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Intelligence in Children Is Multi-Dimensional: Evidence from Online Cognitive Testing and Standardized Assessment

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Abstract

Understanding the structure of intelligence during early development remains a central question in cognitive science. While dominant models conceptualize intelligence as a set of separable domains, it remains unclear whether these domains are fully differentiated in school-aged children. The present study examined the structure of intelligence in children and its correspondence with standardized assessment. A community sample of children (N = 46; ages 6–16 years) completed the Creyos battery of 12 online cognitive tasks alongside the Wechsler Intelligence Scale for Children–Fifth Edition (WISC-V). To capture variability representative of real-world populations, the sample included both typically developing children and those with neurodevelopmental disorders, including Autism Spectrum Disorder (ASD) and Attention Deficit Hyperactivity Disorder (ADHD). To derive a stable factor structure, principal component analysis (PCA) was first conducted in a large independent dataset (N = 7,989), and resulting loadings were applied to the current sample to generate domain scores. Associations between derived components and WISC-V composite scores were examined using Pearson correlations. Results supported a three-component structure reflecting reasoning/verbal ability, working memory processes and visuospatial/planning. However, the components showed substantial overlap and were not fully dissociable. All components were moderately to strongly associated with Full Scale IQ and WISC-V indices (r=.49–.57), indicating that performance across domains reflects shared contributions to general cognitive ability. Findings suggest that intelligence in children is multi-dimensional but less differentiated than in adults. Our findings have important implications for cognitive assessment, as domain-specific interpretations should be made with consideration of the interrelated nature of children's cognitive abilities. Online cognitive tasks captured meaningful variance in general cognitive functioning and may provide scalable tools for assessing intelligence in neurodiverse populations of children.

Introduction

Human intelligence has historically been conceptualized either as a single general ability ("g") or as a set of separable cognitive domains (Spearman, 1904; Thurstone, 1938). These perspectives were later integrated within hierarchical frameworks, most notably the Cattell–Horn–Carroll (CHC) theory, which conceptualizes intelligence as a set of broad and narrow abilities organized under a higher-order general factor (Cattell, 1963; Flanagan & Dixon, 2014). This multidimensional structure has been supported by large-scale neurocognitive studies in adults, demonstrating that performance across diverse cognitive tasks fractionates into separable components associated with distinct functional brain networks (Hampshire et al., 2012; Wilcox et al., 2026; Yoon et al., 2017).

Whether a differentiated structure of intelligence is present in childhood remains unknown. Developmental accounts suggest that cognitive abilities emerge from a more general, domain-integrated system and become increasingly specialized over time (Garrett, 1946; Keith & Reynolds, 2010; Laureys et al., 2022). Consistent with this view, the contribution of a general "g" factor may be stronger earlier in development, with domain-specific abilities becoming more distinct across adolescence (Kane & Brand, 2006). At the same time, some evidence suggests that differentiation may already be present in school-

aged children (Martins et al., 2016), highlighting ongoing debate regarding the developmental structure of intelligence. Importantly, this question may be further complicated in children with neurodevelopmental disorders (NDDs), such as Attention Deficit Hyperactivity Disorder (ADHD) and Autism Spectrum Disorder (ASD), who often show atypical cognitive profiles characterized by uneven skill development (Vaidya et al., 2020). In these populations, cognitive abilities may not follow typical patterns of differentiation, raising the possibility that the structure of intelligence differs not only across development but also as a function of neurodevelopmental variation.

This question has important implications for cognitive assessment. Standardized tools such as the Wechsler Intelligence Scale for Children–Fifth Edition (WISC-V; Wechsler, 2014) assume that intelligence can be partitioned into distinct domains, including verbal comprehension, working memory, fluid reasoning, visual-spatial ability, and processing speed. The structure of the WISC-V is grounded in CHC theory and supported by factor-analytic research in children, which consistently identifies a strong general intelligence factor alongside several broad, interrelated cognitive domains (Canivez et al., 2017; Keith & Reynolds, 2010). However, these domains account for relatively limited unique variance beyond g, highlighting the overlapping nature of cognitive abilities. If these domains are not fully differentiated in childhood, domain-specific interpretations may overstate the independence of children's cognitive abilities and obscure the role of shared, domain-general processes.

