

Sensorimotor and Cognitive Predictors of Early School Achievement: A Longitudinal Study Across Settlement Types in Hungary

Eva Gyarmathy¹

Abstract

This longitudinal study examines the sensorimotor and cognitive readiness of children entering school and explores how these developmental indicators predict academic outcomes across the first two years of schooling, with particular attention to differences by settlement size. The sample comprised Hungarian children from settlements of varying population sizes, assessed at the beginning of Grade 1 and the end of Grade 2. Using the Sensorimotor and Cognitive Profile Test and Raven's Coloured Progressive Matrices, the study evaluated foundational cognitive and sensorimotor functions. Regression analyses show that working memory, temporal sequencing, auditory sequential memory, phoneme discrimination, and quantity concepts strongly predict reading, writing, and arithmetic performance. Sensorimotor indicators – including body schema, finger awareness, and balance – also contribute significantly, particularly to mathematics. Children residing in smaller settlements exhibit marked deficits in these critical domains at school entry, and these disparities persist into Grade 2. The findings underscore the need for early assessment, targeted intervention, and context-sensitive pedagogical strategies to promote neurodevelopmental equity.

Keywords: school readiness, sensorimotor development, cognitive profiling, settlement size, socioeconomic disparities

¹ Apor Vilmos Catholic College
gyarmathy.eva@avkf.hu
<https://orcid.org/0000-0002-3882-9397>

Introduction

This study constitutes one component of a four-year longitudinal research project supported by the Public Education Development Research Program of the Hungarian Academy of Sciences. The research tracks children aged 6 to 8 at the point of school entry, with the principal objective of characterizing school readiness at the onset of formal education. A key component of the project is the examination of developmental disparities between children from small rural settlements and their peers from larger urban municipalities.

Learning is widely recognized as a foundational determinant of both individual achievement and societal progress. Contemporary educational discourse increasingly emphasizes learning agility – the capacity to adapt, acquire new skills, and apply knowledge flexibly across novel or changing contexts – alongside learning motivation, the intrinsic drive that sustains engagement and goal-directed behaviour (Martin, 2024). These constructs are shaped early in life, and the initial encounter with formal schooling plays a pivotal role in shaping children’s self-perceptions, sense of competence, and long-term dispositions toward learning.

The developmental period spanning ages 6 to 8 represents a critical transition from early childhood to formal schooling. This stage, corresponding to the onset of middle childhood, is characterized by substantial psycho-neurological reorganization, including structural and functional changes in the developing brain. Global cognitive restructuring, increasing executive function capacity, and evolving motivational and socio-emotional profiles mark this period as a sensitive window for both developmental consolidation and targeted intervention (Del Giudice, 2014). When educational environments are aligned with the neurocognitive and socio-emotional characteristics of this age group, they can effectively support remediation, compensation, and the prevention of emerging learning difficulties. Conversely, misalignment between pedagogical expectations and developmental readiness may exacerbate disparities and hinder optimal learning trajectories. Importantly, cognitive assessments administered at this age tend to yield more reliable results than in younger children (Anastasi & Urbina, 1997; Sattler, 2001), providing a sound basis for educational decision-making.

The broader developmental context of the 21st century is characterized by unprecedented levels of environmental stimulation – technological, informational, and socio-cultural – that can enhance cognitive development. However, these benefits are unevenly distributed. In line with the Matthew Effect (Merton, 1968), children with favourable internal dispositions or

supportive external environments are disproportionately positioned to capitalize on these opportunities, resulting in accelerated developmental trajectories. Consequently, contemporary cohorts exhibit increasing heterogeneity, with widening disparities between high-performing and struggling learners. This divergence underscores the need for adaptive, equity-oriented educational frameworks capable of addressing increasingly diverse developmental profiles. Divergence is markedly intensified by neurodevelopmental heterogeneity and by socioeconomic factors that shape children's early learning environments and developmental trajectories.

Parallel trends in neurodevelopmental research highlight the growing influence of subtle yet biologically active environmental agents – including neurotoxins, infectious agents, and endocrine disruptors – on the developing brain. Exposure to such factors during critical developmental windows is associated with atypical neurological trajectories, manifesting in learning disorders, attentional dysregulation, hyperactivity, and autism spectrum conditions (Hammel, Set al., 2024; Shelton & Baccarelli, 2024; Zoeller, & Vandenberg, 2024). These outcomes pose significant challenges for affected children, their families, educational systems, and society at large.

Socioeconomic status (SES) plays a central role in shaping children's developmental opportunities and vulnerabilities. Children from socioeconomically disadvantaged backgrounds are disproportionately exposed to risk factors that compromise neurodevelopment and educational attainment. These include increased exposure to environmental toxins, higher prevalence of infectious diseases, and reduced access to preventive and therapeutic healthcare (Caldwell et al., 2017). Low birth weight – more common among children from low-SES families – is strongly associated with delayed developmental milestones and elevated rates of special educational needs (Darvas & Ferge, 2012). In contrast, higher-SES families are typically better positioned to provide enriched learning environments, early intervention, and specialized support.

Recent research shows that socioeconomic inequalities are evident early in life and that factors like home learning environments and preschool participation differentially shape early cognitive and social skills (Pietropoli, & Gracia, 2025). The study of Plavnicka, Chovan and Filakovska Bobakova (2024) directly examines how socioeconomic disadvantage (including parental education and household conditions) relates to early childhood development outcomes, highlighting disparities in early learning conditions for disadvantaged groups. Disadvantaged families often lack the material, informational, and institutional resources

necessary to offer developmentally appropriate learning opportunities that could mitigate or compensate for atypical maturation. This systemic inequity reinforces existing developmental disparities and highlights the need for targeted, context-sensitive educational and public health interventions to promote neurodevelopmental equity from early childhood onward. Taken together, these considerations highlight the necessity of developing a more detailed and empirically grounded understanding of children's readiness for school

Settlement size is closely intertwined with socioeconomic conditions. Individuals living in smaller, particularly rural, settlements tend to experience greater socioeconomic disadvantage than those residing in urban centres – a pattern consistently documented across empirical studies and policy analyses (Javed et al., 2024). Although focused on informal settlements, the study by Acevedo-De-los-Ríos et al. (2025) demonstrates that settlement consolidation, employment opportunities, and socioecological conditions are dynamically interlinked, showing how socioeconomic structures shape settlement development trajectories.

The scale and configuration of settlements are shaped by, and reflective of, broader socioeconomic dynamics, as demonstrated across contemporary urban science, regional economics, and long-term settlement studies. In contemporary cities, urban scaling research demonstrates that socioeconomic outputs such as productivity and inequality systematically increase with population size, driven in part by inequalities operating within cities themselves (Arvidsson et al., 2023). Beyond aggregate population effects, inter-city economic connectivity further conditions these outcomes, as larger settlements benefit from denser firm networks and higher economic returns, indicating that settlement size reflects complex socioeconomic organization rather than mere demographic concentration (Kemp et al., 2024). At the same time, evidence suggests that larger cities tend to exacerbate income disparities and limit intergenerational mobility, reinforcing the link between settlement scale and social inequality (Connor et al., 2025). This relationship is not limited to modern urban systems: archaeological and paleo-demographic studies show that settlement size has long responded to environmental, economic, and institutional pressures, shaping population distribution and social organization in prehistoric and early complex societies (Schmidt et al., 2025; Quinn, 2024). Together, these studies underscore that settlement size functions as a key indicator and outcome of underlying socioeconomic dynamics across time.

A growing body of research demonstrates that settlement size is systematically associated with school success and academic outcomes. Comparative studies of urban and rural students consistently report significant differences in educational achievement and attainment, with

students in larger, urban settlements tending to accumulate higher levels of human capital even after controlling for individual background characteristics (van Maarseveen, 2021). Longitudinal analyses further show that school location – closely linked to settlement size – shapes learning trajectories, as rural, suburban, and urban educational contexts provide markedly different institutional and instructional environments (e.g., McHenry, 2019). Evidence from low- and middle-income contexts reinforces this pattern, with substantial rural-urban learning gaps in secondary education attributed to disparities in school quality and local contextual resources (Sok et al., 2025). Advanced analytical approaches, including machine-learning studies, also reveal pronounced regional and urban-rural disparities in academic performance, highlighting the role of geographically uneven resource distribution (Zheng, Sun & Weng, 2026). Meta-analytic findings confirm these results, showing that neighbourhood and settlement characteristics – including urban-rural status and socioeconomic composition – are robustly associated with educational outcomes across diverse settings (Nieuwenhuis & Hooimeijer, 2016). Wang (2024) shows that socioeconomic status and educational outcomes differ systematically between urban and rural settings, with rural contexts often having weaker SES advantages, illustrating structural socioeconomic disparities by settlement type. Collectively, these studies indicate that settlement size constitutes an important contextual factor shaping educational success. Clarifying the mechanisms through which structural inequalities shape early developmental trajectories is critical for the development of equitable educational policies and practices.

Objectives

This study has two interconnected objectives:

1. To identify which sensorimotor and cognitive functions assessed at school entry predict academic outcomes in reading, writing, and arithmetic by the end of Grades 1 and 2.
2. To examine whether children entering school from settlements of different population sizes differ in their sensorimotor and cognitive readiness, and whether these differences persist during the first two years of schooling.

One of the most critical components of the intervention concerns the transition into formal schooling, with particular emphasis on developing a nuanced understanding of children's

school readiness and identifying the key factors that support successful educational outcomes within their developmental profiles.

Our second focus posits that children entering formal education from small rural communities demonstrate significantly lower levels of school readiness compared to their urban counterparts. Furthermore, it is hypothesized that this initial developmental gap persists over the first two years of schooling, indicating limited compensatory effects of standard educational provision during this critical period of cognitive and academic development.

Methods

Research Design

In the first part of the study, we present findings that identify which cognitive and sensorimotor functions are critical at school entry, given their long-term implications for academic success. The second – and substantively central – part of the study follows the school entry and early academic trajectories of children living in settlements of varying sizes over the first two years of schooling, with particular attention to the functions identified in the first part as determinants of school success.

The study employed a longitudinal design with two measurement points: the beginning of Grade 1 (T1) and the end of Grade 2 (T2). A total of 1,024 children were initially enrolled, but due to student mobility, grade repetition, and staff turnover, the final analytic sample consisted of 757 children with complete data at T2. In the analysis of differences by settlement size, we included only the data of children for whom adequate school-level information was available, as the socioeconomic status of the school was determined on the basis of these institutional data.

Research Groups

The study initially enrolled over one thousand first-grade students attending primary schools located in settlements of varying population sizes within the Diocese of Vác, Hungary. Participants were longitudinally tracked over the first two years of formal schooling to assess developmental trajectories and contextual influences.

Due to substantial turnover among both pupils and teaching staff – attributable to factors such as school transfers, grade repetition, and staff mobility – the final analytic sample comprised 757 children by the conclusion of second grade. Gender distribution within the retained cohort did not exhibit statistically significant differences. At the point of school entry, 94.57% of the children were between 6 and 7 years of age, consistent with normative age expectations for first-grade enrolment.

