills, but also found that response time is more important. In

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addition, deficits in mathematics can also provide insight into the range of cognitive functions needed to learn maths. For example, recent research by Agostini, Zoccolotti, and Casagrande (2022) has shown that children with mathematical difficulties are impaired in cognitive areas such as executive functions, attention, and processing speed. Therefore, this shows that students' failure in mathematics should not be viewed as a single cognitive functioning aspect but rather a combination of cognitive aspects such as memory, speed and attention.

Parviainen (2019) identified the main mathematical skill categories – numerical skills, spatial thinking skills, and mathematical thinking and reasoning skills – in her theoretical framework for a holistic model of the development of early mathematical skills. She emphasized that in early mathematics learning, the simultaneous strengthening of versatile early mathematical skills through conscious early learning practices should be addressed. However, less emphasis was on the sensorimotor area, even though higher-level cognitive development is based on sensorimotor functions.

In contrast, Pickavance et al. (2022) point out that the role of sensorimotor skills in the development of higher-order cognitive domains such as mathematics is underestimated. They argue that inadequate sensorimotor measures explain differences in executive functions and not in lower-level functions. They found interceptive timing performance (the sensorimotor ability to interact with a moving target while the person is moving) to be a determinant of mathematical performance in children aged 5-11 years, and this relationship persisted into the teenage years. Pickavance and colleagues (2022) conclude that children's development of sensorimotor skills should be viewed as part and parcel of their intellectual development. In addition, Giles et al. (2018) observed that interceptive timing (a sensorimotor aspect) serves as a predictive factor for children's performance in mathematics. This shows that sensorimotor functions need to be taken as

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part of teaching mathematical skills. However, it is risky to rely on this study in the quest of integrating sensorimotor in teaching mathematics because the study has only focused on one aspect (interceptive timing) of sensorimotor. Therefore, this makes the current study among the most significant study to expand the conception of the extent to which sensorimotor influence mathematics learning and how they can be identified.

Based on this, we argue that there are three main areas, each of which is necessary for successful mathematics learning as shown in Table 1. An optimal combination of at least the minimal cognitive functions associated with each of these areas gives rise to an individual mathematics learning profile.

Table 1

Three main areas for learning mathematics and the most important cognitive functions

SENSORIMOTOR SYSTEM	EXECUTIVE FUNCTIONS	MATHS FOUNDATIONS
• Spatial orientation • Spatial memory • Sequential processing • Processing speed	• Working memory • Cognitive control • Selective attention	• Number concept • Figural abstraction

Table 1 shows that successful learning of mathematical skills is the result of children's development in sensorimotor and cognitive functioning. However, currently the mainstream mathematics teaching practices rarely consider cognitive and sensorimotor aspects. This can be caused by a lack of clear curricular expectations, teachers' awareness and methodological preparedness, to focus on cognitive and sensorimotor areas. Consequently, the present study identifies the sensorimotor and cognitive profiles that predispose children starting the first grade of primary school to different degrees of success in learning mathematics.

2.1 Aims

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In our research, we aim to identify the sensorimotor and cognitive profiles that predispose children starting the first grade of primary school to different degrees of success in learning mathematics. Our hypotheses are as follows:

1. Cognitive profiles that are beneficial in learning mathematics can be identified.

2. In addition to some other cognitive areas, sensorimotor abilities are crucial in learning mathematics.

3. Methods

3.1. Procedure

Testing can be carried out easily on a tablet or laptop with a touch screen, even without the participation of a specialist. In the case of young children, in a one-on-one situation, the examiner (test leader) helps them understand the tasks. In our research, the children's teachers took on the role of test leaders, for which we prepared them beforehand. The testing took place over two sessions in the weeks following the start of the school year. Based on the online test results, students were sorted into five levels for each indicator, using the sample mean and standard deviation, so that scores on different tests could be compared: 5 – outstanding (by more than 2 SD above the average); 4 – above average (by more than 1 SD above average but not more than 2 SD above the average); 3 – average (average +- 1 SD); 2 – below average (by more than 1 SD but less than 2 SD below average); 1 – to be developed (below average by more than 2 SD).

Table 2

Tasks and indicators of the Sensorimotor and Cognitive Profile Test

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		Name of the test	Test indicators
Maths	Figural abstraction	Figures - figural abstraction, seeing patterns, conclusion	correct answers
	Number concept	Quantities - concept of number and quantity	correct answers
Executive functions	Working memory	Digit Span backward - efficiency of working memory	correct sequence
		Digit Span backward - extent of the working memory	longest sequence
		Digit Span foward - the auditory sequential memory	correct sequence
		Digit Span foward - the scope of the auditory memory	longest sequence
	Control	Go - no go task - braking system efficiency	efficiency points
		Go - no go task - precision of control	precision points
Sensorimotor development	Sequentiality	Spatial sequence - spatial sequential thinking	correct answers
		Time sequence - temporal sequential thinking	correct answers
	Sensorimotor efficiency	Speech sounds discrimination - differentiation of speech sounds	correct answers
		Shape-background - shape-background diffrentiation, scanning	correct answers
		Searching - eye movement control, scanning	correct answers
	Body awareness, orientation	Identification of body parts - body scheme	correct answers
		Identification of fingers - finger awareness	correct answers
		Relationship with objects - using spatial relations	correct answers
	Balancing ability	Balance with eyes open, right leg - sensorimotor intergration	time
		Balance with eyes open, left leg - sensorimotor intergration	time
		Balance with eyes closed, right leg - sensorimotor intergration	time
		Balance with eyes closed, left leg - - sensorimotor intergration	time