Online cognitive assessment platforms offer a scalable approach to examining the structure of cognition across diverse populations. The Creyos battery (Creyos, 2025) includes a set of gamified tasks designed to measure working memory, reasoning, attention, and verbal abilities, and has been validated in adult populations, where performance decomposes into separable cognitive domains consistent with fractionated models of intelligence (Hampshire et al., 2012). However, it remains unclear whether similar cognitive structures are observed in children, or whether these tasks capture domain-specific versus domain-general processes during development.

To address this gap, the present study examined the structure of cognitive performance in a community sample of school-aged children, including both typically developing children and those with NDDs, and its association with standardized measures of intelligence. Children completed the Creyos online cognitive battery alongside the WISC-V. To establish a stable and developmentally generalizable factor structure, principal component analysis (PCA) was first conducted in a large independent dataset (N = 7,989) of children and adolescents with and without NDDs who completed the same cognitive tasks, and the resulting loadings were applied to the child sample to derive domain scores. We then tested whether cognitive performance in children reflects separable domains, and whether these domains show meaningful associations with their Full Scale IQ and WISC-V subscales. We hypothesized that performance would reflect multiple cognitive domains, but with greater overlap than previously observed in adults (Hampshire et al., 2012).

Methods

Participants

Participants were English-speaking Canadian school-aged children. Participants were recruited through online advertisements (e.g., on Facebook, Instagram) addressed to parents. Parents first completed screening questions to determine their child's eligibility for participation. Inclusion criteria were as follows: must be able to speak English, Canadian, between the ages of 6–16 years, with or without a diagnosed neurodevelopmental disorder. For those diagnosed with a neurodevelopmental disorder (e.g., ASD, ADHD), children must have received a diagnosis from a developmental pediatrician, psychiatrist, clinical psychologist or the equivalent. Typically developing children were required to be healthy, medication-free and have no known psychiatric disorder or a history of brain injury. Exclusion criteria included diagnosed global developmental delay (GDD), or a recent completion of the WISC-V (within the past year) by psychologist, or other clinician/health professional.

Parents were informed that if they planned to have their child complete a cognitive evaluation in the near future, they should not participate in the study due to practice effects, which could invalidate the assessment.

The study protocol was approved by the Health Sciences Research Board of Western University (#125164). Parents provided informed consent and children provided assent. Interested families were provided with study information and consent materials, which were reviewed with a study team member either in person or online prior to obtaining consent. Families were also informed that the results of the study were strictly for research purposes and were not equivalent to a clinical evaluation. Following this review, consent and assent were obtained, and a copy of the signed consent form was provided to families in person or electronically. The study procedures were conducted according to the Declaration of Helsinki.

Testing Materials

Demographic Questionnaire

Diagnostic and health information was obtained through a structured parent-report demographic questionnaire administered via Qualtrics (Qualtrics, 2025). Parents were asked to indicate whether their child had received a formal developmental diagnosis from a healthcare professional (e.g., developmental pediatrician, psychiatrist, or clinical psychologist). If yes, parents selected the diagnosis from a predefined list (e.g., ASD, ADHD) and had the option to provide additional details in an open-response field. Parents also reported whether their child was currently taking any medications and whether the child had any history of neurological or psychiatric conditions. For typically developing children, parents indicated that their child had no prior diagnosis of a neurodevelopmental, neurological, or psychiatric disorder and was not currently taking medication.

Online Cognitive Test Battery

The online cognitive tests are a validated battery (40 minutes), 12 in total that measure (1) short-term memory, (2) reasoning, (3) verbal abilities that are “gamified” to maintain interest. The short-term memory tasks include: Spatial Span (SS), Monkey Ladder (ML), Paired Associates (PA), and Token Search (TS). The Reasoning tasks include: Rotations (R), Feature Match (FM), Odd One Out (OOO), Polygons (P), and Spatial Planning (SP). The verbal tasks include: Grammatical Reasoning (GR), Double Trouble (DT), and Digit Span (DS). The tests are on-demand through the research platform provided by Creyos (http://www.creyos.com). Detailed descriptions of the cognitive tasks included in the present assessment are provided in the supplementary materials (Wild et al., 2018).