Table 1

Number of Children Participating in the Assessment of School Readiness and Early School Success Profile

	Children tested in 1st grade	Children tested in 2nd grade	Children tested in both grades
SUM	1050	804	757

Beyond the individual-level assessment data collected for all participating children, a subset of schools also provided institutional-level information, thereby enabling more differentiated analyses of contextual factors shaping educational performance. While every child contributed data pertinent to indicators of school readiness and subsequent success, the analytical focus of the second part of this paper is restricted to students attending schools that submitted additional sociological indicators. These include aggregated measures of the socioeconomic status (SES) distribution within the student population, as well as institutional characteristics such as total teacher headcount and average class size.

Settlement-level population data were retrieved from official statistical records to support contextual classification and comparative analysis. One small-town class was excluded from the second-year assessment due to organizational restructuring within the school; however, longitudinal data collection was successfully completed for all remaining classes across both measurement waves.

Settlement size was operationalized using official population statistics and categorized into four groups:

- Capital (~1 million people)

- Large towns (20,000–100,000)
- Small towns (3,000–20,000)
- Villages (<3,000 inhabitants)

Table 2

Distribution of participants in the school readiness assessment across settlements of different size

N	Grade1	Grade2
Capital	42	43
City	145	146
Town	116	92
Village	107	102
SUM	410	383

The participating schools included both church-run and state-run institutions. No significant differences were found between these two types of schools in terms of children’s abilities and developmental outcomes. In contrast, settlement size showed a clear association with class-level cognitive profiles. This study focuses primarily on that relationship.

Socioeconomic Indicators

Settlement size in Hungary is closely associated with socioeconomic patterns, but it is not synonymous with SES (Demeter, et al. 2025). To avoid conceptual conflation, the present study analyses settlement size and school-level SES indicators separately. School-level SES indicators included the proportion of disadvantaged and multiply disadvantaged students attending the given school.

Assessment Tools

Sensorimotor and Cognitive Profile Test

The Sensorimotor and Cognitive Profile Test (Gyarmathy, 2009) evaluates foundational functions and skills essential for the development of learning abilities – cognitive functions

(working memory, abstraction, executive functions), sensorimotor functions (body schema, spatial orientation, sequential processing), and academic skills (reading, spelling, arithmetic).

The test was designed to provide a comprehensive overview of individual or group strengths and areas for improvement, thereby supporting the creation of effective development plans and tailored instructional strategies that meet individual and group-specific needs. Data-driven decision-making is particularly critical for learners from socioeconomically disadvantaged backgrounds and/or those with atypical neurological development, making this test a valuable tool for fostering inclusive educational environments.

The current version of the test evolved from the Hungarian adaptation of the International Cognitive Profile Test (Smythe, 2002), a multilingual instrument originally designed for assessing dyslexia across languages (Gyarmathy & Smythe, 2000; Smythe, 2002). Previous online versions of the Cognitive Profile Test have been used in multiple studies (Gyarmathy et al., 2019; 2021), and its validation was supported by international collaboration (Kertzman et al., 2017). The extension of this test to the kindergarten-to-school transition was developed and validated within our research project funded by the Hungarian Academy of Sciences' Public Education Development Program. The latest version is available in multiple languages – including English, German, Spanish, Finnish, Hungarian, and Ukrainian – facilitating the assessment of multilingual children and enabling comparative research. (Validation across languages is ongoing.)

Test design prioritized engagement and the perception of competence among participants, encouraging enthusiastic participation from children.

The test is available entirely free of charge, and its online administration platform can be accessed by educators and other specialists without the requirement of prior specialized training (<http://kognitivprofil.hu>). A supplementary instructional video series is provided to support a more detailed understanding of the administration protocol and underlying methodological principles. The online system has been operational since 2007 and currently reports a user base exceeding 60,000 individuals.

Technological advancements have enabled the development of a version suitable for young children, allowing active participation in assessments from the age of five using touchscreen devices. In addition to cognitive subtests, sensorimotor subtests were incorporated, enabling the evaluation of foundational sensorimotor functions that support cognitive development.

Some subtests are also suitable for assessing sensorimotor functions in adults and can be used to identify problem areas in cases of age-related cognitive decline.

Test Structure

The test is suitable for children and adults across various age groups. Subtests are marked with letters and colours to indicate their applicability to specific age ranges:

- Ages 5–10
- Ages 7–13
- Ages 10–16
- Ages 12 and above

The substantial overlap between age bands allows flexible adaptation to individual developmental stages. The examiner determines the appropriate band for each individual or group. Results are interpreted within the selected band.

The test can be repeated annually, as it measures functions and abilities rather than knowledge or content. This makes it suitable for longitudinal tracking and impact assessment. Results are presented both as categorical ratings and numerical scores.

Categories are based on data collected during the assessment period, using mean and standard deviation values to define five levels:

- 5 – Excellent: more than 2 SD above the mean
- 4 – Above average: between 1 and 2 SD above the mean
- 3 – Average: within ± 1 SD of the mean
- 2 – Needs development: between 1 and 2 SD below the mean
- 1 – Significantly underdeveloped: more than 2 SD below the mean

These categories provide a quick overview of strengths and weaknesses, while numerical scores offer more detailed insights. Results are also visualized using radar charts.

Downloadable data can be used to analyse individuals, classes, or other groups, and custom charts can be created from the exported data.

Reference values are based on large datasets and offer guidance for interpreting developmental profiles. Group profiles can be constructed, and individual results can be

compared against these profiles. Context-specific analysis is essential for data-driven decision-making, meaning that local results should be interpreted in relation to standard benchmarks, which in turn can inform understanding of local conditions.

The test evaluates three broad domains: cognitive functions, sensorimotor functions, and academic skills. Each domain includes multiple subfunctions assessed through various subtests:

- Cognitive functions: abstraction, visual and auditory processing, executive functions
- Executive functions refer to high-level cognitive abilities involved in planning, problem-solving, attention regulation, and emotional self-control.
- Sensorimotor functions: body schema, spatial orientation, visual and auditory perception, sequential processing
- Academic skills: reading, spelling, arithmetic

The test comprises 20 subtests and a developmental questionnaire. Subtests are brief, and the full test can be completed in under an hour. However, not all subtests need to be administered, and testing can be split across sessions. The profile-based structure and dual reporting format (scores and categories) allow examiners to select subtests aligned with the assessment goals and the age of the participant, thereby reducing testing time.

Subtests in the Sensorimotor and Cognitive Profile Test

Cognitive Functions

- **Working Memory:** Digit span backward
- **Auditory Sequential Memory:** Digit span forward
- **Control Function:** Go/No-Go task
- **Figural Abstraction:** Logical matrices
- **Speech Comprehension:** Understanding simple declarative sentences

Sensorimotor Functions

- **Body Schema:** Identification of body parts
- **Finger Awareness:** Movement and recognition of fingers

- **Spatial Orientation:** Differentiation between left and right sides
- **Spatial Relations:** Following instructions involving spatial relationships
- **Spatial Sequential Processing:** Arranging blocks based on a visual pattern
- **Temporal Sequential Processing:** Ordering a story using a sequence of images
- **Spatial Sequential Memory:** A Corsi block-tapping style task with animal images.
- **Balance:** Standing on one leg (eyes open and closed)
- **Phoneme Discrimination:** Determining whether words are identical or different
- **Musical Perception:** Recognition of musical tones

Academic Skills

- **Quantity Concept:** Understanding more-less-equal relationships
- **Arithmetic:** Addition and subtraction
- **Quantities 1:** Speed of identifying more-less-equal relationships
- **Quantities 2:** Estimating the magnitude of arithmetic operations
- **Phonological Awareness:** Identifying the initial letter of words
- **Word Reading:** Identifying real words among pseudo-words

Reliability and validity: Internal consistency coefficients range from $\alpha = .78$ to $.91$, and test-retest reliability from $r = .72$ to $.89$. Construct validity is supported through correlations with Raven's CPM and academic performance.

Raven's Coloured Progressive Matrices

Raven's Coloured Progressive Matrices is a standardized, non-verbal measure of fluid intelligence that assesses inductive reasoning, analogical problem-solving, and visuospatial analytic ability. The instrument consists of a series of pattern-completion tasks in which examinees identify the missing element that best completes a matrix according to underlying perceptual and logical rules. Designed to minimize linguistic, cultural, and educational biases, the RCPM is particularly suitable for children, older adults, and individuals with developmental, communicative, or learning difficulties (Raven & Raven, 2003). Performance

on Raven's Matrices correlates with mathematical achievement (Pind et al., 2003), making it a valuable comparative indicator in our longitudinal research project.

Teacher-Based Assessment of Academic Performance

Teachers assessed students' academic performance annually using a 1–5 rating scale, with 1 denoting inadequate performance and 5 denoting excellent performance.

Procedure

All children completed the same battery of subtests at the beginning of the first school year (T1) and the end of the second (T2), except basic sensorimotor items removed at T2 to avoid ceiling effects, and academic subtests added at T2.

On both measurement occasions, the assessments were administered by the children's own teachers, who had received brief preparatory training prior to test administration.

Statistical Analyses

We calculated Pearson correlation coefficients to examine linear relationships between the results of the Cognitive Profile Test, background variables, and teacher evaluations across both school years. Statistical significance was assessed using p-values. All statistical analyses were conducted using the `scipy.stats` module in Python (Virtanen et al., 2020).

- Group differences across settlement types were analysed using one-way ANOVA.
- Predictive relationships were examined using multiple regression analyses.
- Effect sizes (η^2 , Cohen's *d*) and p-values were reported.
- Assumptions of normality and homogeneity were tested.

Results

Predictors of Academic Achievement

The aim of this research was to identify sensorimotor and cognitive profiles that predict varying levels of academic success among first-grade students, thereby informing pedagogical practice. Certain abilities and foundational functions are either critical or difficult to compensate for, meaning their absence poses a fundamental risk to academic achievement. Identifying these key factors is essential for shaping the learning environment and designing individual and group-level interventions.

For the proper development of various school-related abilities, the maturity of several sensorimotor and cognitive functions is required. Among these, the most important ones can be identified – those that appear to form the foundation of learning ability at the time of school entry. Additionally, other significant indicators that generally influence learning have also emerged during the analysis of the research data (see Table 3).