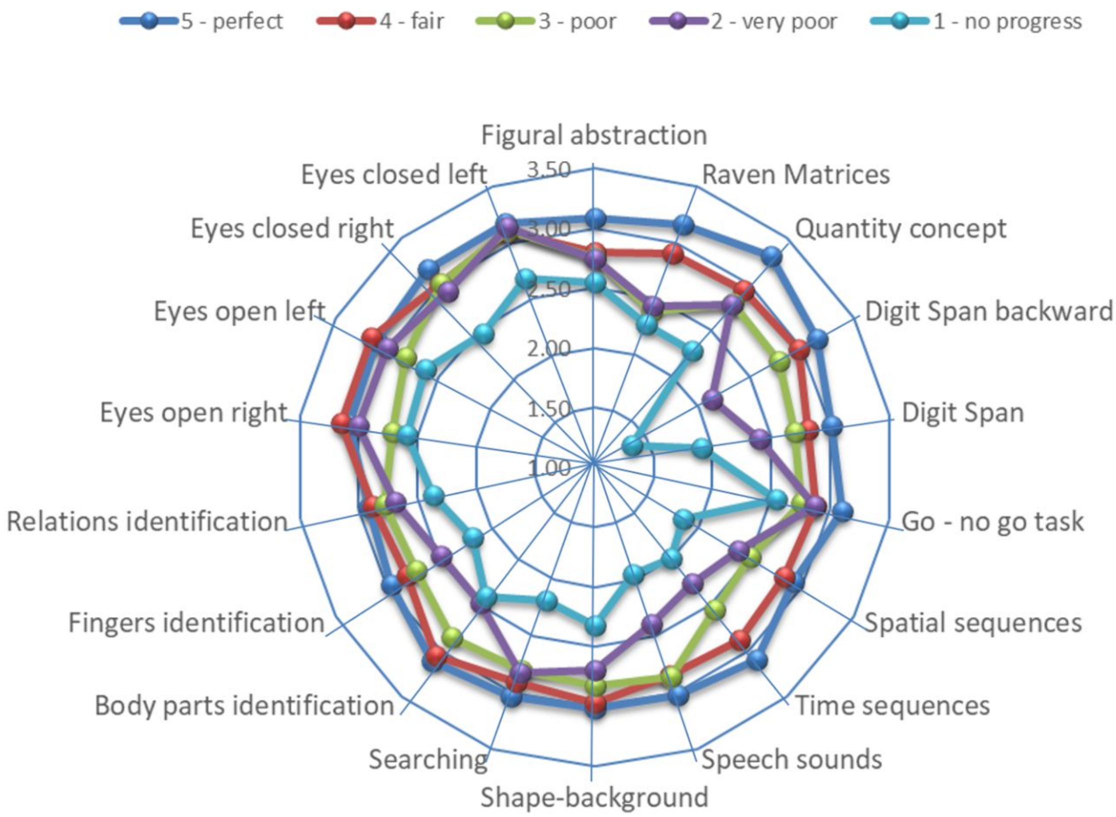
4. Results

We do not use all the indicators in the presentation of the results, only the most relevant ones. The five groups of students showing different levels of mathematics learning do not differ in gender or age, only in ability structure. Of the groups, Group 1, which is lagging in terms of mathematics development, differs from the other groups significantly in their profile. The chart shows that it is not so much in intellectual ability that these children are lagging, but rather in executive functions and some sensorimotor areas (Figure 1).

On the chart, Group 2 appears visually to be a slightly milder version of Group 1 and also shows poor executive function and sensorimotor scores. Group 3 has a less undulating profile, even less so for Group 4. Group 5 shows a consistent ability structure, providing a stable background for learning at school. The results indicate that the group that is doing very well in mathematics is not restricted to the particularly outstanding (they achieved around category 3 in terms of the test scores). In other words, with a normal level of maturity, it is possible to be successful in school mathematics. The profile can be plotted as a star diagram, but the continuous line representation creates specific shapes that make the differences visible.

Figure 1

Cognitive profiles of the five differently progressing groups in mathematics. The sensorimotor and cognitive indicators are likewise plotted on a scale of 1-5



Visually visible differences between the profiles of groups 1-5 were verified by a paired-sample t-test. Group 5 scored better than the other groups on all tasks, with significant differences on most items, even in the closed-eyes right-leg position.