The Creyos platform provides a suite of web-based cognitive tasks designed for use with children, adolescents, and adults. The platform draws on normative data from upwards of 85,000 volunteer participants, encompassing more than 8 million cognitive task scores gathered for database construction and assessment of task psychometrics. These cognitive measures have demonstrated validity across multiple large-scale studies involving both healthy individuals and clinical populations (Brenkel et al., 2017; Levine et al., 2013). In young adult populations, performance on the Creyos battery has shown convergence with established standardized measures of cognitive functioning, including the Wechsler Adult Intelligence Scale–Revised (WAIS-R; Wechsler, 1981; Levine et al., 2013) and the Montreal Cognitive Assessment (MoCA; Brenkel et al., 2017). To date, however, formal validation of these tasks in child samples remains limited. A subset of tasks from the battery has been used in prior research, demonstrating a unitary factor structure of executive functioning in children (Laureys et al., 2022).

Standardized Intelligence Testing

The Wechsler Intelligence Scale for Children–Fifth Edition (WISC-V; Wechsler, 2014) is a standardized, norm-referenced assessment of intellectual functioning for children aged 6–16 years. The measure consists of 10 primary subtests that contribute to the Full Scale IQ (FSIQ), a composite index of general intellectual ability which takes about 90 minutes to complete. In addition to FSIQ, the WISC-V yields five primary index scores: Verbal Comprehension, Visual Spatial, Fluid Reasoning, Working Memory, and Processing Speed. All scores are standardized based on age-normed data (M = 100, SD = 15), with higher scores indicating better performance relative to same-age peers. The normative sample included ~ 2,200 children and adolescents (Wechsler, 2014).

Experimental Procedure

After consenting to participate in the study, participants first completed a short demographic questionnaire online, through Qualtrics. Next, participants completed the Creyos battery (12 online cognitive tests), which were completed independently at home. Families were encouraged to have the children complete the tasks alone. Before each game, participants watched a short instructional video

on how to play the game. Tasks are designed to be self-guided. Field testing was previously conducted in a separate sample of children, including those with NDDs, to evaluate comprehension of the task instructions (Hennessy et al., 2024). Audiovisual instructions were well understood across task domains, with over 90% of children reporting that they understood how to complete the tasks and 80–90% of parents indicating that the instructions were appropriate for their child's ability level. All children were able to complete the full task battery, supporting the feasibility of the protocol for school-aged and neurodiverse populations.

Participants then completed an in-person WISC-V. Testing was conducted in a quiet 1:1 setting by trained research team members, including graduate students enrolled in accredited clinical psychology programs and a doctoral-level examiner. In total (including the Creyos battery), testing time was approximately 2 hours, with one required in-person session.

Validation Dataset

To derive a stable cognitive factor structure, an independent validation dataset was used consisting of cognitive performance data collected through the Brain Balance Achievement Centers across North America. This dataset has been described previously in detail (Al-Saoud et al., 2025; Jackson & Wild, 2021). Briefly, the sample comprised a large, heterogeneous community cohort of children and adolescents (N = 7,989) between the ages of 7 and 18 years, including both typically developing participants and those with NDDs (e.g., ADHD, ASD) (Jackson & Wild, 2021).

Participants completed the 12-task web-based cognitive battery administered via the Creyos platform at home. The tasks were completed in a self-administered format. Specifically, parents were asked to register the child on the Creyos platform using their assigned study ID, and then allow the child to complete the battery independently. Performance metrics were derived from task accuracy and response characteristics, and demographic variables (e.g., age, sex) were available for all participants.

Data preprocessing procedures included removal of incomplete cases and adjustment for demographic variables, including age and sex. The dataset provided a large-scale, ecologically valid sample for identifying robust patterns of covariance across cognitive tasks.