Table 3

Correlations between sensorimotor and cognitive functions at the beginning of the first grade and school skills at the end of first grade (N=1050; $p < 0.001$)

COGNITIVE AREA	MATH	COGNITIVE AREA	READING	COGNITIVE AREA	WRITTING
working memory	0.4791	working memory	0.4059	working memory	0.3998
temporal sequential processing	0.4333	temporal sequential processing	0.3880	temporal sequential processing	0.3951
speech sound discrimination	0.3608	speech sound discrimination	0.3817	speech sound discrimination	0.3529
spatial sequential processing	0.3583	quantity concept	0.3471	spatial sequential processing	0.3100
quantity concept	0.3493	body scheme	0.2925	body scheme	0.3008
body scheme	0.2709	spatial sequential processing	0.2881	quantity concept	0.2894
finger awareness	0.2568	finger awareness	0.2772	finger awareness	0.2759
spatial relations	0.2457	spatial relations	0.2467	phonological awareness	0.2533
phonological awareness	0.2401	phonological awareness	0.2355	figural abstraction	0.2362
figural abstraction	0.2314	speech comprehension	0.2344	balance eyes closed, right leg	0.2297
balance eyes closed, right leg	0.2255	balance eyes closed, right leg	0.2011	spatial relations	0.2223

Synthesising the factors underlying performance across the three school-related domains, several core functions emerge as cross-domain determinants of academic achievement. As shown in Table 3, the maturity of specific sensorimotor and cognitive processes is predictive of later school success. In particular, working memory, temporal sequence processing, and auditory sequential memory exhibit the strongest associations. Phoneme discrimination and the early establishment of quantity concepts also play a central role. Overall, the efficiency of sequential processing appears to confer a general advantage across academic domains.

The contribution of body schema and finger awareness to the acquisition of school skills is less widely recognised. Within the balance subtest indexing sensorimotor integration, the ability to maintain unilateral stance on the dominant (typically right) leg with eyes closed emerged as a particularly salient indicator. Because visual input cannot support postural control under these conditions, successful performance requires sustained concentration and reflects a higher level of neural coordination.

These findings underscore the importance of early preschool interventions and the systematic assessment of developmental profiles prior to school entry. When the requisite maturation has not occurred during the critical early years, targeted and intensive support is recommended both before and throughout the first year of schooling.

Assessment Results and Educational Achievement

We compared performance on tasks assessing cognitive and sensorimotor maturity at the end of second grade with the results of school-skills – numeracy, quantitative concepts, and word reading – assessments administered at T2 and with teacher evaluations.

The measures of school-skills showed strong correlations with teacher ratings (Table 4), indicating that these tasks function as reasonably valid indicators of school-related competencies. The correlations are consistently higher at the end of second grade than at the beginning of first grade. This pattern may reflect the increasing stability of test performance as children mature, as well as the stronger temporal alignment between the abilities assessed within the same academic year and teachers' evaluations, which are based on contemporaneous observations.

Table 4

Correlations between tested school-skills and teachers' evaluation of children in the first and second grade ($p < 0.001$)

Teachers' evaluation N=757	Test results	Math ability	Processing quantity	Reading ability
	Grade	2	2	2
Reading	1	0,4179	0,2691	0,3894
Writing	1	0,3993	0,2562	0,3986
Reading/Writing	2	0,5624	0,3511	0,4882
Math	1	0,5076	0,3899	0,3799
Math	2	0,5924	0,4097	0,3840

The correspondence between test performance and teacher assessments is not complete. Test scores reflect children's performance at a single point in time under standardized conditions, whereas teacher-evaluations integrate observations made over an extended period and incorporate subjective judgments as well as motivational and emotional factors that are not captured by the test.

Analysing the cognitive and sensorimotor domains separately showed that performance at school entry is strongly associated with academic outcomes at the end of Grade 1, and for several functions these associations persist into Grade 2 (Tables 5–8). The predictive contribution of cognitive indicators remains robust through the second year of schooling. Multiple component functions exert substantial influence on the development of reading, writing, and arithmetic, and specific developmental immaturities emerge as particularly salient predictors of later learning difficulties

Table 5

The correlations between the cognitive indices and two independent indicators of school performance – tested academic abilities and teacher evaluations – across first and second grade

N=757		Test results on school-abilities			Teacher-evaluation				
		Math ability	Processing quantity	Reading ability	Math	Math	Reading	Writting	Reading / Writting
Indicator	Grade	2	2	2	1	2	1	1	2
Non-verbal reasoning (Raven Matrices)	1	0.3435 (0.0)	0.3292 (0.0)	0.2319 (0.0)	0.5095 (0.0)	0.4323 (0.0)	0.4292 (0.0)	0.4233 (0.0)	0.4273 (0.0)
Non-verbal reasoning (Raven Matrices)	2	0.4096 (0.0)	0.4101 (0.0)	0.2996 (0.0)	0.5458 (0.0)	0.5367 (0.0)	0.4301 (0.0)	0.4122 (0.0)	0.5167 (0.0)
Figural abstraction	1	0.1740 (0.0)	0.2085 (0.0)	0.1476 (0.0001)	0.2653 (0.0)	0.1585 (0.0002)	0.2090 (0.0)	0.2615 (0.0)	0.1954 (0.0)
Figural abstraction	2	0.3217 (0.0)	0.3106 (0.0)	0.2136 (0.0)	0.3631 (0.0)	0.3911 (0.0)	0.2758 (0.0)	0.2987 (0.0)	0.3693 (0.0)
Working Memory	1	0.2690 (0.0)	0.2772 (0.0)	0.1707 (0.0)	0.4929 (0.0)	0.3561 (0.0)	0.4261 (0.0)	0.4116 (0.0)	0.3794 (0.0)
Working Memory	2	0.3257 (0.0)	0.2996 (0.0)	0.2328 (0.0)	0.4073 (0.0)	0.4003 (0.0)	0.4025 (0.0)	0.3625 (0.0)	0.4273 (0.0)
Auditory sequential memory	1	0.2544 (0.0)	0.2371 (0.0)	0.2277 (0.0)	0.4537 (0.0)	0.3449 (0.0)	0.4326 (0.0)	0.3734 (0.0)	0.3965 (0.0)

Auditory sequential memory	2	0.2908 (0.0)	0.2728 (0.0)	0.2570 (0.0)	0.3863 (0.0)	0.3801 (0.0)	0.3914 (0.0)	0.3762 (0.0)	0.4279 (0.0)
Speech comprehension	1	0.1459 (0.0001)	0.074 (0.0465)	0.085 (0.0224)	0.2858 (0.0)	0.2677 (0.0)	0.1272 (0.0027)	0.2916 (0.0)	0.148 (0.0005)
Control function	1	0.1298 (0.0004)	0.1147 (0.0018)	0.1289 (0.0005)	0.2025 (0.0)	0.1891 (0.0)	0.1917 (0.0)	0.1717 (0.0)	0.2011 (0.0)
Control function	2	0.2049 (0.0)	0.1211 (0.0007)	0.1254 (0.0004)	0.2235 (0.0)	0.2583 (0.0)	0.2013 (0.0)	0.2308 (0.0)	0.2695 (0.0)

Non-verbal intellectual ability, as measured by Raven’s Coloured Progressive Matrices, emerges as the strongest single predictor of overall academic achievement; however, it provides limited information about the specific developmental domains in which targeted support is required. In contrast, the component measures of the cognitive profile offer a more differentiated view of the underlying developmental processes.

Among the tasks assessing second-grade academic abilities, reading performance appears largely independent of other domains, showing significant associations only with Raven scores and auditory sequential memory at Grade 2. In contrast, counting and quantity-related tasks already reflect substantial working-memory demands and sequential processing, and by Grade 2 they also demonstrate associations with figural abstraction. Test performance correlates more strongly with teacher evaluations than with standardized outcomes, particularly for data collected in the second grade. Speech comprehension assessed at T1 shows the strongest predictive relationship with writing performance in Grade 1, while also contributing meaningfully to mathematics achievement and exhibiting weaker associations with reading. In terms of control functions, the results from assessments conducted in the first grade do not yet show any relationship with achievement in either year group, but by the end of the second grade, the connection becomes more apparent (Table 5).

Table 6

The correlations between higher-order sensorimotor indicators and two independent indicators of school performance – tested academic abilities and teacher evaluations – across first and second grade (N = 757; p < 0.001)

N=757		Test results on school-abilities			Teacher-evaluation				
		Math ability	Processing quantity	Reading ability	Math	Math	Reading	Writing	Reading / Writing
Indicator	Grade	2	2	2	1	2	1	1	2

Spatial sequential processing	1	0.1903 (0.0)	0.2655 (0.0)	0.1505 (0.0)	0.3904 (0.0)	0.2872 (0.0)	0.3104 (0.0)	0.3324 (0.0)	0.2658 (0.0)
Spatial sequential processing	2	0.1459 (0.0)	0.1658 (0.0)	0.1372 (0.0001)	0.2123 (0.0)	0.2221 (0.0)	0.1729 (0.0)	0.1357 (0.0005)	0.1982 (0.0)
Temporal sequential processing	1	0.2939 (0.0)	0.3054 (0.0)	0.2218 (0.0)	0.4734 (0.0)	0.3418 (0.0)	0.4066 (0.0)	0.4201 (0.0)	0.3527 (0.0)
Temporal sequential processing	2	0.2222 (0.0)	0.1707 (0.0)	0.2055 (0.0)	0.2479 (0.0)	0.2811 (0.0)	0.2348 (0.0)	0.2322 (0.0)	0.3137 (0.0)
Speech sound discrimination	1	0.2304 (0.0)	0.2113 (0.0)	0.2294 (0.0)	0.4489 (0.0)	0.3725 (0.0)	0.4712 (0.0)	0.4407 (0.0)	0.4466 (0.0)
Phonological awareness - number of mistakes	1	0.0917 (0.0128)	0.1471 (0.0001)	0.123 (0.0009)	0.3146 (0.0)	0.2094 (0.0)	0.3391 (0.0)	0.3404 (0.0)	0.2772 (0.0)

In contrast to cognitive functions, sensorimotor maturity is often regarded as secondary, even by specialists, yet the influence of several sensorimotor domains measured at the start of first grade can still be detected at the end of the second grade.

Higher-order sensorimotor functions – spatial and temporal sequencing, and speech sound discrimination – those emerging from the integration of more basic perceptual-motor processes, are not uniformly mature at school entry. Analyses of these functions revealed substantial predictive contributions to achievement in reading, writing, and arithmetic.

Temporal sequencing demonstrated significant associations with all second-grade academic indicators, suggesting broad relevance for early learning. Phoneme discrimination, assessed in T1, showed similarly wide predictive utility, contributing not only to literacy outcomes but even more strongly to arithmetic performance. A comparable pattern was observed for phonological awareness: the ability to identify initial phonemes in words correlated more robustly with mathematics achievement than with reading or writing. Taken together, these

findings indicate that the examined functions exert a stronger influence on academic performance in Grade 1 than in Grade 2, underscoring their particular importance in the earliest phases of formal learning (Table 6).

As demonstrated in earlier analyses, temporal sequencing exerts a particularly strong influence on later academic outcomes, with all second-grade skill indicators showing significant associations. Speech-sound discrimination assessed in the first year likewise exhibited broad predictive utility. Notably, its predictive strength extended beyond literacy-related outcomes and was even more pronounced for arithmetic performance. A comparable pattern emerged for phonological awareness: the ability to identify the initial phoneme of words at the beginning of Grade 1 showed a slightly stronger association with mathematics achievement at the end of Grade 2 than with reading or writing performance. Analysis of the data presented in Table 6 indicates that the higher-order sensorimotor functions constitute strong predictors of achievement in arithmetic, reading, and writing.