Table 3

Results And T-Test of The Groups – Reasoning, Quantity, Working Memory, Control Functions

Groups of different progress	Figural abstraction	Quantity concept	Digit Span	Digit Span backward	Go - no go task
			longest	longest	recall
5 - perfect	3.08	3.30	3.15	3.01	3.10
4 - fair	2.80	2.93	2.96	2.81	2.88
3 - poor	2.75	2.79	2.78	2.69	2.75
2 - very poor	2.74	2.77	2.13	2.39	2.87
1 - no progress	2.55	2.27	1.36	1.91	2.55
Average	**2.93**	**3.07**	**2.91**	**2.84**	**2.96**

Group 4 differed from the poorer performers in fewer areas. A comparison with Group 5 shows which areas are disadvantageous for them, contributing to somewhat more delayed progress (abstraction, quantity concept, control functions, and especially several sensorimotor areas). Comparison of the other groups does not show significant differences, only in working memory and temporal sequences. These functions develop at the end of the neurological maturation process at this age. Presumably, at the start of school, it is an advantage if a child matures faster, to the extent that this is reflected in success in learning mathematics.

Table 4

T-Tests of the Groups (P-Values) – Reasoning, Quantity, Working Memory, Control Functions

Test name	Figural abstraction	Quantity concept	Digit Span	Digit Span backward	Go - no go task
5 v. 1-3	0.0000	0.0000	0.0000	0.0000	0.0000
4 v. 1-3	0.2711	0.0107	0.0000	0.0014	0.1459
4 v. 5	0.0002	0.0000	0.0094	0.0033	0.0013
3 v. 4	0.9305	0.6798	0.0000	0.1203	0.0690
2 v. 3	0.5115	0.9443	0.0048	0.0070	0.6907
1 v. 2	0.4322	0.2913	0.0000	0.0072	0.5335
1 v. 4	0.0831	0.0001	0.0000	0.0000	0.0317
1 v. 5	0.0003	0.0000	0.0000	0.0000	0.0000

Table 4

Results and T-Test of the Groups – Basic Sensorimotor Abilities

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Groups of different progress	Body parts identification	Relations identification	Spatial sequences	Time sequences	Speech sounds	Shape-background searching
5 - perfect	3.11	2.91	2.91	3.10	3.03	3.03
4 - fair	3.06	2.88	2.83	2.88	2.85	2.90
3 - poor	2.86	2.78	2.50	2.56	2.86	2.81
2 - very poor	2.48	2.70	2.39	2.26	2.39	2.83
1 - no progress	2.41	2.36	1.86	2.00	1.95	2.18
Average	**3.00**	**2.85**	**2.77**	**2.89**	**2.87**	**2.92**

The compared groups	Body parts identification	Relations identification	Spatial sequences	Time sequences	Speech sounds	Shape-background searching
5 v. 1-3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4 v. 1-3	0.0002	0.0050	0.0000	0.0000	0.0005	0.0047
4 v. 5	0.5094	0.5013	0.0698	0.0004	0.0079	0.0324
3 v. 4	0.5624	0.1322	0.2996	0.0000	0.5927	0.9708
2 v. 3	0.1400	0.0608	0.9060	0.7684	0.2606	0.2685
1 v. 2	0.2784	0.7862	0.0278	0.3782	0.0032	0.1268
1 v. 4	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000
1 v. 5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

The results show that sensorimotor abilities play a major role in learning mathematics. Not only higher-order sensorimotor domains, such as spatial and temporal sequences, do so, but lower-level ones, like body schema and basic areas of perception, such as shape-background discrimination or speech sound differentiation, also play a role in the success of learning mathematics (Tables 4 & 5).

Table 5

Results and T-Test of the groups – Main Sensorimotor Abilities, and Balancing

Groups of different progress	Spatial sequences	Speech sounds	Shape-background searching	Eyes open right	Eyes open left	Eyes closed right	Eyes closed left
5 - perfect	2.91	3.03	3.03	3.08	3.10	3.17	3.17
4 - fair	2.83	2.85	2.90	3.15	3.16	3.01	3.10
3 - poor	2.50	2.86	2.81	2.71	2.83	3.00	3.11
2 - very poor	2.39	2.39	2.83	3.00	3.00	2.91	3.13
1 - no progress	1.86	1.95	2.18	2.59	2.64	2.45	2.68
Average	**2.77**	**2.87**	**2.92**	**3.04**	**3.06**	**3.05**	**3.12**

The compared groups	Spatial sequences	Speech sounds	Shape-background searching	Eyes open right	Eyes open left	Eyes closed right	Eyes closed left
5 v. 1-3	0.0000	0.0000	0.0000	0.0001	0.0021	0.0003	0.0524
4 v. 1-3	0.0000	0.0005	0.0047	0.0004	0.0020	0.1283	0.5009
4 v. 5	0.0698	0.0079	0.0324	0.3758	0.3665	0.0548	0.3514
3 v. 4	0.2996	0.5927	0.9708	0.2150	0.0709	0.0034	0.0172
2 v. 3	0.9060	0.2606	0.2685	0.6150	0.6303	0.1457	0.4088
1 v. 2	0.0278	0.0032	0.1268	0.1431	0.3623	0.0265	0.0457
1 v. 4	0.0000	0.0000	0.0000	0.0011	0.0006	0.0012	0.0011
1 v. 5	0.0000	0.0000	0.0000	0.0003	0.0004	0.0000	0.0005