Statistical analyses

The statistical analyses were conducted using Statistical Package for the Social Sciences (v.29 SPSS, Chicago, IL) as well as R software (v.4.5.2; R Core Team, 2025). The present study had two primary aims: (1) to examine the extent to which Creyos tasks cluster according to underlying cognitive constructs in school-aged children, and (2) to investigate the association between performance on Creyos cognitive tasks and performance on the WISC-V in school-aged children.

Creyos performance scores were first converted into standard scores (M = 100, SD = 15) in order to compare them to WISC-V composite scores. The following calculation was used: Standard Score = 100 + 15×(Participant's Raw Score−Mean of Norm Group/SD of Norm Group). Group norms were available through the Creyos database for children ages > 10 years. For children < 10 years, group norms were derived from a previously published child data set (Hennessy et al., 2024).

Principal Component Analysis

Prior work using the Creyos 12-task battery has identified three core cognitive domains: short-term memory, reasoning, and verbal ability. These cognitive domains were based on PCA performed in large adult sample (N > 57,000, Hampshire et al., 2012). In the present study, this prior adult research was used to inform the expected number of components. PCA with varimax rotation was conducted in this validation dataset to derive a stable factor structure of cognitive performance. Factor loadings below .40 were suppressed. Interpretation focused on the relative strength of task loadings to identify the primary component associated with each task. The three resulting factor loadings were subsequently applied to the current study sample to generate domain scores, allowing for examination of cognitive structure in the smaller, well-characterized cohort of school-aged children.

Domain scores were then calculated for the current dataset using the component loadings of all 12 tasks. The details for domain score calculations have been previously described in full (Wild et al., 2018); briefly, the individual test scores were normalized (M = 0.0, SD = 1.0). The domain scores were calculated using the formula $Y = X\ (Ar^{+})^{T}$, where Y is the N × 3 matrix of domain scores, X is the N × 12 matrix of test *z*-scores, and Ar is the 12 × 3 matrix of Varimax-rotated principal component weights from the previous PCA analysis. An "overall" domain score was also calculated, which reflected the average of the three PCA domains.

Pearson's Correlation

To examine the second aim, these domain scores were correlated using Pearson's Correlation with participants' WISC-V composite scores, to determine their association. WISC-V composites were also correlated with the calculated overall Creyos score, representing performance across all 12 tasks.

Results

Participants

A total of 46 children between the ages of 6 and 16 years (M = 9.7, SD = 2.6) were consented for the study and completed the WISC-V. Eleven children had incomplete Creyos task scores. Following the removal of cases with missing Creyos data, the final analytic sample consisted of 20 typically developing (TD) children, 11 children with ADHD, and 4 children with ASD. Note that two children with co-morbid ASD/ADHD were included in ASD diagnostic group.

Age distributions were comparable across groups, with mean ages ranging from 9.40 to 11.09 years. Sex distribution varied across groups, with a higher proportion of males in the ASD and ADHD groups, consistent with known prevalence patterns. Participant demographics are summarized in Table 1.

Table 1
Participant Demographics

Group	N	Age	Sex (M/F)
TD	20	9.40 (2.46)	(10/10)
ASD	4	10.00 (2.83)	(3/1)
ADHD	11	11.09 (2.59)	(6/5)

Note. Count (n), mean (standard deviation) age, and sex (male, female) based on participant diagnosis.

Performance Summary

Descriptive statistics for WISC-V composite scores and Creyos task performance are presented in Table 2 and Table 3. Participants performed within the average to above-average range on standardized measures of intelligence, with a mean FSIQ of 106.54 (SD = 15.91). Across WISC-V indices, the highest mean performance was observed for Fluid Reasoning (M = 111.43, SD = 14.75), followed by Visual Spatial ability (M = 108.41, SD = 15.45), whereas Verbal Comprehension (M = 105.23, SD = 15.42), Working Memory (M = 103.43, SD = 17.74) and Processing Speed (M = 101.50, SD = 14.26) were closer to the normative mean.