Basic sensorimotor functions are typically well-consolidated by the onset of formal schooling, including competencies such as body-part identification, finger gnosis and spatial-relation skills. The integrity of the body schema constitutes a critical foundational component for early mathematical learning, as does the capacity to process spatial relations and comprehend spatial relational vocabulary. Importantly, body schema, finger awareness, and spatial-relation skills assessed at the beginning of Grade 1 demonstrate significant longitudinal predictive validity for mathematics performance at the end of Grade 2. These findings indicate that sensorimotor maturity at school entry serves as a key developmental substrate for the acquisition of early numeracy skills. In effect, during the initial phase of schooling – when counting and basic quantitative concepts are first introduced – sensorimotor functions exert a measurable and enduring influence on subsequent mathematical achievement (Table 7).

Table 7

The correlations between basic sensorimotor indicators and two independent indicators of school performance – tested academic abilities and teacher evaluations – across first and second grade

N=757	Test results on school-abilities	Teacher-evaluation
-------	----------------------------------	--------------------

		Math ability	Processing quantity	Reading ability	Math	Math	Reading	Writing	Reading / Writing
Indicator	Grade	2	2	2	1	2	1	1	2
Body scheme	1	0.0641 (0.0806)	0.1210 (0.0009)	0.1152 (0.0017)	0.2886 (0.0)	0.3054 (0.0)	0.1611 (0.0001)	0.2930 (0.0)	0.1336 (0.0014)
Finger awareness	1	0.066 (0.0722)	0.1483 (0.0001)	0.1082 (0.0032)	0.2916 (0.0)	0.2909 (0.0)	0.2035 (0.0)	0.2879 (0.0)	0.2012 (0.0)
Finger awareness	2	0.1661 (0.0)	0.1159 (0.0012)	0.1805 (0.0)	0.2672 (0.0)	0.2374 (0.0)	0.3138 (0.0)	0.2287 (0.0)	0.3170 (0.0)
Spatial relations	1	0.1427 (0.0001)	0.1186 (0.0012)	0.1286 (0.0005)	0.2915 (0.0)	0.2822 (0.0)	0.1859 (0.0)	0.2938 (0.0)	0.1342 (0.0014)

Higher-order cognitive functions are hierarchically dependent on the integrity of basic developmental processes. Insufficient maturation in these foundational domains can introduce instability and variability into subsequent cognitive performance. Although such effects are not consistently captured in standardized measures of arithmetic or word-reading proficiency, teacher evaluations indicate that core sensorimotor functions exert a substantial influence on the acquisition of these academic skills. This suggests that subtle deficits in early sensorimotor maturation may manifest primarily in classroom learning behaviours and skill acquisition trajectories rather than in isolated test scores.

Summary of Predictors of Academic Achievement

Re-analysis confirms that the functions identified above account for a substantially larger proportion of variance in Grade 1 performance than in end-of-Grade-2 outcomes, indicating that their predictive weight is concentrated at the earliest measurement point.

We conducted separate analyses to estimate the contributions of cognitive and sensorimotor domains to academic achievement at T1 and T2. Indicators assessed at school entry demonstrated robust associations with end-of-year performance, and a substantial proportion of these associations remained stable into the second grade. Although a broad set of functions

supports the acquisition of reading, writing, and arithmetic, specific developmental immaturities emerged as particularly strong predictors of subsequent learning difficulties. Multiple regression analyses identified the following as significant predictors of Grade 2 academic outcomes:

- **Working memory** ($\beta = 0.41, p < 0.001$)
- **Temporal sequential processing** ($\beta = 0.38, p < 0.001$)
- **Auditory sequential memory** ($\beta = 0.33, p < 0.001$)
- **Phoneme discrimination** ($\beta = 0.29, p < 0.001$)
- **Quantity concepts** ($\beta = 0.27, p < 0.001$)

Sensorimotor indicators also contributed:

- **Body schema** ($\beta = 0.28, p < 0.001$).
- **Finger awareness** ($\beta = 0.27, p < 0.001$).
- **Balance (eyes closed)** predicted mathematics ($\beta = 0.22, p < 0.001$).

Control-related processes did not correlate with academic performance at the beginning of schooling; however, by the end of Grade 2 they demonstrated significant predictive value, suggesting a developmental shift in their contribution to learning outcomes. Sensorimotor maturity exerted a stable longitudinal influence. Measures of body-part identification and finger awareness obtained at school entry continued to predict academic performance in Grade 2, with especially strong associations observed for mathematics achievement. Teacher evaluations correlated moderately with test results, but discrepancies suggest that combining standardized assessments with classroom observations yields more reliable insights.

Within a neuro-constructivist framework (Karmiloff-Smith, 2009), higher-order cognitive functions are understood to emerge from the progressive specialization and integration of lower-level perceptual and sensorimotor processes. Consequently, insufficient maturation in these basic domains can cause instability and variability into later-developing cognitive operations. Although these dependencies are not consistently reflected in standardized assessments of arithmetic or word-reading proficiency, teacher evaluations indicate that core sensorimotor functions exert a substantial influence on the acquisition and consolidation of

these skills. This pattern suggests that subtle immaturities in early sensorimotor development may manifest primarily in learning behaviours, task engagement, and skill-acquisition trajectories rather than in isolated test scores.

Settlement Size Differences

Initial Settlement-Based Differences at School Entry

ANOVA results showed significant differences across settlement types in working memory, sequential processing, phoneme discrimination, and body schema at T1. Children from villages scored significantly lower than those from large towns and the capital. These disparities persisted into Grade 2, although effect sizes decreased slightly.

Figure 1

Sensorimotor and Cognitive Developmental Delays Observed at School Entry in Children from Small Settlements (N = 410)

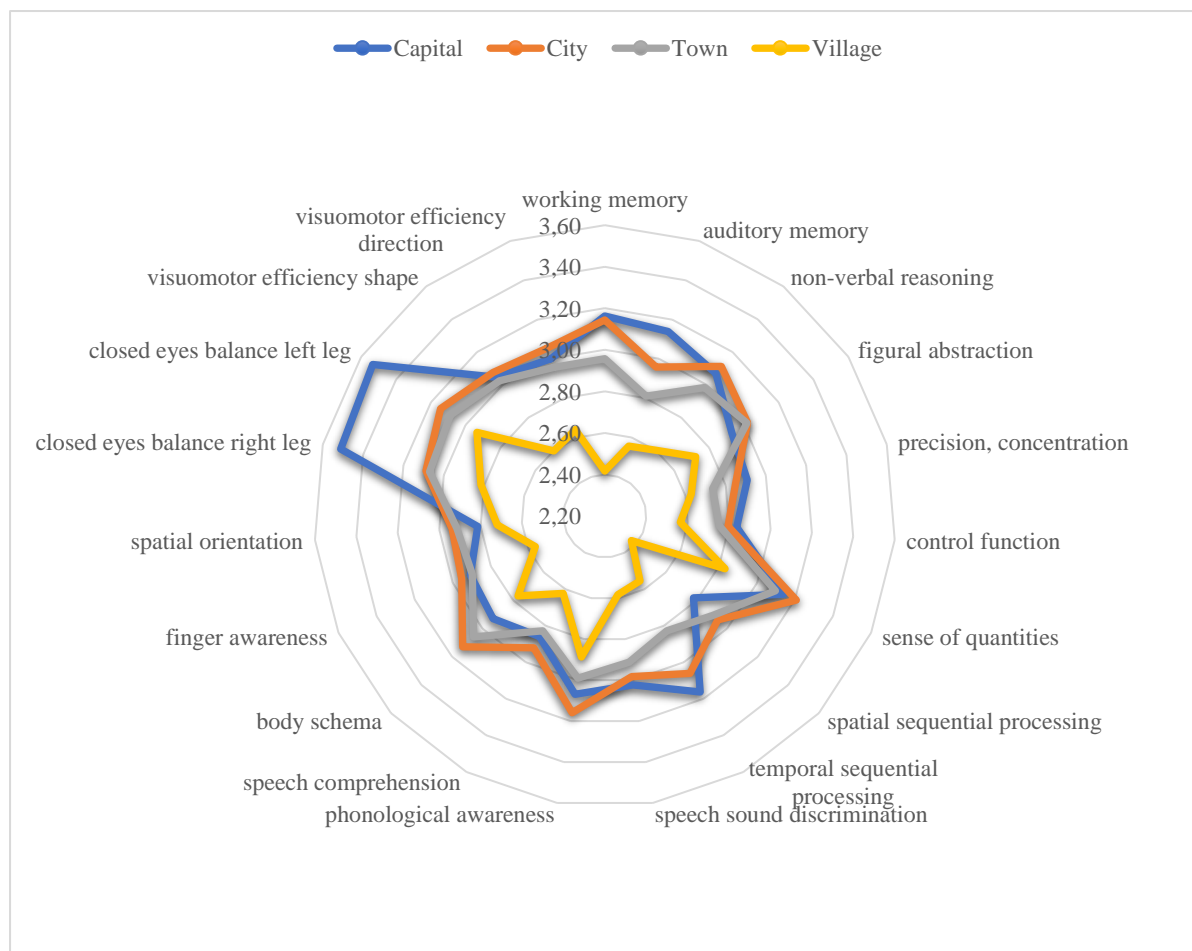


Figure 1 illustrates the developmental disadvantage observed among children from the smallest settlements at the school-entry. Tables 8 to 10 report the mean scores for children living in different settlement types, the significance of group differences relative to the full sample based on t-tests, and the variance of the results. The latter is particularly noteworthy: children from small settlements exhibit substantially greater variability in their test performance. This heightened heterogeneity may itself constitute an additional challenge for schools serving these communities. Children living in small settlements lag behind those from larger settlements in every cognitive and sensorimotor indicator. In some measures, this lag is particularly significant.

Table 8

Mean cognitive abilities at T1, results of two-tailed independent t-tests comparing each settlement-size group to the overall sample mean, and the corresponding variances.