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4. Discussion and Further Steps

Our developmental indicators measured at the start of schooling indicate that 20% of children lack the necessary maturity foundations to learn mathematics. Abstract thinking, quantity concept and working memory were part of the cognitive aspects that were identified to be influential in learning mathematical skills. The results imply the possibility of identifying cognitive aspects that enhances mathematics learning among students. Laja and Hijirian (2022) argue that teachers can improve mathematics teaching practices only if they know the cognitive development level of each student. Therefore, the identified cognitive aspects that enhance mathematics learning provide the basis for teachers to improve their mathematics learning assessment and teaching practices.

These results are consistent with previous studies (Tikhomirova, Malykh & Malykh, 2020; Cueli et al., 2020; Agostini et al., 2022) that showed that cognitive aspects influence mathematics learning among children. However, our study slightly differs from other studies such as (Laja and Hijirian, 2022) whose focus was on general gender-based cognitive development without specific aspects and (Agostini et al., 2022) whose focus was on attention rather than other cognitive aspects identified in our study. Therefore, it can be argued that our study offers a more comprehensive and specific set of cognitive aspects for teachers to consider in their mathematics teaching practices.

Also, results show that body scheme and spatial orientation, sensorimotor efficiency, seriality and sense of balance are sensorimotor aspects that determine the learning of mathematics. This means teachers should consider sensorimotor development as part of their mathematics teaching practices. The significance of sensorimotor in teaching mathematics was alluded to by Piaget (1955) who emphasized on teaching children the physical rules before teaching abstract representations. Therefore, teachers

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should be considerate of learners' sensorimotor development in their teaching and assessment practices.

The results from our study are similar to those from (Giles et al. 2018; Pickavance et al. 2022) in which sensorimotor areas were considered a crucial part of mathematics learning. Nevertheless, the previous studies have rarely focused on comprehensive aspects of sensorimotor aspects, which makes the importance of sensorimotor skills in the background of mathematical ability under-reported in research and teaching practice. For instance, Giles et al. (2018) focused only on one aspect of sensorimotor (interceptive timing). Therefore, since our study has covered a considerable number of sensorimotor aspects, it offers a comprehensive and deeper understanding of how crucial sensorimotor areas are to the learning of mathematics.

Our results indicate that the maturation of the nervous system is an important determinant of mathematics learning, and that developmental differences translate into performance differences. This in turn strongly influences further motivation, and self-concept in mathematics.

In this pilot study of our follow-up research, only a brief comparison was possible, but this early data already indicate that the profile procedure can reveal the background cognitive abilities necessary for learning mathematics. The Sensorimotor and Cognitive Profile Test is administered by teachers to children so that they can plan their progress and methods of teaching mathematics based on the cognitive profile of children starting first grade.

In the future, we will check the results of a year's schooling on a larger sample. Our goal is to reveal successful profiles predestined for disorders so that when teachers detect them, they can offer appropriate developmental sessions to the children, instead of attempting to engage in cognitive functions that these children do not yet possess.

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The neural maturation of children starting school is still in progress and can be easily developed. With targeted pieces of training, fast development can be achieved by knowing the individual profile. In our research project founded by the Hungarian Academy of Sciences, our Learning Environment Research Group examines the broad cognitive profile of first-grade children and checks our assumptions to create a learning environment in which targeted training based on specific cognitive profile characteristics can be provided. Further steps include the international adaptation and verification of the test material, conducting comparative studies, and creating a rolling standard while developing self-differentiating-choice adaptive games.

4. Conclusion and Recommendations

The present study assessed both sensorimotor and cognitive development of first graders. From the present study, it was observed that 20% of learners had less developed their sensorimotor while 53% appeared to have been matured fully. By comparing the sensorimotor and cognitive development and learners' achievement, we noted that those with immature sensorimotor had low performance especially in abstract thinking. We argue that teachers should be supported with means to assess both sensorimotor and cognitive development of learners in order to identify early and relevant interventions.

5. Acknowledgements

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1. Introduction

Mathematical thinking influences individuals' experiences of the environment, contributing to their perception and meaning-making about the world. (Tall, 1995) However, in education, mathematics teaching still focuses mainly on numeracy (Linder and Simpson, 2018), and the school measures children's mathematical knowledge through counting operations. Numbers are part of the language of mathematics that children have to master, but the emphasis in school is so much on learning to count that those who perform less well in this end up excluded from mathematical thinking through