Performance across Creyos tasks was similarly centered around the normative mean (M = 100), with task scores ranging from approximately 92 to 101. Tasks involving reasoning and attention (e.g., Rotations, Feature Match) tended to show slightly higher mean performance, whereas tasks with greater working memory or verbal demands (e.g., Double Trouble, Grammatical Reasoning, Polygons, Monkey Ladder) showed lower mean scores.

Variability in performance was observed across both the WISC-V and Creyos battery, with standard deviations ranging from 14 to 23. Relative to the normative standard deviation of 15 used in score standardization, several tasks demonstrated elevated variability, indicating notable inter-individual differences in performance. These patterns suggest that while overall performance was within the typical range, there was meaningful heterogeneity in cognitive functioning across participants, supporting the subsequent analyses of cognitive structure.

Table 2

Performance on WISC-V Composites

Measure	***n***	***M***	***SD***
WISC-V Composites			
Verbal Comprehension Index (VCI)	46	105.23	15.42
Visual Spatial Index (VSI)	46	108.41	15.45
Fluid Reasoning Index (FRI)	46	111.43	14.75
Working Memory Index (WMI)	46	103.43	17.74
Processing Speed Index (PSI)	46	101.50	14.26
Full Scale IQ (FSIQ)	46	106.54	15.91

Note. n = sample size; M = mean; SD = standard deviation.

Table 3

Performance on Creyos (Online) Cognitive Tasks

Task	Description (Cognitive Domain)	*n*	*M*	*SD*
Spatial Span	Visuospatial working memory (recall of spatial sequences)	35	96.35	16.66
Grammatical Reasoning	Verbal reasoning (sentence comprehension and logical evaluation)	35	93.51	19.29
Double Trouble	Inhibitory control and attention (Stroop-like interference task)	35	92.77	17.96
Odd One Out	Abstract reasoning (rule detection and pattern identification)	35	93.66	19.24
Monkey Ladder	Visuospatial working memory (sequence recall under increasing load)	35	93.99	17.35
Rotations	Mental rotation (visuospatial processing)	35	101.42	20.68
Feature Match	Selective attention and processing speed (visual search)	35	100.38	23.89
Digit Span	Verbal working memory (recall of numerical sequences)	35	94.08	16.54
Spatial Planning	Planning and executive function (multi-step problem solving)	35	97.16	16.64
Paired Associates	Associative memory (learning and recalling object–location pairs)	35	98.11	16.09
Polygons	Visuospatial reasoning (shape comparison and transformation)	35	93.42	17.14
Token Search	Working memory and search strategy (tracking hidden items across trials)	35	99.46	17.14

Note. n = sample size; M = mean; SD = standard deviation. Creyos scores are based on a max or final (average) score depending on the task. Task selection was guided by the Creyos research manual (see https://creyos.com/hubfs/PDFs/Creyos-Research-Manual.pdf).

Principal Component Analysis

The PCA conducted on the validation dataset demonstrated excellent sampling adequacy (Kaiser-Meyer-Olkin [KMO] = .94), and Bartlett's test of sphericity indicated that correlations between variables were sufficiently large for PCA, $\chi^2(66) = 7059.12$, $p < .001$. A three-component solution accounted for 57% of the total variance. To aid interpretability, an orthogonal varimax rotation was applied. The rotated solution yielded a clear and interpretable three-component structure:

Component 1 (C1) was primarily characterized by loadings from Polygons, Grammatical Reasoning, Feature Match, Rotations, and Digit Span, and was interpreted as a Verbal/Reasoning component.

Component 2 (C2) was primarily characterized by loadings from Odd One Out, Spatial Span, Paired Associates, Token Search, and Monkey Ladder and was interpreted as a Working Memory component.

Component 3 (C3) was primarily characterized by loadings from Spatial Planning and Double Trouble, and was interpreted as an Executive control /Planning component.

Rotated component loadings are presented in Table 4 (Loadings < .4 were supressed). These factor loadings were subsequently used to derive domain scores in the current study.