Ability area/Average N=410	Working memory	Auditory memory	Non-verbal reasoning	Figural abstraction	Speech comprehension	Precision, concentration	Control function
Capital	3.16	3.14	3.07	2.93	2.86	2.91	2.84
City	3.14	2.96	3.11	3.02	2.92	2.85	2.80
Town	2.96	2.81	2.98	3.02	2.83	2.74	2.75
Village	2.42	2.56	2.60	2.72	2.62	2.63	2.56
Average All	2.92	2.87	2.94	2.92	2.81	2.78	2.74
Ability area/ttest N=410	Working memory	Auditory memory	Non-verbal reasoning	Figural abstraction	Speech comprehension	Precision, concentration	Control function
Capital	0.0341	0.0064	0.1648	0.9839	0.5606	0.0955	0.2090
City	0.0008	0.0532	0.0040	0.1622	0.0422	0.1048	0.2024
Town	0.5010	0.7960	0.4175	0.2243	0.7234	0.6457	0.6326
Village	0.0000	0.0010	0.0000	0.0024	0.0092	0.0373	0.0146
Ability area/STD N=410	Working memory	Auditory memory	Non-verbal reasoning	Figural abstraction	Speech comprehension	Precision, concentration	Control function
Capital	0.43	0.35	0.59	0.70	0.52	0.37	0.48
City	0.58	0.55	0.56	0.65	0.39	0.46	0.48
Town	0.67	0.78	0.63	0.69	0.56	0.56	0.52
Village	1.02	0.90	0.63	0.56	0.79	0.68	0.70
STD - All	0.67	0.64	0.60	0.65	0.56	0.52	0.55

The robust association between working memory and intelligence test performance reported in previous research (Kovacs, Molenaar, & Conway, 2019; Conway et al., 2021) is also evident in our cognitive indicators. Marked developmental delays in working memory are accompanied by reduced non-verbal reasoning performance, as assessed by the Coloured Raven’s Test. Because the Figure subtest – measuring figural abstraction – contains fewer elements within each matrix, it imposes a lower working-memory load. Consequently, children from small settlements show a somewhat reduced disadvantage on this task relative to the full sample. In effect, the gap in reasoning related skills is narrower for this specific measure.

Furthermore, across all measures tapping sequential and speech-related functions – core components underpinning higher-order cognitive processes – children from small settlements consistently exhibit lower performance (Table 9). This pattern suggests that the observed disadvantages are rooted in earlier and more foundational developmental deficits

Table 9

Mean higher-order sensorimotor abilities at T1, results of two-tailed independent t-tests comparing each settlement-size group to the overall sample mean, and the corresponding variances.

Ability area/Average N=410	Spatial sequential processing	Temporal sequential processing	Speech sound discrimination	Phonological awareness	Sense of quantities
Capital	2.78	3.16	3.02	3.07	3.14
City	2.94	3.06	2.98	3.16	3.21
Town	2.91	2.83	2.91	2.99	3.10
Village	2.37	2.56	2.58	2.89	2.83
Average All	2.75	2.90	2.88	3.03	3.07
Ability area/ttest N=410	Spatial sequential processing	Temporal sequential processing	Speech sound discrimination	Phonological awareness	Sense of quantities
Capital	0.8762	0.0057	0.0976	0.6925	0.5139
City	0.0004	0.0019	0.0473	0.0298	0.0533
Town	0.0100	0.4956	0.3954	0.5276	0.6699
Village	0.0000	0.0000	0.0003	0.0371	0.0032

Ability area/ STD N=410	Spatial sequential processing	Temporal sequential processing	Speech sound discrimination	Phonological awareness	Sense of quantities
Capital	0.47	0.43	0.16	0.46	0.71
City	0.27	0.49	0.55	0.59	0.71
Town	0.32	0.58	0.61	0.58	0.69
Village	0.83	0.88	0.80	0.70	0.72
STD - All	0.47	0.59	0.53	0.58	0.71

In fact, the issue arises even earlier, as a similar situation is evident in the most basic sensorimotor functions – village children lag behind their city peers in every basic sensorimotor indicator, with several measures showing significant differences (see Table 11). Notably, children from the capital exhibit an advantage in balancing, that is, in sensorimotor integration, which indicates greater neurological maturity. This is an important marker of cognitive development and serves as a positive predictor for future performance. For children living in small settlements, delays in finger awareness, perception of directions, and shapes represent a serious burden when it comes to acquiring school skills.

The pattern of disadvantage emerges even earlier, as comparable disparities are already observable in the most fundamental sensorimotor functions: children living in villages score lower than their urban peers on all basic sensorimotor indicators, with several measures showing statistically significant differences (Table 10). Children from the capital, in particular, demonstrate superior performance in balance tasks – an index of sensorimotor integration – suggesting more advanced neurological maturation. Sensorimotor integration is a key developmental marker and a well-established predictor of later cognitive and academic performance.

Delays in finger awareness, directional perception, and shape discrimination among children from small settlements constitute a substantial developmental risk, as these foundational skills play a critical role in the acquisition of early school competencies.

Table 10

Mean basic sensorimotor abilities at T1, results of two-tailed independent t-tests comparing each settlement-size group to the overall sample mean, and the corresponding variances.

Ability area/Average N=410	Body schema	Finger awareness	Spatial orientation	Closed eyes balance right leg	Closed eyes balance left leg	Visuomotor efficiency shape	Visuomotor efficiency direction
Capital	2.93	2.91	2.81	3.51	3.53	3.05	3.00
City	3.13	2.95	2.94	3.09	3.14	3.08	3.05
Town	3.06	2.90	2.91	3.07	3.09	3.03	2.96
Village	2.77	2.56	2.72	2.81	2.94	2.60	2.64
Average All	2.97	2.83	2.85	3.12	3.18	2.94	2.91

Ability area/ttest N=410	Body schema	Finger awareness	Spatial orientation	Closed eyes balance right leg	Closed eyes balance left leg	Visuomotor efficiency shape	Visuomotor efficiency direction
Capital	0.5574	0.3113	0.5140	0.0000	0.0000	0.2447	0.3450
City	0.0414	0.0035	0.0535	0.6136	0.5989	0.0149	0.0107
Town	0.3793	0.1697	0.2406	0.8264	0.7090	0.1503	0.4545
Village	0.0038	0.0000	0.0082	0.0021	0.0085	0.0000	0.0001

Ability area/STD N=410	Body schema	Finger awareness	Spatial orientation	Closed eyes balance right leg	Closed eyes balance left leg	Visuomotor efficiency shape	Visuomotor efficiency direction
Capital	0.55	0.37	0.55	0.67	0.77	0.38	0.22
City	0.64	0.24	0.27	0.52	0.42	0.54	0.52
Town	0.70	0.40	0.34	0.71	0.67	0.55	0.46
Village	0.79	0.69	0.64	0.76	0.62	0.74	0.79
STD - All	0.67	0.43	0.45	0.67	0.62	0.55	0.50

Overall, children living in small settlements begin school with a broad sensorimotor and cognitive immaturity. Notably, spatial and temporal sequential processing shows a particularly marked delay among children from small settlements. Substantial differences are also evident in the maturity of speech-sound discrimination, although these disparities are less pronounced than those observed in sequential processing. Once again, children living in small villages lag behind in functions that are decisive for starting school.

During our research, a young teacher from a disadvantaged village reported that it was only after reviewing the data that she realised the difficulties in her classroom were not due to shortcomings in her own teaching. Instead, the data revealed that nearly all of her pupils required substantial developmental support before they could acquire basic school competencies. For these children, movement-based rhymes and songs proved to be the most effective instructional tools. It was only after a full year of such foundational developmental work that they became ready to begin learning to count, read, and write.

Given the wide variance in the data, the problem could be even more severe for some children. It is important to note that not all small settlements are alike, and even in a very disadvantaged village, there may be children who develop well. In this light, those who display delays may find themselves in an extremely serious situation.

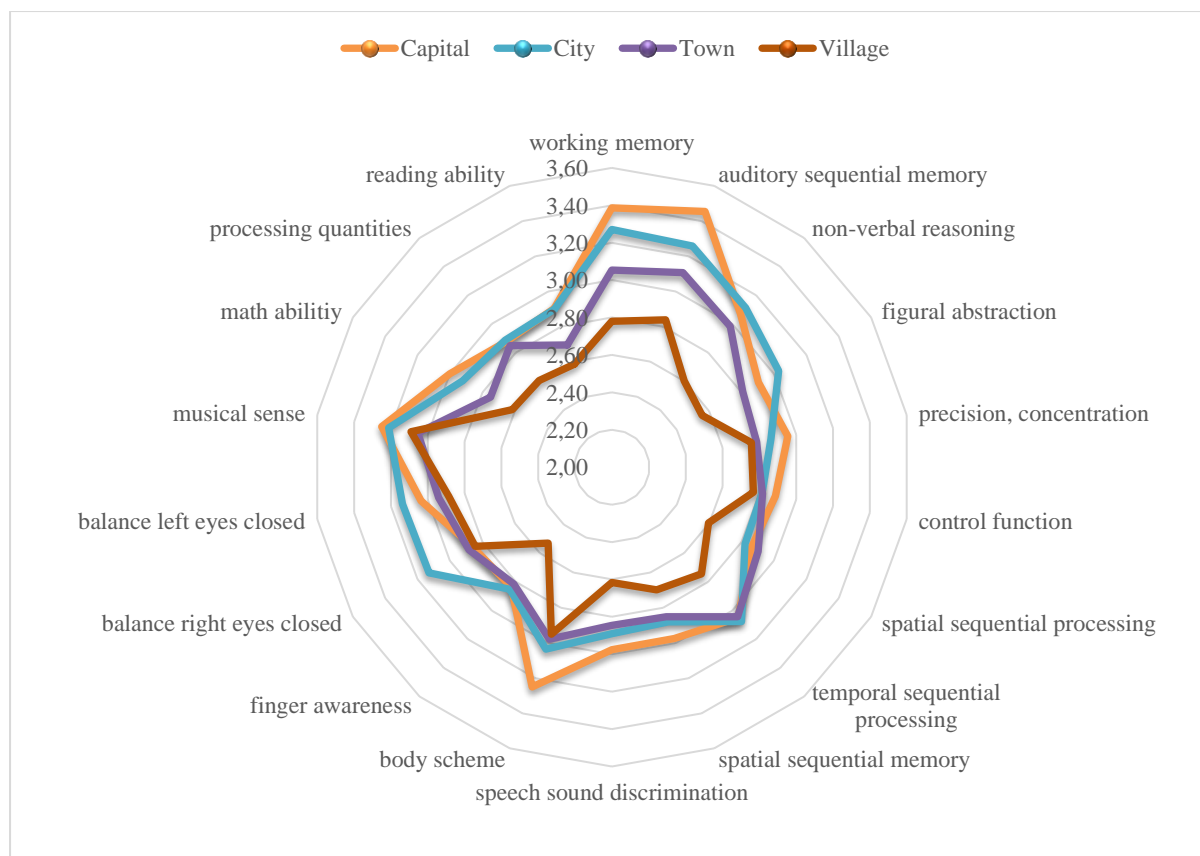
Differences at the end of the second school year

At the conclusion of the second school year, children were re-assessed using the Sensorimotor and Cognitive Profile Test. As described in the Method section, in this iteration (T2), several low-difficulty sensorimotor items were excluded to reduce ceiling effects and enhance measurement sensitivity. Concurrently, three school-relevant subtests – arithmetic operations, quantitative reasoning, and reading proficiency – were introduced to capture academic skill acquisition.

Analysis of the visualized results (Figure 2) indicates that although children living in small settlements continue to show a marked developmental lag relative to their urban peers, some degree of convergence is evident. Nevertheless, working memory and sequential processing remain the domains with the largest discrepancies compared with children from other settlement types. These findings suggest that although developmental trajectories are advancing, structural disparities linked to settlement size persist and warrant sustained attention in both research and intervention design.

