



# Validation of the Children's International Cognitive Ability Resource (Ch-ICAR)

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## Abstract

The International Cognitive Ability Resource, abbreviated ICAR, counters some of the practical problems researchers face when using good, but proprietary, licensed intelligence tests like the Wechsler tests, which include unfeasible administration times and financial costs. So far, ICAR has been validated for adolescents and adults in many countries, offering a viable test alternative for these populations. For use among children, however, the appropriateness of this resource was yet unknown. Therefore, we set out to develop a children's ICAR: an instrument composed of ICAR-items, which provides a measure of cognitive ability in children between 11 and 14 years of age. The present article discusses the compilation process of the Ch-ICAR drawing from a pilot study, and evaluates its validity based on two additional studies. The pilot study involved 99 primary school pupils and aimed to select items for the Ch-ICAR instrument. Study 1 investigated the basic psychometric qualities of the Ch-ICAR in a sample of 820 secondary school pupils. Study 2 examined the construct validity by cross-validating the Ch-ICAR with on the one hand Raven's 2 Progressive Matrices, and on the other hand the Flemish CoVaT-CHC Basic Version, relying on samples of 91 secondary and 96 primary school pupils, respectively. Results support the utility of the Ch-ICAR as a measure of children's cognitive abilities within a research context.

**Keywords** ICAR · Cognitive ability · Test development · Children's cognition

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## Introduction

*[L]ife is an intelligence test, and the importance of measuring intellectual ability as people respond to life's challenges cannot be overstated.* (Dworak et al., 2021).

Cognitive ability refers to the capacity to acquire, process, manipulate, organize, and apply knowledge effectively (Gottfredson, 1997). It is widely recognized to reliably predict important outcomes such as academic achievement (Roth et al., 2015; Tikhomirova et al., 2020; Vilia et al., 2017) and work performance (Sackett et al., 2017; Schmidt, 2016). Furthermore, cognitive ability is significantly associated with happiness (Ali et al., 2013; Kanazawa, 2013) and overall health (Wrulich et al., 2014). Unsurprisingly, cognitive ability and its assessment therefore belong to the most discussed and central topics within psychology (Gottfredson & Saklofske, 2009).

For children, the most commonly used test worldwide to measure cognitive ability is the Wechsler Intelligence Scale for Children (WISC; Evers et al., 2012; Flanagan & Alfonso, 2017; Weiss et al., 2019). The WISC is a time- and field-tested instrument that has strong psychometric features (Oakland et al., 2016) and boasts international positive reviews (e.g., Na & Burns, 2016, for the English version; Kwaliteitscentrum voor Diagnostiek, 2023, for the Dutch version). However, the WISC is primarily designed for clinical contexts, and less attuned to the needs of many research settings. Because this test can only be administered individually, the workload soon becomes unmanageable for studies aiming at larger samples, even when using abbreviated scales like the Wechsler Abbreviated Scale of Intelligence, Second Edition (WASI-II; Wechsler, 2011) or other short forms containing a reduced number of subtests (Aubry & Bourdin, 2018). Financially as well, the cost of administering the WISC often exceeds budgets of (junior) researchers.

To alleviate the practical problems that researchers encounter with Wechsler scales and other proprietary licensed intelligence tests, and “to address the need for psychometrically valid tools that are well-suited for large-scale, remote data collection” (Dworak et al., 2021, p. 3), an interuniversity team of cognitive ability experts developed the International Cognitive Ability Resource (ICAR; Revelle et al., 2020), a public-domain measure of cognitive ability designed for online administration.

Public-domain measures are valuable tools in a research context. Open-access instruments enable more researchers to conduct studies, share findings, and ultimately advance the field (Condon & Revelle, 2014). The public nature

of these instruments encourages collaboration within the research community regarding test development, refinement, and validation (Goldberg, 1999). On the downside, publicly available measures of cognitive ability sometimes either lack sufficient psychometric rigor (e.g., Cog15; Kajonius, 2014; Kristjánssdóttir & Zaiter, 2023) or are too narrow in focus, concentrating exclusively on a particular type of item (e.g., only matrix reasoning; Zorowitz et al., 2023).