Table 4
Rotated Component Loadings

Task	C1	C2	C3
Spatial Span	0.431	0.602	
Grammatical Reasoning	0.635		
Double Trouble	0.441		0.623
Odd One Out		0.718	
Monkey Ladder	0.449	0.567	
Rotations	0.589		
Feature Match	0.611	0.403	
Digit Span	0.566	0.489	
Spatial Planning			0.778
Paired Associates		0.593	
Polygons	0.732		
Token Search		0.578	

Note. Loadings ≥ .40 are shown. Component 1 (C1) reflects verbal/reasoning processes, Component 2 (C2) reflects working memory processes, and Component 3 (C3) reflects executive control and planning. Several tasks demonstrated cross-loadings across components, indicating overlap between cognitive domains.

The rotated component matrix revealed a three-component structure; however, the pattern of loadings indicated substantial overlap across components. While several tasks showed primary loadings consistent with hypothesized domains, many demonstrated cross-loadings above 0.40, particularly among working memory and visuospatial tasks. For example, Spatial Span, Monkey Ladder, Feature Match, and Digit Span loaded on both Component 1 and Component 2, while Double Trouble showed loadings across Components 1 and 3. This pattern suggests that cognitive domains in children are not fully dissociable, with shared variance across reasoning, working memory, and visuospatial processes.

Calculation of Domain Scores in the Current Sample

The factor loadings derived from the independent PCA were applied to the current sample to compute domain scores for each participant. Specifically, task performance scores were weighted by their corresponding component loadings and aggregated to yield scores for each cognitive domain (Component 1, Component 2, Component 3), following previously established procedures (e.g., Wild et al., 2018). An overall Creyos score was calculated as the mean of the three domain scores.

Pearson's Correlation

Pearson's correlations revealed that all three Creyos-derived components were significantly associated with WISC–V composite scores, with moderate to strong effect sizes (r = .35–.61, Table 5). Notably, each component demonstrated associations across multiple WISC indices rather than showing domain-specific correspondence. For example, Component 2 (Working Memory) was associated not only with the WISC Working Memory Index (r = .53), but also with Visual Spatial (r = .50), Processing Speed (r = .50) and Full Scale IQ (r = .57). Similarly, Components 1 and 3 showed broad associations across verbal, visuospatial, and processing speed indices.

Importantly, all components were strongly associated with Full Scale IQ (r = .56–.61). C1 (r = 61) and the overall Creyos score (r = .59) showed the strongest association with the FSIQ suggesting that performance across tasks reflects shared contributions to general cognitive ability. This pattern supports the notion that cognitive domains in children are interrelated and not fully differentiated.

Table 5

Pearson Correlations Between WISC–V Composites and Creyos Domain Scores

WISC–V Composite	C1	C2	C3	Overall Creyos Score
VCI	.36*	.29	.35*	.34*
VSI	.47*	.50*	.47*	.50*
FRI	.52*	.48*	.56*	.54*
WMI	.56*	.53*	.49*	.54*
PSI	.48*	.50*	.47*	.50*
FSIQ	.61*	.57*	.56*	.59*

Note. **Note.** Values represent Pearson correlation coefficients. C1 = Verbal/Reasoning component; C2 = Working Memory component; C3 = Visuospatial Memory/Planning component. VCI = Verbal Comprehension Index; VSI = Visual Spatial Index; FRI = Fluid Reasoning Index; WMI = Working Memory Index; PSI = Processing Speed Index; FSIQ = Full Scale IQ. * $p < 0.05$.

Discussion

Understanding whether intelligence is organized into distinct cognitive domains in childhood is critical for both theory and clinical assessment. While models of intelligence in adults consistently support a multidimensional structure, it remains unclear whether these domains are similarly differentiated in school-aged children. The present study addressed this question by examining the structure of cognitive performance in children using domain-level scores derived from online cognitive tasks and evaluating their correspondence with standardized measures of intelligence.