Figure 2

Sensorimotor and Cognitive Developmental Delays Among Children from Small Settlements at the End of Grade 2 (N = 383)



The analysis was constrained by the inability to account for dynamic changes in class composition resulting from pupil turnover. Consequently, children exhibiting the most pronounced developmental challenges – specifically those retained for grade repetition – a were systematically excluded from the measurement cohort. This exclusion introduces a selection bias that may underestimate the extent of skill deficits within the broader population.

Simultaneously, a subset of pupils previously enrolled in higher year groups had been reassigned to T2, indicating the presence of partial developmental delays or insufficient mastery of foundational competencies. These compositional shifts underscore the need for longitudinal tracking and more nuanced sampling strategies to accurately capture the developmental trajectories of all learners, including those experiencing academic discontinuity.

End-of-Year 2 (T2) assessment data indicate that children attending schools in small villages continue to underperform relative to peers in larger settlements across multiple developmental domains (Table 11 to 14). The disparity is particularly pronounced in working memory, auditory sequential memory and performance on figural abstraction tasks indicating

that the gap remains clearly detectable. The comparatively lower Raven-based non-verbal reasoning scores with lower variances observed in children from small settlements provide evidence of residual cognitive insufficiencies that remain salient at this stage of development.

Table 11

Mean cognitive scores at T2, results of two-tailed independent t-tests comparing each settlement-size group to the overall sample mean, and the corresponding variances.

Ability area/Average N=383	Working memory	Auditory sequential memory	Non-verbal reasoning	Figural abstraction	Precision, concentration	Control function
Capital	3.39	3.45	3.07	2.90	2.95	2.89
City	3.27	3.26	3.11	3.03	2.86	2.82
Town	3.05	3.11	2.98	2.81	2.78	2.82
Village	2.78	2.84	2.60	2.56	2.76	2.77
Average All	3.12	3.16	2.94	2.82	2.84	2.82
Ability area/ttest N=383	Working memory	Auditory sequential memory	Non-verbal reasoning	Figural abstraction	Precision, concentration	Control function
Capital	0.0124	0.0023	0.1648	0.5479	0.1407	0.3104
City	0.0160	0.0499	0.0040	0.0075	0.5022	0.9392
Town	0.5455	0.7184	0.4175	0.7424	0.5250	0.9182
Village	0.0001	0.0001	0.0000	0.0017	0.2899	0.4220
Ability area/STD N=383	Working memory	Auditory sequential memory	Non-verbal reasoning	Figural abstraction	Precision, concentration	Control function
Capital	0.62	0.63	0.59	0.62	0.30	0.32
City	0.69	0.60	0.56	0.70	0.51	0.48
Town	0.58	0.60	0.63	0.54	0.62	0.49
Village	0.80	0.70	0.63	0.91	0.66	0.51
STD - All	0.67	0.63	0.60	0.69	0.52	0.45

However, subsequent inferential statistical analyses indicate that, although the patterns are directionally consistent, the observed differences do not uniformly reach conventional levels of statistical significance. This limitation is closely linked to a structural issue highlighted in the study's Limitations. National data from Hungary show that 4–5% of children repeat first grade because they are unable to meet the required competencies (Rodler, 2025). In small settlements, a disproportionately high number of children begin Grade 1 with marked

immaturity in the foundational functions necessary for acquiring school skills. As a result, these communities have elevated proportions of repeaters and older pupils who subsequently struggle in Grade 2. Although these older repeaters often exhibit persistent academic difficulties for multiple reasons, they nonetheless possess advantages in terms of neurological maturity and familiarity with school routines.

Overall, children residing in rural areas consistently demonstrated the lowest performance across all assessed cognitive domains. Yet, the magnitude of the performance gap relative to peers in more urbanized settings was substantially pronounced only in specific domains. In these areas, increased within-group variance was also evident, suggesting considerable heterogeneity in developmental outcomes among rural children.

This pattern suggests that while a subset of children in small settlements exhibit age-appropriate cognitive development, a considerable proportion experience persistent difficulties that appear unresponsive to conventional educational practices. These outliers contribute disproportionately to both the increased variance and the overall reduction in mean performance scores, highlighting the need for differentiated support strategies and context-sensitive interventions tailored to the specific challenges of rural educational environments.

Table 12

Mean higher-order sensorimotor function scores at T2, results of two-tailed independent t-tests comparing each settlement-size group to the overall sample mean, and the corresponding variances.

Ability area/Average N=383	Spatial sequential processing	Temporal sequential processing	Spatial sequential memory	Speech sound discrimination
Capital	2.86	3.05	2.98	2.98
City	2.82	3.08	2.88	2.89
Town	2.90	3.04	2.85	2.85
Village	2.60	2.74	2.70	2.62
Average All	2.79	2.98	2.85	2.83
Ability area/ttest N=383	Spatial sequential processing	Temporal sequential processing	Spatial sequential memory	Speech sound discrimination
Capital	0.3983	0.5772	0.2303	0.0487
City	0.5208	0.1937	0.5206	0.1172

Town	0.0587	0.4613	0.8379	0.5881
Village	0.0040	0.0116	0.0840	0.0019
Ability area/STD N=383	Spatial sequential processing	Temporal sequential processing	Spatial sequential memory	Speech sound discrimination
Capital	0.47	0.72	0.73	0.16
City	0.54	0.73	0.75	0.38
Town	0.39	0.67	0.62	0.47
Village	0.68	0.92	0.68	0.71
STD - All	0.52	0.76	0.70	0.43

According to the data obtained during T2, the lag of small settlements is not significant in spatial and temporal sequential processing, and is even smaller in the test used only in this phase, a spatial sequential memory subtest, a task similar to the Corsi Test. This test requires the concurrent engagement of temporal sequencing and spatial processing, which would theoretically amplify performance disparities between groups with differing working-memory capacities. However, our findings indicate that performance differences are not significant. It is plausible that multiple sources of variance – both cognitive and procedural – jointly shaped this result (Table 12).

Working memory, a key feature of the cognitive system, allows for maintaining and processing information simultaneously and in a controlled manner. Working memory processing continuously develops across childhood, with significant increases both in verbal and visuospatial working memory, however, verbal and visuospatial working memory may show different developmental trajectories, as verbal working memory relies on internal verbal rehearsal, which is less developed in younger children (Buttelmann, et al, 2020). Research using normative Corsi data shows that spatial memory spans increase incrementally with age throughout childhood; 8-year-olds are still in the process of reaching adult-like capacity. Thus, even those who perform poorly relative to older or higher-performing peers will still show better absolute performance than expected based solely on separate temporal or sequential deficits (Farrell Pagulayan et al, 2006).

During middle childhood, children may adopt alternative encoding strategies, such as chunking spatial configurations or encoding global spatial patterns rather than strictly maintaining temporal order, which can reduce effective sequential demands (Morey, Rhodes, & Cowan, 2019). Performance may also be supported by compensatory engagement of other

working memory components, such as spatial rehearsal or simultaneous visuospatial encoding processes, which can partially offset weaknesses in temporal sequencing (Logie, Camos, & Cowan, 2021). Finally, standard span-based measures like the Corsi task have methodological limitations, as they yield coarse performance indices that may obscure qualitative differences in encoding precision, order maintenance, and strategy use, potentially masking underlying cognitive processing deficits (Schuchardt, Maehler, & Hasselhorn, 2017).

Table 13

Mean deeper sensorimotor function scores at T2, results of two-tailed independent t-tests comparing each settlement-size group to the overall sample mean, and the corresponding variances.

Ability area/Average N=383	Body scheme	Finger awareness	Balance right eyes closed	Balance left eyes closed	Musical sense
Capital	3.25	2.84	2.86	3.04	3.25
City	3.03	2.85	3.13	3.14	3.21
Town	2.98	2.82	2.88	2.94	3.05
Village	2.95	2.53	2.85	2.89	3.09
Average All	3.05	2.76	2.93	3.00	3.15
Ability area/ttest N=383	Body scheme	Finger awareness	Balance right eyes closed	Balance left eyes closed	Musical sense
Capital	0.0297	0.3958	0.4139	0.8598	0.1819
City	0.8614	0.0934	0.0185	0.0850	0.1751
Town	0.5479	0.3819	0.2879	0.3967	0.0671
Village	0.3203	0.0021	0.1363	0.1444	0.2705
Ability area/STD N=383	Body scheme	Finger awareness	Balance right eyes closed	Balance left eyes closed	Musical sense
Capital	0.61	0.53	0.71	0.43	0.61
City	0.67	0.49	0.65	0.74	0.57
Town	0.63	0.51	0.57	0.54	0.27
Village	0.67	0.78	0.81	0.84	0.35
STD - All	0.64	0.58	0.68	0.64	0.45

Finger awareness – defined as the capacity to consciously perceive, differentiate, and control individual fingers – is increasingly recognized as a key predictor of academic readiness and early school success. Despite its developmental significance, persistent deficits in this domain remain evident. Longitudinal observations indicate that by the end of Year 2, a substantial proportion of children have yet to attain age-appropriate proficiency in finger awareness, even though this function is typically expected to mature prior to school entry.

This lag is particularly concerning given the abundance of pedagogical and recreational modalities available to support its development. Activities such as finger-based play, musical instrument instruction, finger puppetry, shadow play, and fine motor arts offer rich opportunities for sensorimotor refinement. The continued underdevelopment of finger awareness, despite these accessible interventions, suggests potential gaps in implementation, engagement, or contextual relevance – warranting further investigation into both environmental and instructional factors that may hinder optimal maturation.

The disadvantage associated with children living in the smallest settlements is also reflected in the school-related skills assessed by the test and corroborated by teacher evaluations. Although their performance does not differ significantly from that of the overall sample, the consistently lower scores – interpreted in light of the methodological limitations outlined earlier – provide a clear indication that children in small settlements face persistent developmental challenges that may hinder their school achievement.

Table 14

Mean academic abilities scores at T2, results of two-tailed independent t-tests comparing each settlement-size group to the overall sample mean, and the corresponding variances.

Ability area/Average N=383	Math ability	Processing quantities	Reading ability
Capital	3.00	2.88	2.90
City	2.92	2.89	2.90
Town	2.75	2.85	2.70
Village	2.62	2.61	2.59
Average All	2.82	2.80	2.77
Ability area/ttest	Math ability	Processing quantities	Reading ability
Capital	0.0177	0.3578	0.1081
City	0.0162	0.0713	0.0068

Town	0.3537	0.4391	0.2716
Village	0.0030	0.0016	0.0052
Ability area/STD N=383	Math ability	Processing quantities	Reading ability
Capital	0.00	0.40	0.37
City	0.34	0.38	0.37
Town	0.57	0.49	0.57
Village	0.71	0.67	0.67
STD - All	0.40	0.48	0.50

Summary of Findings on Settlement-Size Difference

Multiple indicators demonstrate that children residing in small villages commence schooling with substantially lower maturity levels than their urban counterparts, and this developmental gap remains largely unchanged by the second year. Teacher-reported evaluation exhibits a comparable trend, though the observed differences are not statistically significant when stratified by settlement size.