The ICAR, on the other hand, is psychometrically sound and offers a wide variety of subtests (Revelle et al., 2017) including items of high and low difficulty. The items can be programmed into any software of choice, and the extensive database (The International Cognitive Ability Resource Team, 2014) makes it possible to tailor the instrument to the intended audience or to switch up the items and minimize test–retest effects. In the earliest days of the project, the ICAR consisted of just 60 items, divided over four subtests: Verbal Reasoning, Three-dimensional Rotation, Matrix Reasoning, and Letter-Number Series (Condon & Revelle, 2014). This original ICAR60, as well as a 16-item subset known as the ICAR16, was validated in a sample of 96,958 participants ranging in age from 14 to 90 years (Condon & Revelle, 2014). Since its initial validation, the ICAR has established itself as a cognitive ability measure for research on adolescents and adults (used in 79 published studies according to Dworak et al., 2021, and more since), the majority of studies employing the ICAR16.

The appropriateness of an ICAR for children, however, is still unknown. Considering the dynamic nature of brain development across the lifespan, with rapid changes in early childhood and more gradual changes in adulthood, it is essential to acknowledge that the ICAR items designed for adults may not be adequate for children (Flanagan & McDonough, 2018). For instance, through neurodevelopment, brains become more organized, efficient, and faster at processing information during childhood and adolescence (Lenroot & Giedd, 2006; Low & Cheng, 2006). Moreover, research suggests that age and frontal lobe development play pivotal roles in shaping cognitive ability (Shaw et al., 2006), highlighting the need for assessment tools tailored to the cognitive abilities of children. Therefore, we aimed to compile an instrument based on ICAR items that unites the existing practical advantages of the ICAR with an adequate measurement of the cognitive ability of children between the ages of 11 and 14. As the ICAR project is not based a priori on a particular theoretical framework such as the Cattell-Horn-Carroll (or CHC) model of intelligence (Schneider & McGrew, 2012), we also looked into the question of which broad cognitive abilities are measured by which ICAR subtest. The compilation of a children’s ICAR, or Ch-ICAR in brief, not only

broadens the scope of the ICAR project; it also addresses a notable gap in the literature, for at the moment there is a lack of psychometrically sound measures of cognitive ability that are freely available, limited in administration time, and suited for children.

In this article, we first discuss the pilot study we carried out to compile the Ch-ICAR. Next, we discuss two studies conducted to assess the psychometrics of this newly compiled instrument. Study 1 investigated the basic psychometric qualities of the Ch-ICAR. Study 2 cross-validated the Ch-ICAR with two commercial tests, on the one hand Raven's 2 Progressive Matrices, and on the other hand the Flemish CoVaT-CHC Basic Version. The former is a measure of nonverbal intelligence, which provides an effective estimate of cognitive ability (McLeod & McCrimmon, 2021) and is commonly used and suitable for group administration (Oakland et al., 2016). The latter is a comprehensive measure of intelligence, whose composition reflects the CHC model of intelligence (Magez et al., 2015). In Flanders, the CoVaT offers a valid alternative to other intelligence tests, since—unlike Raven's Matrices—it encompasses multiple broad cognitive abilities (Flanagan & McDonough, 2018). Cross-validation of the Ch-ICAR using both Raven and CoVaT instruments provides us with empirical verification as to whether the Ch-ICAR is indeed a valid measure for children's cognitive ability.

## Pilot study

In an initial phase, we solicited feedback from experts in the field and from children of the target age to assess the suitability of various ICAR item types<sup>1</sup> for constructing a preliminary instrument. This preliminary instrument consisted of four subtests: Verbal Reasoning, Matrix Reasoning, Number Series, and Figural Analogies, with 16, 11, 23 and 20 items, respectively (we adopted all items available on the ICAR website, except for the subtest Number Series, where we selected a mix of easy and more challenging items). Verbal Reasoning contains questions on vocabulary and general knowledge as well as mathematical problems.<sup>2</sup> Matrix

Reasoning items consist of eight geometric shapes, placed in a 3-by-3 grid, with one shape missing; participants have to choose the response option that represents the missing ninth shape. Number Series items show a short sequence of numbers; participants have to complete the sequence by entering the next number of the sequence. Figural Analogies items consist of three colored geometric shapes, with the first two shapes standing in a certain relation to each other; participants have to choose the response option that represents the missing fourth shape, which stands in the same relation to the third as the second does to the first. A specimen of each item type can be found in Table 14 (the final compilation of the Ch-ICAR is discussed further and is available on the ICAR website<sup>3</sup>).

Subsequently, we carried out a pilot study with the preliminary instrument. The main objective of this pilot study was to select items for the Ch-ICAR instrument that provide an accurate estimate of cognitive ability, while putting minimal strain on researchers' time and participants' cognitive load. With that goal in mind, we aimed to reduce the number of items to ten at most per subtest.