Consistent with prior work, cognitive performance in children showed evidence of multiple, partially overlapping components. However, these domains were not fully dissociable and showed substantial overlap, with all components demonstrating moderate to strong associations with Full Scale IQ and WISC-V indices. This pattern indicates that, although intelligence in childhood is multi-dimensional, it remains relatively less differentiated than in adult populations, with performance across domains reflecting shared contributions from domain-general processes.

These findings align with developmental accounts proposing that cognitive abilities emerge from a more integrated system early in life and become increasingly specialized over time. For example, executive functioning in younger children has been shown to load onto a more unitary construct, with distinct components such as working memory, inhibition, and cognitive flexibility becoming more separable across adolescence (Brydges et al., 2014; Karr et al., 2018; Laureys et al., 2022). This developmental shift is thought to reflect ongoing maturation of frontoparietal networks and prefrontal cortex systems that support higher-order cognition (Baum et al., 2017; Duerden et al., 2020).

The present findings further suggest that cognitive performance on Creyos tasks in children aged 6–16 years broadly reflects cognitive processes emphasized in prior adult literature, including reasoning and working memory.. However, the observed factor structure also revealed less clear differentiation between domains, consistent with developmental accounts of immature or still-integrating cognitive systems. At the same time, aspects of the online assessment format may have contributed to observed overlap across components. Unlike standardized in-person assessment, online measures provide less environmental control and may place increased demands on attention, motivation, and task comprehension, which could influence performance across domains (Simmons et al., 2023; Viñas-Guasch et al., 2023). Although Creyos-derived components demonstrated consistent associations with WISC-V indices, these correlations were modest, suggesting that the measures may capture related but not equivalent constructs. Accordingly, the present findings support the potential utility of Creyos as an accessible screening tool for general cognitive functioning, while also highlighting the need for further validation.

Factor structure

The observed factor structure revealed three broad components reflecting verbal/reasoning processes, working memory, and visuospatial working memory/planning. However, these components were not cleanly dissociable, with several tasks loading across multiple components. This pattern suggests that

cognitive performance in children is supported by overlapping domain-general processes rather than fully independent cognitive systems.

Component 1 reflected a combined verbal and reasoning domain, with tasks traditionally associated with these constructs loading onto a single factor. Rather than separating into distinct verbal and reasoning components, this convergence suggests shared underlying demands, such as cognitive control, rule application, and flexible reasoning. This interpretation is consistent with prior work demonstrating that verbal and reasoning processes recruit overlapping frontoparietal control networks (Hampshire et al., 2012; Sahyoun et al., 2010; Xu et al., 2021), and that the degree of differentiation between these systems may depend on task demands. Although Digit Span loaded onto both the verbal/reasoning and working memory components, its stronger loading onto the verbal/reasoning component is consistent with Creyos' classification and prior work which conceptualized the task within the verbal domain (Hampshire et al., 2012).

Component 2 primarily reflected working memory processes, but also included tasks typically classified as reasoning and attention. This pattern indicates that performance across these tasks is driven by shared demands on the temporary storage and manipulation of information, rather than discrete cognitive domains. This finding aligns with developmental evidence demonstrating a close relationship between working memory and reasoning in children, supported by shared executive processes and overlapping neural systems (Rosenberg et al., 2020; Wang et al., 2021).

Component 3 reflected executive control and planning, capturing tasks that required inhibition, and the coordination of complex cognitive operations in the context of goal-directed behavior. Although similar to Component 2 in its reliance on higher-order executive processes, this component showed a stronger emphasis on cognitive control and strategic planning than working memory specifically. The co-loading of a spatial planning and inhibitory task is consistent with models proposing that executive functioning reflects partially separable but overlapping control processes that support complex goal-directed behavior (Friedman & Miyake, 2017).

WISC-V and Creyos Associations

The pattern of associations between Creyos-derived components and WISC–V performance suggests that these components reflect general cognitive functioning rather than discrete, domain-specific abilities. All components were related to multiple WISC–V indices, indicating substantial overlap in the cognitive processes captured by both assessment approaches.