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their initial failure (Carpenter. Fennema & Franke, 1996). Significant changes should be carried out in teaching mathematics to first graders in at least two respects: numeracy should be linked much more to mathematical thinking and the teaching of mathematics should progress in line with children's neurological maturation. (Bobis et al., 2005) The first task involves reconsidering the teaching materials used for mathematics instruction. The second task is much more complex, because the development of children's nervous system is extremely diverse not in small part due to the recently expanded information space, as a consequence of which the development of a wide range of basic sensorimotor functions has become necessary. Piaget (1955) cautioned that children may need to learn physical rules before learning abstract representations. Since individuals may have different ability structures, they are likely to take different learning paths. Laja and Hijirian (2022) observed gender-based differences in cognitive development among university students that affected their learning of mathematics. They argue that these differences should be taken as opportunities for improving teaching approaches to suit individual learners' needs. We argue that it is important to know the ability profiles that are beneficial and work well in learning mathematics, as well as the characteristics representing obstacles to the learning progress. However, research shows that attention seems to have been directed to the first challenges since the majority of teacher training is focused on improving teaching materials and strategies (Gosztonyi, 2020, 2023). Therefore, the second challenge is worth being considered in research.

2. Learning basic mathematics

Research findings have repeatedly suggested that information processing speed, visuospatial abilities, working memory, number sense, and fluid intelligence contribute significantly to school performance (Rohde & Thompson, 2007; Tikhomirova, Malykh & Malykh, 2020). Cueli and colleagues (2020) found that attention is highly important in

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young children's numeracy skills, but also found that response time is more important. In addition, deficits in mathematics can also provide insight into the range of cognitive functions needed to learn maths. For example, recent research by Agostini, Zoccolotti, and Casagrande (2022) has shown that children with mathematical difficulties are impaired in cognitive areas such as executive functions, attention, and processing speed. Therefore, this shows that students' failure in mathematics should not be viewed as a single cognitive functioning aspect but rather a combination of cognitive aspects such as memory, speed and attention.

Parviainen (2019) identified the main mathematical skill categories – numerical skills, spatial thinking skills, and mathematical thinking and reasoning skills – in her theoretical framework for a holistic model of the development of early mathematical skills. She emphasized that in early mathematics learning, the simultaneous strengthening of versatile early mathematical skills through conscious early learning practices should be addressed. However, less emphasis was on the sensorimotor area, even though higher-level cognitive development is based on sensorimotor functions.

In contrast, Pickavance et al. (2022) point out that the role of sensorimotor skills in the development of higher-order cognitive domains such as mathematics is underestimated. They argue that inadequate sensorimotor measures explain differences in executive functions and not in lower-level functions. They found interceptive timing performance (the sensorimotor ability to interact with a moving target while the person is moving) to be a determinant of mathematical performance in children aged 5-11 years, and this relationship persisted into the teenage years. Pickavance and colleagues (2022) conclude that children's development of sensorimotor skills should be viewed as part and parcel of their intellectual development. In addition, Giles et al. (2018) observed that interceptive timing (a sensorimotor aspect) serves as a predictive factor for children's

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performance in mathematics. This shows that sensorimotor functions need to be taken as part of teaching mathematical skills. However, it is risky to rely on this study in the quest of integrating sensorimotor in teaching mathematics because the study has only focused on one aspect (interceptive timing) of sensorimotor. Therefore, this makes the current study among the most significant study to expand the conception of the extent to which sensorimotor influence mathematics learning and how they can be identified.

Based on this, we argue that there are three main areas, each of which is necessary for successful mathematics learning as shown in Table 1. An optimal combination of at least the minimal cognitive functions associated with each of these areas gives rise to an individual mathematics learning profile.

Table 1

Three main areas for learning mathematics and the most important cognitive functions

SENSORIMOTOR SYSTEM	EXECUTIVE FUNCTIONS	MATHS FOUNDATIONS
• Spatial orientation	• Working memory	• Number concept
• Spatial memory	• Cognitive control	• Figural abstraction
• Sequential processing	• Selective attention	
• Processing speed		

Table 1 shows that successful learning of mathematical skills is the result of children's development in sensorimotor and cognitive functioning. However, currently the mainstream mathematics teaching practices rarely consider cognitive and sensorimotor aspects. This can be caused by a lack of clear curricular expectations, teachers' awareness and methodological preparedness, to focus on cognitive and sensorimotor areas. Consequently, the present study identifies the sensorimotor and cognitive profiles that predispose children starting the first grade of primary school to different degrees of success in learning mathematics.

2.1 Aims

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In our research, we aim to identify the sensorimotor and cognitive profiles that predispose children starting the first grade of primary school to different degrees of success in learning mathematics. Our hypotheses are as follows:

1. Cognitive profiles that are beneficial in learning mathematics can be identified.

2. In addition to some other cognitive areas, sensorimotor abilities are crucial in learning mathematics.

3. Methods

3.1. Procedure

Testing can be carried out easily on a tablet or laptop with a touch screen, even without the participation of a specialist. In the case of young children, in a one-on-one situation, the examiner (test leader) helps them understand the tasks. In our research, the children's teachers took on the role of test leaders, for which we prepared them beforehand. The testing took place over two sessions in the weeks following the start of the school year. Based on the online test results, students were sorted into five levels for each indicator, using the sample mean and standard deviation, so that scores on different tests could be compared: 5 – outstanding (by more than 2 SD above the average); 4 – above average (by more than 1 SD above average but not more than 2 SD above the average); 3 – average (average +- 1 SD); 2 – below average (by more than 1 SD but less than 2 SD below average); 1 – to be developed (below average by more than 2 SD).