The data suggest a near-linear association between settlement size and children's sensorimotor and cognitive development, indicating that urbanicity may function as a proxy for access to developmental resources or environmental stimulation.

These findings not only corroborate prior research on the relationship between settlement size and intellectual development but also delineate specific domains where children in smaller settlements may be disproportionately disadvantaged. The results underscore the need for targeted interventions and further investigation into the structural and contextual factors contributing to these disparities.

An additional salient finding is the markedly higher variance in developmental outcomes among children residing in rural settlements. This elevated intra-group heterogeneity indicates that, within these educational contexts, pupils exhibit a broader spectrum of cognitive and sensorimotor competencies than typically observed (Tables 15 to 16).

Table 15

Variances of the measured domains at T1

Ability area/ STD in T1 N=410	Working memory	Auditory memory	Non-verbal reasoning	Figural abstraction	Speech compre- hension	Precision, concentration	Control Function
Capital	0.43	0.35	0.59	0.70	0.52	0.37	0.48
City	0.58	0.55	0.56	0.65	0.39	0.46	0.48
Town	0.67	0.78	0.63	0.69	0.56	0.56	0.52
Village	1.02	0.90	0.63	0.56	0.79	0.68	0.70
STD - All	0.67	0.64	0.60	0.65	0.56	0.52	0.55

Ability area/ STD in T1 N=410	Spatial sequential processing	Temporal sequential processing	Speech sound discrimination	Phonological awareness	Sense of quantities
Capital	0.47	0.43	0.16	0.46	0.71
City	0.27	0.49	0.55	0.59	0.71
Town	0.32	0.58	0.61	0.58	0.69
Village	0.83	0.88	0.80	0.70	0.72
STD - All	0.47	0.59	0.53	0.58	0.71

Ability area/ STD in T1 N=410	Body schema	Finger awareness	Spatial orientation	Closed eyes balance right leg	Closed eyes balance left leg	Visuomotor efficiency shape	Visuomotor efficiency direction
Capital	0.55	0.37	0.55	0.67	0.77	0.38	0.22
City	0.64	0.24	0.27	0.52	0.42	0.54	0.52
Town	0.70	0.40	0.34	0.71	0.67	0.55	0.46
Village	0.79	0.69	0.64	0.76	0.62	0.74	0.79
STD - All	0.67	0.43	0.45	0.67	0.62	0.55	0.50

Such dispersion imposes increased demands on instructional differentiation, as educators must accommodate a wider range of developmental profiles within a single classroom setting. This complexity may inadvertently constrain the learning trajectories of children with high developmental potential, whose progress can be hindered by the necessity to address more foundational needs within the same pedagogical framework. The findings underscore the importance of targeted support structures and adaptive teaching strategies to mitigate the impact of developmental disparity on educational equity.

Table 16

Variances of the measured domains at T2

Ability area/STD in T2 N=383	Working memory	Auditory sequential memory	Non-verbal reasoning	Figural abstraction	Control function
------------------------------------	-------------------	----------------------------------	-------------------------	------------------------	---------------------

Capital	0,62	0,63	0,59	0,62	0,32
City	0,69	0,60	0,56	0,70	0,48
Town	0,58	0,60	0,63	0,54	0,49
Village	0,80	0,70	0,63	0,91	0,51
STD - All	0,67	0,63	0,60	0,69	0,45

Ability area/STD in T2 N=383	Spatial sequential processing	Temporal sequential processing	Spatial sequential memory	Speech sound discrimination
Capital	0,47	0,72	0,73	0,16
City	0,54	0,73	0,75	0,38
Town	0,39	0,67	0,62	0,47
Village	0,68	0,92	0,68	0,71
STD - All	0,52	0,76	0,70	0,43

Ability area/STD in T2 N=383	Body scheme	Finger awareness	Balance right eyes closed	Balance left eyes closed	Musical sense
Capital	0,61	0,53	0,71	0,43	0,61
City	0,67	0,49	0,65	0,74	0,57
Town	0,63	0,51	0,57	0,54	0,27
Village	0,67	0,78	0,81	0,84	0,35
STD - All	0,64	0,58	0,68	0,64	0,45

Ability area/STD in T2 N=383	Math ability	Processing quantities	Reading ability
Capital	0,00	0,40	0,37
City	0,34	0,38	0,37
Town	0,57	0,49	0,57
Village	0,71	0,67	0,67
STD - All	0,40	0,48	0,50

Discussion

The early years of formal schooling constitute a critical developmental window during which children's cognitive, sensorimotor, and academic competencies undergo rapid and interdependent transformation. Within this period, learning agility – the capacity to adapt, acquire new skills efficiently, and flexibly apply emerging knowledge – has become increasingly salient in contemporary educational contexts. Complementing this is learning motivation, which sustains engagement, perseverance, and task-directed effort, thereby shaping the quality and trajectory of early academic development.

The acquisition of foundational academic competencies such as reading, writing, and arithmetic presupposes a sufficient level of neurological and cognitive maturation. When formal instruction is introduced before children have reached the requisite developmental readiness, performance difficulties of varying severity frequently emerge. These patterns underscore the necessity of aligning instructional expectations with established neurodevelopmental trajectories in order to maximise learning efficiency and reduce the risk of cumulative and persistent academic disadvantage.

Socioeconomic disparities further intensify these challenges. Children from lower-SES backgrounds are more likely to enter school with less fully developed cognitive and sensorimotor profiles, increasing the likelihood that instructional demands will exceed their developmental preparedness. As a result, early performance difficulties may accumulate more rapidly in these groups – not due to inherent limitations, but as a consequence of differential access to early developmental opportunities, environmental stimulation, and structured learning experiences.

Neuro-constructivism conceptualizes development as a process of progressive specialization, in which cognitive functions emerge from the interaction of multiple low-level neural and behavioural constraints. Karmiloff-Smith (2007) emphasizes that developmental disorders should not be viewed as static deficits but as developmental trajectories shaped by early atypicalities that cascade across levels of processing. She highlights the importance of studying processes rather than end-state performance, noting that similar behavioural outcomes can arise from different underlying mechanisms.

The present findings reinforce the central role of early developmental readiness in shaping academic outcomes and reveal persistent disparities across settlement types. Sensorimotor and cognitive functions assessed at school entry were strong predictors of later academic performance, highlighting the need for early, targeted, and context-sensitive educational interventions. Our results further demonstrate that children from smaller settlements begin school with lower levels of developmental readiness, and these disparities remain evident through Grade 2. This pattern supports the hypothesis that standard educational provision alone does not fully compensate for early developmental disadvantages.

Among the cognitive predictors, working memory exerted the strongest influence on academic skills, consistent with extensive evidence linking it to literacy and numeracy acquisition. Sequential processing also emerged as a particularly powerful predictor, aligning

with research emphasising the role of temporal and auditory sequencing in reading fluency, phonological processing, and mathematical reasoning. Sensorimotor functions – often underemphasised in educational discourse – likewise contributed substantially, particularly to mathematics outcomes. Sensorimotor integration, operationalised through balance-based assessments, was especially informative: the ability to maintain unilateral stance on the dominant leg with eyes closed demonstrated strong predictive value. Because this task requires postural control in the absence of visual input, successful performance reflects advanced neural coordination and sustained attentional regulation, both of which are relevant for classroom learning.

Taken together, these findings highlight the importance of early kindergarten interventions and pre-school assessments of cognitive and sensorimotor profiles. When developmental readiness is insufficient, targeted and intensive support prior to and throughout the first school year appears essential. Finally, discrepancies observed between standardised test outcomes and teacher evaluations indicate that robust, data-informed decision-making is best achieved by integrating psychometric assessment results with continuous, context-sensitive observational data from educators. Such an approach offers a more comprehensive understanding of children’s developmental profiles and supports more equitable and effective educational planning.

Educational Implications

- Early assessment of sensorimotor and cognitive profiles is essential.
- Targeted interventions should focus on sequential processing, phoneme discrimination, and body schema.
- Rural schools may require additional resources to address developmental disparities.

Limitations

- Sample attrition and pupil turnover introduced selection bias, as grade reassignment and dropout prevented the inclusion of learners with the most pronounced developmental delays. This likely constrained the accuracy with which the full range of developmental trajectories could be represented.

- SES data were available only at the school level, limiting the precision of socioeconomic analyses.
- Academic subtests administered at T2 may have been more demanding, which could have contributed to reduced effect sizes relative to T1.
- Class-level SES indicators may obscure within-school variability, potentially masking important differences among pupils within the same institution.
- The assessment procedure itself may have functioned as an intervention, as teachers reported that access to test results increased their confidence and encouraged them to adapt instruction more closely to children's developmental profiles. Consequently, the act of measurement may have influenced the learning environment independently of any additional developmental methods employed.

References

- Acevedo-De-los-Ríos, A., Chumpitaz-Requena, F. R., Rondinel-Oviedo, D. R., Cárdenas-Mamani, Ú., & Redondo, J. M. (2025). Exploring the urban systemic scenarios of improving socioecological conditions in an informal settlement of a developing country with a system dynamics model. *Environmental Science & Policy*, 169, 104079. <https://doi.org/10.1016/j.envsci.2025.104079>
- Anastasi, A., & Urbina, S. (1997). *Psychological testing* (7th ed.). Prentice Hall, London
- Arvidsson, M., Lovsjö, N., & Keuschnigg, M. (2023). *Urban scaling laws arise from within-city inequalities*. *Nature Human Behaviour*, 7(3), 365–374. <https://doi.org/10.1038/s41562-022-01509-1>
- Barrett, N., Cowen, J. M., & Toma, E. F. (2015). Charter school location and student outcomes: Urban, suburban, and rural differences. *Journal of Urban Economics*, 86, 48–61. <https://doi.org/10.1016/j.jue.2014.12.003>
- Buttelmann, F., Könen, T., Hadley, L. V., Meaney, J. A., Auyeung, B., Morey, C. C., Chevalier, N., & Karbach, J. (2020). Age-related differentiation in verbal and visuospatial working memory processing in childhood. *Psychological research*, 84(8), 2354–2360. <https://doi.org/10.1007/s00426-019-01219-w>