The association between the verbal/reasoning component and overall intellectual functioning highlights the central role of higher-order reasoning and executive control processes in supporting general cognitive ability, consistent with theoretical accounts of "g" (Cattell, 1963; Flanagan & Dixon, 2014). Notably, this component was not uniquely associated with verbal comprehension, despite including tasks with verbal elements. This likely reflects differences in construct measurement, as WISC–V verbal subtests emphasize acquired knowledge and language-based reasoning, whereas Creyos tasks place

greater demands on executive and working memory processes. For example, although digit span is verbally mediated, it is more strongly associated with short-term and working memory capacity than verbal comprehension specifically (Baddeley, 2003).

More broadly, the lack of domain-specific correspondence between Creyos components and WISC–V indices suggests that performance on these tasks is supported by shared, domain-general processes that span multiple areas of cognition. This pattern aligns with developmental accounts of cognitive organization, in which cognitive domains are less differentiated in childhood and remain closely interconnected.

Limitations

A few important limitations of the current study should be mentioned. First, the study's relatively small sample size somewhat limits interpretations. A larger study may have revealed more distinct patterns in the cognitive data, and allowed for comparisons across diagnostic groups. However, participation in the study required significant time and effort from participants as they took part in several standardized assessments. Further, it was required that participants had not received an assessment in the past year (using the same tools), or plan to be assessed in the near future due to practice effects. Although it would be beneficial to have a larger diagnostic population, particularly with respect to children with ASD, the present study was intended to be reflective of a diverse, community sample. While the current sample size was relatively modest, the PCA used to calculate the domain scores was derived from a substantially larger dataset, reducing concerns regarding the stability of the component structure. Building on prior research conducted predominantly in typically developing samples, the current findings suggest that cognitive domain structure may be less clearly delineated in more heterogeneous community samples. Future work may seek to replicate findings in samples with more balanced diagnostic groups, to further strengthen validation methods. The broad age range was selected to align with the normative age range of the WISC-V; however, developmental differences across childhood and adolescence may have contributed to variability in the observed cognitive patterns. In future work, older adolescents in particular, may exhibit more adult-like cognitive organization. Of note, the majority of participants with missing scores were diagnosed with ADHD, which may reflect difficulties sustaining attention during the online tasks. As mentioned, another potential limitation pertains to the lack of researcher control around the online assessment tool. As Creyos tasks were completed at home, it is possible children could have completed the tasks with assistance from caregivers. However, based on previous work it is likely that the sample could complete the games independently (Hennessy et al., 2024). Additionally, part of the battery's appeal and clinical utility may lie in its potential for at-home administration. In such cases, having a clinician present virtually may be beneficial for conducting behavioural observations.

Conclusions

Findings have important implications for how cognitive abilities are interpreted in childhood. Although domain-level scores are commonly used to characterize specific strengths and weaknesses, the observed overlap between domains suggests that performance may reflect shared, domain-general processes rather than discrete abilities. As such, domain-specific interpretations should be made with caution, particularly in younger populations.

The observed correspondence between performance on online cognitive tasks and standardized measures suggests that these approaches capture related aspects of general cognitive functioning. Online cognitive tasks may offer a practical and scalable approach for capturing broad cognitive functioning, particularly in settings where access to traditional psychoeducational assessment is limited. At the same time, their use should be guided by an understanding of the developmental nature of cognitive systems and the overlap between domains.

Future research should examine how cognitive domains differentiate over time, including longitudinal work to track developmental change. Extending this work to diverse and neurodevelopmental populations will be important for understanding variability in cognitive organization and its implications for assessment and intervention.

Declarations

Conflict of Interests:

Author Contribution

A.H. and E.G.D. conceived and designed the study. A.H., S.A.-S., and K.R. collected and organized the data. E.S.N. and A.H. conducted the statistical analyses. A.H. wrote the main manuscript text. E.S.N., M.B.-R., J.D.O., and E.G.D. contributed to interpretation of the findings and manuscript revisions. All authors reviewed and approved the final manuscript.

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Data Availability

The datasets generated and/or analyzed during the current study are not publicly available due to participant privacy and ethical restrictions but are available from the corresponding author upon reasonable request and with appropriate institutional approval.

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