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Table 2

Tasks and indicators of the Sensorimotor and Cognitive Profile Test

		Name of the test	Test indicators
Maths	Figural abstraction	Figures - figural abstraction, seeing patterns, conclusion	correct answers
	Number concept	Quantities - concept of number and quantity	correct answers
Executive functions	Working memory	Digit Span backward - efficiency of working memory	correct sequence
		Digit Span backward - extent of the working memory	longest sequence
		Digit Span foward - the auditory sequential memory	correct sequence
		Digit Span foward - the scope of the auditory memory	longest sequence
	Control	Go - no go task - braking system efficiency	efficiency points
		Go - no go task - precision of control	precision points
Sensorimotor development	Sequentiality	Spatial sequence - spatial sequential thinking	correct answers
		Time sequence - temporal sequential thinking	correct answers
	Sensorimotor efficiency	Speech sounds discrimination - differentiation of speech sounds	correct answers
		Shape-background - shape-background diffrentiation, scanning	correct answers
		Searching - eye movement control, scanning	correct answers
	Body awareness, orientation	Identification of body parts - body scheme	correct answers
		Identification of fingers - finger awareness	correct answers
		Relationship with objects - using spatial relations	correct answers
	Balancing ability	Balance with eyes open, right leg - sensorimotor intergration	time
		Balance with eyes open, left leg - sensorimotor intergration	time
		Balance with eyes closed, right leg - sensorimotor intergration	time
		Balance with eyes closed, left leg - - sensorimotor intergration	time

4. Results

We do not use all the indicators in the presentation of the results, only the most relevant ones. The five groups of students showing different levels of mathematics learning do not differ in gender or age, only in ability structure. Of the groups, Group 1, which is lagging in terms of mathematics development, differs from the other groups significantly in their profile. The chart shows that it is not so much in intellectual ability that these children are lagging, but rather in executive functions and some sensorimotor areas (Figure 1).

On the chart, Group 2 appears visually to be a slightly milder version of Group 1 and also shows poor executive function and sensorimotor scores. Group 3 has a less undulating profile, even less so for Group 4. Group 5 shows a consistent ability structure, providing a stable background for learning at school. The results indicate that the group that is doing very well in mathematics is not restricted to the particularly outstanding (they achieved around category 3 in terms of the test scores). In other words, with a normal level of maturity, it is possible to be successful in school mathematics. The profile can be plotted as a star diagram, but the continuous line representation creates specific shapes that make the differences visible.

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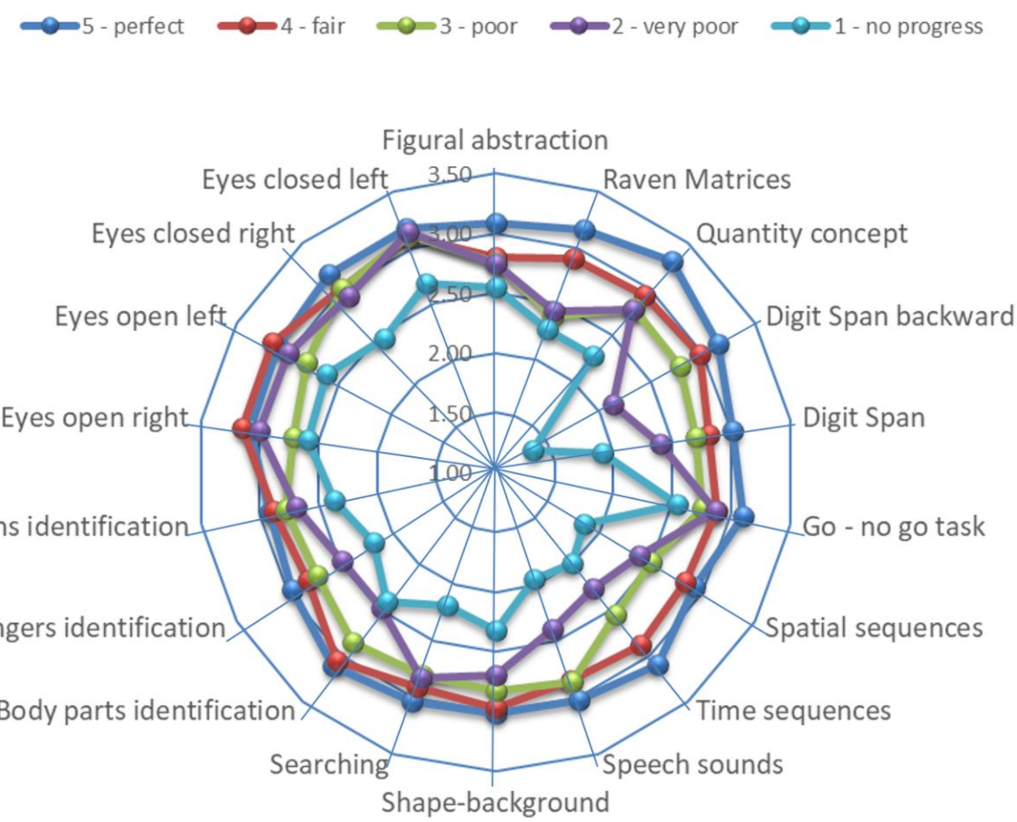
Figure 1

Cognitive profiles of the five differently progressing groups in mathematics. The sensorimotor and cognitive indicators are likewise plotted on a scale of 1-5



Visually visible differences between the profiles of groups 1-5 were verified by a paired-sample t-test. Group 5 scored better than the other groups on all tasks, with significant differences on most items, even in the closed-eyes right-leg position.