- Caldwell, J. T., Ford, C. L., Wallace, S. P., Wang, M. C., & Takahashi, L. M. (2017). Racial and ethnic residential segregation and access to health care in rural areas. *Health & Place*, 43, 104–112. <https://doi.org/10.1016/j.healthplace.2016.11.015>
- Connor, D. S., Xie, S., Jang, J., Frazier, A. E., Kedron, P., Jain, G., Yu, Y., & Kemeny, T. (2025). Big cities fuel inequality within and across generations. *PNAS nexus*, 4(2). <https://doi.org/10.1093/pnasnexus/pgae587>
- Conway, A. R., Kovacs, K., Hao, H., Rosales, K. P., & Snijder, J. P. (2021). Individual differences in attention and intelligence: A united cognitive/psychometric approach. *Journal of Intelligence*, 9(3), 34. <https://doi.org/10.3390/jintelligence9030034>
- Cortés Pascual, A., Moyano Muñoz, N., & Quílez Robres, A. (2019). The relationship between executive functions and academic performance in primary education: Review and meta-analysis. *Frontiers in Psychology*, 10, 1582. <https://doi.org/10.3389/fpsyg.2019.01582>
- Darvas, Á., & Ferge, Zs. (2012). Gyerekesély program a társadalmi és politikai mezőben [Child Opportunity Programme in the social and political sphere]. In L. Bass (Ed.), *Az ötödik év után: Egy félbeszakadt akciókutatás története, 2006–2011* (pp. 9–24). Gyerekesély Közhasznú Egyesület, Budapest
- Demeter, G Földvári, P., Péntzes, J. & Szilágyi, Zs (2025). *Regional inequalities, backwardness and peripheralization in Hungary: an attempt to reconstruct historical HDI at settlement level, 1880-2022: working paper*. GISHistorical Studies (10). Bölcsészettudományi Kutatóközpont Történettudományi Intézet, Regensburg, Debrecen, Budapest. ISBN 9789634165064
- Farrell Pagulayan, K., Busch, R. M., Medina, K. L., Bartok, J. A., & Krikorian, R. (2006). Developmental normative data for the Corsi Block-tapping task. *Journal of clinical and experimental neuropsychology*, 28(6), 1043–1052. <https://doi.org/10.1080/13803390500350977>
- Hagelkruys, D., Böhm, C., Motschnig, R., Kertzman, S., Sirota, A., Lerer, B., & Gyarmathy, E. (2016). Adapting a stand-alone computerized cognitive test battery for online use: A case study in the context of users with special needs. *Computers in Human Behavior*, 63, 757–768. <https://doi.org/10.1016/j.chb.2016.05.069>

- Hammel, S. C., et al. (2024). Early childhood exposure to environmental phenols and parabens, phthalates, organophosphate pesticides, and trace elements in association with attention deficit hyperactivity disorder (ADHD) symptoms in the CHARGE study. *Environmental Health*, 23(27).
<https://doi.org/10.1186/s12940-024-01065-3>
- Gyarmathy É. (2009). Kognitív Profil Teszt. *Iskolakultúra* 3-4, 60-73.
- Gyarmathy, É., Gyarmathy, Zs., Szabó, Z., Pap, A., & Kraiciné Szokoly, M. (2019). Tizenévesek és felnőttek kognitív profiljának online mérése [Online measurement of cognitive profiles of teenagers and adults]. *Opus et Educatio*, 6(3), 297–309.
- Gyarmathy, É., Gyarmathy, Zs., & Szabó, Z. (2021). A Sakkpalota képességfejlesztő program hatásvizsgálata [Impact evaluation of the Chess Palace skills development programme]. *Új Pedagógiai Szemle*, 71(3–4).
- Javed, M. S., Nisar, U., G, V. S. R., Warsi, S. H., Billah, M. M., & Karkkulainen, E. A. (2024). Mapping the disparities between urban and rural areas in the global attainment of sustainable development goals: Economic and social aspects of global rural–urban migration. *Educational Administration: Theory and Practice*, 30(6), 2052–2064.
<https://doi.org/10.53555/kuey.v30i6.5649>
- Karmiloff-Smith, A. (2009). Nativism versus neuroconstructivism: Rethinking the study of developmental disorders. *Developmental Psychology*, 45(1), 56–63.
<https://doi.org/10.1037/a0014506>
- Kemp, J. T., Kline, A. G., & Bettencourt, L. M. A. (2024). *Inter-city firm connections and the scaling of urban economic outputs*. *PNAS Nexus*, 3(11),
<https://doi.org/10.1093/pnasnexus/pgae503>
- Kertzman, S., Gyarmathy, E., Vainder, M., Vojtová, V., Mikulášek, L., Sirota, A., Motschnig, R., Hagelkruys, D., & Lerer, B. (2017). Web-based real-time neuropsychological assessment in dyslexia. *BMC Psychiatry*.
- Kovacs, K., Molenaar, D., & Conway, A. R. (2019). The domain specificity of working memory is a matter of ability. *Journal of Memory and Language*, 109, 104048.
<https://doi.org/10.1016/j.jml.2019.104048>

- Logie, R. H., Camos, V., & Cowan, N. (2021). Working memory: Theories, models, and controversies. *Annual Review of Psychology*, 72, 1–28.
<https://doi.org/10.1146/annurev-psych-010419-051043>
- Martin, A. J. (2024). Growth goals: A review of the construct, predictors, consequences, and intervention. In A. J. Elliot (Ed.), *Advances in motivation science* (Vol. 11, pp. 123–169). Academic Press.
- McDonough, P. M., Gildersleeve, R. E., & Jarsky, K. M. (2010). The golden cage of rural college access: How higher education can respond to the rural life. *Journal of Higher Education*, 81(1), 1–30. <https://doi.org/10.1080/00221546.2010.11778970>
- McHenry-Sorber, E. (2019). Why Rural Matters 2018-2019: The Time is Now: Interview with Authors Jerry Johnson, Daniel Showalter, and Sara Hartman. *The Rural Educator*, 40(3), 62-64. <https://doi.org/10.35608/ruraled.v40i3.930>
- Merton, R. K. (1968). The Matthew effect in science. *Science*, 159(3810), 56–63.
- Miller, P., Votruba-Drzal, E., & Coley, R. L. (2019). Poverty and academic achievement across the urban to rural landscape: Associations with community resources and stressors. *RSF: The Russell Sage Foundation Journal of the Social Sciences*, 5(2), 106–122. <https://doi.org/10.7758/RSF.2019.5.2.06>
- Morey, C. C., Rhodes, S., & Cowan, N. (2019). Sensory-motor integration and working memory. *Psychonomic Bulletin & Review*, 26(4), 1137–1146.
<https://doi.org/10.3758/s13423-019-01633-9>
- Mrazik, M., & Dombrowski, S. C. (2010). The neurobiological foundations of giftedness. *Roeper Review*, 32(4), 224–234. <https://doi.org/10.1080/02783193.2010.508154>
- Nieuwenhuis, J., & Hooimeijer, P. (2016). The association between neighbourhoods and educational achievement, a systematic review and meta-analysis. *Journal of housing and the built environment: HBE*, 31(2), 321–347. <https://doi.org/10.1007/s10901-015-9460-7>
- Pietropoli, I., & Gracia, P. (2025). Social inequalities in children’s cognitive and socioemotional development: The role of home learning environments and early childhood education. *Research in Social Stratification and Mobility*, 97, 101034.
<https://doi.org/10.1016/j.rssm.2025.101034>

- Pind, J., Gunnarsdóttir, E. K., & Jóhannesson, H. S. (2003). Raven's Standard Progressive Matrices: New school-age norms and a study of the test's validity. *Personality and Individual Differences*, 34(3), 375–386. [https://doi.org/10.1016/S0191-8869\(02\)00058-2](https://doi.org/10.1016/S0191-8869(02)00058-2)
- Plavnicka, J., Chovan, S., & Filakovska Bobakova, D. (2024). Understanding the impact of socioeconomic factors on early childhood development in marginalised Roma communities: The role of parental education and household equipment. *Children*, 11(6), 622. <https://doi.org/10.3390/children11060622>
- Quinn, C. P. (2024). *Settlement ecology of Bronze Age Transylvania*. *Frontiers in Human Dynamics*, 6, 1360479. <https://doi.org/10.3389/fhumd.2024.1360479>
- Raven, J., & Raven, J. (2003). Raven Progressive Matrices. In R. S. McCallum (Ed.), *Handbook of nonverbal assessment* (pp. 223–237). Kluwer Academic/Plenum Publishers.
- Rodler L. (2025). Továbbra is az elsősök között a legmagasabb az évismétlők aránya. [The proportion of repeaters continues to be highest among first-grade students.] *EduLine*. https://eduline.hu/kozoktatas/20250420_evismetles_elso_soztalyosok_egyre_tobben_i_smetelnek_korai_iskolkezdes_plusz_egy_ev_ovi?utm_source=chatgpt.com
- Roscigno, V. J., & Crowley, M. L. (2001). *Rurality, institutional disadvantage, and achievement/attainment*. *Rural Sociology*, 66(2), 268–292. <https://doi.org/10.1111/j.1549-0831.2001.tb00063.x>
- Schmidt, I., Gehlen, B., Winkler, K., Arrizabalaga, A., Arts, N., Bicho, N., ... Maier, A. (2025). *Large scale and regional demographic responses to climatic changes in Europe during the Final Palaeolithic*. *PLOS ONE*, 20(4), e0310942. <https://doi.org/10.1371/journal.pone.0310942>
- Schuchardt, K., Maehler, C., & Hasselhorn, M. (2017). Working memory deficits in children with specific learning disorders. *Journal of Learning Disabilities*, 50(4), 422–436. <https://doi.org/10.1177/0022219416662036>
- Shelton, J. F., & Baccarelli, A. (2024). The contribution of environmental pollutants to the risk of autism and other neurodevelopmental disorders: A systematic review of case-control studies. *Neuroscience & Biobehavioral Reviews*, 164, 105815. <https://doi.org/10.1016/j.neubiorev.2024.105815>

- Sullivan, K., McConney, A., & Perry, L. B. (2018). A comparison of rural educational disadvantage in Australia, Canada, and New Zealand using OECD's PISA. *SAGE Open*, 8(4). <https://doi.org/10.1177/2158244018805791>
- Sumi, S. S., Jahan, N., Rahman, S. T., Seddeque, A., & Hossain, M. T. (2021). Explaining rural–urban differences in the academic achievement of secondary students: An empirical study in Magura District of Bangladesh. *Asia Pacific Journal of Educators and Education*, 36(1), 195–216.
- van Maarseveen, R. (2021). The urban–rural education gap: Do cities indeed make us smarter? *Journal of Economic Geography*, 21(5), 683–714.
<https://doi.org/10.1093/jeg/lbaa033>
- Virtanen, P., Gommers, R., Oliphant, T. E., Haberland, M., Reddy, T., Cournapeau, D., et al., & SciPy 1.0 Contributors. (2020). SciPy 1.0: Fundamental algorithms for scientific computing in Python. *Nature Methods*, 17(3), 261–272.
<https://doi.org/10.1038/s41592-019-0686-2>
- Wang, N. (2024). *The urban–rural heterogeneous effect of family SES on achievement: The mediating role of culture*. *Behavioral Sciences*, 14(2), 84.
<https://doi.org/10.3390/bs14020084>
- Zeng, B., Sun, J., & Wen, H. (2026). Analyzing factors associated with student achievement in large-scale educational assessments: A two-stage machine learning approach. *International Journal of Educational Research*, 136, 102886.
<https://doi.org/10.1016/j.ijer.2025.102886>
- Zoeller, R. T., & Vandenberg, L. N. (2024). Exposure to endocrine disruptors in early life and neuroimaging findings in childhood and adolescence: A scoping review. *Current Environmental Health Reports*, 11, 416–442.
<https://doi.org/10.1007/s40572-024-00457-4>