Five class groups of three different primary schools in Flanders<sup>4</sup> took part in the pilot study ( $N_{\text{pilot}} = 99$ , male 41%). All participants were in their last year of primary education (age 11–12). In Flanders, primary education is marked by its comprehensive nature, the absence of ability groups, and open and free accessibility. As a result, Flemish primary education classrooms exhibit a diverse and inclusive pupil population. For practical reasons, each class only took two or three of the four subtests we had previously selected. The combination and order of subtests were assigned at random, the items were administered digitally, and testing took place in the classroom. In line with the recommendation of the ICAR team to take into account possible interruptions due to device malfunctions (Condon & Revelle, 2014), no time limit was imposed.

We noticed that many participants asked for additional explanation about the subtests Matrix Reasoning and Figural Analogies during the test-taking process. To improve the instructions in the final instrument, we added an example item to each of these two subtests. Seeing that items of limited complexity were scarce in the ICAR database, we designed the example items ourselves (Table 15). Upon

<sup>1</sup> Including Verbal Reasoning, Three-dimensional Rotation, Matrix Reasoning, Letter-Number Series, Number Series, and Figural Analogies. We decided not to include Three-dimensional Rotation and Letter-Number Series in the preliminary instrument because the former proved unsuitable for the target audience, with half of the children unable to solve any items, and the latter raised concerns about test conditions—specifically, if participants are allowed (or not prevented) from writing down the alphabet, the items become significantly easier.

<sup>2</sup> As such, in our opinion, the name of the subtest does not quite cover the content, but for matters of consistency and comparability, we chose to retain the original subtest name.

<sup>3</sup> The Ch-ICAR can be accessed via this link: <https://icar-project.com/projects/childrens-icar>, users will only need to create a user account.

<sup>4</sup> For the Verbal Reasoning items, we procured the Dutch translation by Fontaine (Nelissen et al., *In preparation*). With regard to the instructions, we provided each subtest with a written explanation in Dutch ourselves.

**Table 1** Primary findings of the pilot study

Subtest	<i>N</i>	Number of items in preliminary instrument	Cronbach's alpha in preliminary instrument	Average PC ( <i>SD</i> ) in preliminary instrument	Cronbach's alpha in final Ch-ICAR	Average PC ( <i>SD</i> ) in final Ch-ICAR
Verbal Reasoning	46	16	0.50	0.34 (0.14)	0.65	0.40 (0.24)
Matrix Reasoning	66	11	0.63	0.29 (0.20)	0.69	0.31 (0.25)
Number Series	71	23	0.88	0.35 (0.20)	0.85	0.43 (0.31)
Figural Analogies	56	20	0.77	0.23 (0.18)	0.83	0.33 (0.31)

<sup>a</sup>The weighted CoVaT overall score = 2\*Gf + 2\*Gc + Gv

Average PC is the average proportion of correct responses based on the total score of the participants that completed the full subtest.

completing an example item, participants receive immediate feedback regarding the correctness of the chosen answer and an explanation of why the chosen answer is either correct or incorrect.

For the final item selection, we prioritized items with stronger item–subscale correlations while maintaining a balanced range of difficulty levels. Additionally, we ensured that selected items showed minimal sex differences and avoided disproportionate response times. This approach allowed us to build a diverse and robust final set of items for the Ch-ICAR. Detailed statistics for each subtest can be found in Appendix Tables 16, 17, 18 and 19. Ultimately, we selected a total of 31 items for the final Ch-ICAR: eight items each for Verbal Reasoning, Number Series, and Matrix Reasoning, and seven for Figural Analogies (Appendix Table 20 contains the final item set). Table 1 provides a concise overview of the primary findings of the pilot study. This table serves as a brief summary of key insights and observations from the preliminary study. For a more comprehensive understanding and detailed item-level information, readers are invited to consult Appendix Tables 16, 17, 18 and 19.

## Study 1: Basic psychometric qualities of the Children's ICAR

Study 1 investigated the basic psychometric qualities of the Ch-ICAR in a large sample of pupils in Flanders. We assessed (1) the internal structure of the test and the psychometric properties of the individual items, (2) the distribution of the Ch-ICAR scores and the distribution of the Ch-ICAR scores over sex (although small sex differences in specific cognitive abilities may exist, the equality in cognitive ability is well established in literature, e.g., Deary et al., 2007; Ferguson & Horwood, 1997; Nisbett et al., 2012), (3) the internal consistency of the different subtests and the Ch-ICAR as a whole, and (4) the construct validity by examining the relation with school achievement and a basic mathematical skill test.