Table 3

Results And T-Test of The Groups – Reasoning, Quantity, Working Memory, Control Functions

Only

Groups of different progress	Figural abstraction	Quantity concept	Digit Span	Digit Span backward	Go - no go task
			longest	longest	recall
5 - perfect	3.08	3.30	3.15	3.01	3.10
4 - fair	2.80	2.93	2.96	2.81	2.88
3 - poor	2.75	2.79	2.78	2.69	2.75
2 - very poor	2.74	2.77	2.13	2.39	2.87
1 - no progress	2.55	2.27	1.36	1.91	2.55
Average	**2.93**	**3.07**	**2.91**	**2.84**	**2.96**

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Group 4 differed from the poorer performers in fewer areas. A comparison with Group 5 shows which areas are disadvantageous for them, contributing to somewhat more delayed progress (abstraction, quantity concept, control functions, and especially several sensorimotor areas). Comparison of the other groups does not show significant differences, only in working memory and temporal sequences. These functions develop at the end of the neurological maturation process at this age. Presumably, at the start of school, it is an advantage if a child matures faster, to the extent that this is reflected in success in learning mathematics.

Table 4

T-Tests of the Groups (P-Values) – Reasoning, Quantity, Working Memory, Control Functions

Test name	Figural abstraction	Quantity concept	Digit Span	Digit Span backward	Go - no go task
5 v. 1-3	0.0000	0.0000	0.0000	0.0000	0.0000
4 v. 1-3	0.2711	0.0107	0.0000	0.0014	0.1459
4 v. 5	0.0002	0.0000	0.0094	0.0033	0.0013
3 v. 4	0.9305	0.6798	0.0000	0.1203	0.0690
2 v. 3	0.5115	0.9443	0.0048	0.0070	0.6907
1 v. 2	0.4322	0.2913	0.0000	0.0072	0.5335
1 v. 4	0.0831	0.0001	0.0000	0.0000	0.0317
1 v. 5	0.0003	0.0000	0.0000	0.0000	0.0000

Table 4

Results and T-Test of the Groups – Basic Sensorimotor Abilities

Groups of different progress	Body parts identification	Relations identification	Spatial sequences	Time sequences	Speech sounds	Shape-background searching
5 - perfect	3.11	2.91	2.91	3.10	3.03	3.03
4 - fair	3.06	2.88	2.83	2.88	2.85	2.90
3 - poor	2.86	2.78	2.50	2.56	2.86	2.81
2 - very poor	2.48	2.70	2.39	2.26	2.39	2.83
1 - no progress	2.41	2.36	1.86	2.00	1.95	2.18
Average	**3.00**	**2.85**	**2.77**	**2.89**	**2.87**	**2.92**

The compared groups	Body parts identification	Relations identification	Spatial sequences	Time sequences	Speech sounds	Shape-background searching
5 v. 1-3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4 v. 1-3	0.0002	0.0050	0.0000	0.0000	0.0005	0.0047
4 v. 5	0.5094	0.5013	0.0698	0.0004	0.0079	0.0324
3 v. 4	0.5624	0.1322	0.2996	0.0000	0.5927	0.9708
2 v. 3	0.1400	0.0608	0.9060	0.7684	0.2606	0.2685
1 v. 2	0.2784	0.7862	0.0278	0.3782	0.0032	0.1268
1 v. 4	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000
1 v. 5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

The results show that sensorimotor abilities play a major role in learning mathematics. Not only higher-order sensorimotor domains, such as spatial and temporal sequences, do so, but lower-level ones, like body schema and basic areas of perception, such as shape-background discrimination or speech sound differentiation, also play a role in the success of learning mathematics (Tables 4 & 5).

Table 5

Results and T-Test of the groups – Main Sensorimotor Abilities, and Balancing

Groups of different progress	Spatial sequences	Speech sounds	Shape-background searching	Eyes open right	Eyes open left	Eyes closed right	Eyes closed left
5 - perfect	2.91	3.03	3.03	3.08	3.10	3.17	3.17
4 - fair	2.83	2.85	2.90	3.15	3.16	3.01	3.10
3 - poor	2.50	2.86	2.81	2.71	2.83	3.00	3.11
2 - very poor	2.39	2.39	2.83	3.00	3.00	2.91	3.13
1 - no progress	1.86	1.95	2.18	2.59	2.64	2.45	2.68
Average	**2.77**	**2.87**	**2.92**	**3.04**	**3.06**	**3.05**	**3.12**

The compared groups	Spatial sequences	Speech sounds	Shape-background searching	Eyes open right	Eyes open left	Eyes closed right	Eyes closed left
5 v. 1-3	0.0000	0.0000	0.0000	0.0001	0.0021	0.0003	0.0524
4 v. 1-3	0.0000	0.0005	0.0047	0.0004	0.0020	0.1283	0.5009
4 v. 5	0.0698	0.0079	0.0324	0.3758	0.3665	0.0548	0.3514
3 v. 4	0.2996	0.5927	0.9708	0.2150	0.0709	0.0034	0.0172
2 v. 3	0.9060	0.2606	0.2685	0.6150	0.6303	0.1457	0.4088
1 v. 2	0.0278	0.0032	0.1268	0.1431	0.3623	0.0265	0.0457
1 v. 4	0.0000	0.0000	0.0000	0.0011	0.0006	0.0012	0.0011
1 v. 5	0.0000	0.0000	0.0000	0.0003	0.0004	0.0000	0.0005

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4. Discussion and Further Steps

Our developmental indicators measured at the start of schooling indicate that 20% of children lack the necessary maturity foundations to learn mathematics. Abstract thinking, quantity concept and working memory were part of the cognitive aspects that were identified to be influential in learning mathematical skills. The results imply the possibility of identifying cognitive aspects that enhances mathematics learning among students. Laja and Hijirian (2022) argue that teachers can improve mathematics teaching practices only if they know the cognitive development level of each student. Therefore, the identified cognitive aspects that enhance mathematics learning provide the basis for teachers to improve their mathematics learning assessment and teaching practices.

These results are consistent with previous studies (Tikhomirova, Malykh & Malykh, 2020; Cueli et al., 2020; Agostini et al., 2022) that showed that cognitive aspects influence mathematics learning among children. However, our study slightly differs from other studies such as (Laja and Hijirian, 2022) whose focus was on general gender-based cognitive development without specific aspects and (Agostini et al., 2022) whose focus was on attention rather than other cognitive aspects identified in our study. Therefore, it can be argued that our study offers a more comprehensive and specific set of cognitive aspects for teachers to consider in their mathematics teaching practices.

Also, results show that body scheme and spatial orientation, sensorimotor efficiency, seriality and sense of balance are sensorimotor aspects that determine the learning of mathematics. This means teachers should consider sensorimotor development as part of their mathematics teaching practices. The significance of sensorimotor in teaching mathematics was alluded to by Piaget (1955) who emphasized on teaching children the physical rules before teaching abstract representations. Therefore, teachers

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should be considerate of learners' sensorimotor development in their teaching and assessment practices.

The results from our study are similar to those from (Giles et al. 2018; Pickavance et al. 2022) in which sensorimotor areas were considered a crucial part of mathematics learning. Nevertheless, the previous studies have rarely focused on comprehensive aspects of sensorimotor aspects, which makes the importance of sensorimotor skills in the background of mathematical ability under-reported in research and teaching practice. For instance, Giles et al. (2018) focused only on one aspect of sensorimotor (interceptive timing). Therefore, since our study has covered a considerable number of sensorimotor aspects, it offers a comprehensive and deeper understanding of how crucial sensorimotor areas are to the learning of mathematics.

Our results indicate that the maturation of the nervous system is an important determinant of mathematics learning, and that developmental differences translate into performance differences. This in turn strongly influences further motivation, and self-concept in mathematics.

In this pilot study of our follow-up research, only a brief comparison was possible, but this early data already indicate that the profile procedure can reveal the background cognitive abilities necessary for learning mathematics. The Sensorimotor and Cognitive Profile Test is administered by teachers to children so that they can plan their progress and methods of teaching mathematics based on the cognitive profile of children starting first grade.

In the future, we will check the results of a year's schooling on a larger sample. Our goal is to reveal successful profiles predestined for disorders so that when teachers detect them, they can offer appropriate developmental sessions to the children, instead of attempting to engage in cognitive functions that these children do not yet possess.

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The neural maturation of children starting school is still in progress and can be easily developed. With targeted pieces of training, fast development can be achieved by knowing the individual profile. In our research project founded by the Hungarian Academy of Sciences, our Learning Environment Research Group examines the broad cognitive profile of first-grade children and checks our assumptions to create a learning environment in which targeted training based on specific cognitive profile characteristics can be provided. Further steps include the international adaptation and verification of the test material, conducting comparative studies, and creating a rolling standard while developing self-differentiating-choice adaptive games.

5. Conclusion and Recommendations

The present study assessed both sensorimotor and cognitive development of first graders. From the present study, it was observed that 20% of learners had less developed their sensorimotor while 53% appeared to have been fully matured . By comparing the sensorimotor and cognitive development and learners' achievement, we noted that those with immature sensorimotor had low performance especially in abstract thinking. We argue that teachers should be supported with means to assess both sensorimotor and cognitive development of learners in order to identify early and relevant interventions.

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