## Method

### Participants

A sample of Flemish pupils ( $N_1 = 820$ , male 53.5%, female 45.7%, 0.8% did not specify their sex) was recruited from 23 different schools all across Flanders. All participants were in their first year of regular secondary education ( $M_{\text{age}} = 12.02$ ,  $SD_{\text{age}} = 0.56$ ), and other than that there were no exclusion criteria for participation. Table 2 offers a comprehensive overview of the demographics and associated statistics.

The research project<sup>5</sup> encompassing the ICAR studies was approved by the Ethical Commission of the Faculty of Psychology and Educational Sciences of Ghent University (reference number 2021/59). Both the parents of the participants and the participants themselves gave their informed consent for participation, as well as for storage and use of the data by the researchers.

### Materials

**Socioeconomic status** To define the socioeconomic status (SES) of the participants, we used a questionnaire for parents with three indicators that are official markers for school funding in Flanders: financial capacity of the parents, educational level of both parents, and home language (Ministry of Education & Training, 2012). Following official criteria for these indicators, the following participant characteristics were seen as indicative of low SES: receiving a bursary, having one or two parents whose highest attained degree is primary education or lower, and having a home language other than Dutch. In our sample, 10% of the participants had a home language other than Dutch (for 8%, home language was unspecified), 28% of the parents received a bursary (for 17%, financial capacity was unspecified), 10% had one parent with primary education or lower as the highest degree, and 5% had both parents with primary education or lower as

<sup>5</sup> Entitled: "Study orientation in secondary education."

**Table 2** Demographic information Study 1 and Study 2

	Study 1	Study 2 (RPM sample)	Study 2 (CoVaT sample)
Number	820	91	96
Female, <i>n</i> (%)	375 (46%)	55 (60%)	48 (50%)
Mean age ( <i>SD</i> ) (years)	12.02 (0.56)	12.99 (0.57)	11.05 (0.27)
Age range (years)	10–14	12–15	10–12
Socioeconomic status			
Home language is not Dutch, <i>n</i> (%)	83 (10%)	3 (3%)	3 (3%)
Receiving a bursary, <i>n</i> (%)	231 (28%)		
Highest attained degree is primary education or lower Parent 1, <i>n</i> (%)	83 (10%)		
Highest attained degree is primary education or lower Parent 2, <i>n</i> (%)	81 (10%)		
No. of schools	23	2	3
Number of pupils per school, <i>M</i> ( <i>SD</i> )	35.65 (22.95)	45.50 (38.89)	32.00 (23.64)
Number of pupils per school: range	8–83	18–73	15–59

the highest degree (for 9%, educational level of the parents was unspecified).

**Children’s ICAR** To recapitulate, the Ch-ICAR as compiled after our pilot study comprises eight Verbal Reasoning items, eight Matrix Reasoning items, eight Number Series items, and seven Figural Analogies items (see “Pilot study” section for a description of the subtests). Except for Number Series items (which are open-ended), each item consists of eight response options, including “none of these” and “I don’t know.” Responses on the items are converted to binary values: Right answers are scored as 1, wrong answers as zero. The subtest scale scores are calculated as the sum of the binary values of each item of the subtest. The Ch-ICAR total score is calculated as the sum of the subtest scale scores.

**Academic performance School achievement.** Data on school achievement include the GPA (weighted average of assignments and tests of all subjects on a scale from 0 to 100), as well as four separate subjects scores: Mathematics, Dutch, Natural Sciences, and Technics (also on a scale from 0 to 100). As secondary education in Flanders does not feature standardized tests at the time of writing, the GPA and subject scores are based on the assessment of the individual teachers. To avoid possible bias, we standardized the achievement scores within schools.<sup>6</sup> Schools with fewer than

ten participants were excluded for the corresponding analyses as well as pupils that changed schools within the year. This resulted in a sample of 722 pupils, drawn from a total of 19 distinct schools.

**Basic mathematical skill test: CDR** We included an additional, standardized external criterion, related to cognitive ability, to detect and control for school specific effects. We administered a basic mathematical skill test to all participants, namely the shortened version (18 items, McDonald’s  $\omega = 0.72$ ) of the Cognitive Developmental Skills in Arithmetics (*Cognitieve Deelhandelingen van het Rekenen* [CDR]; Desoete & Roeyers, 2006).

### Procedure

Participants completed the Ch-ICAR and the CDR at the beginning of the school year (September–November 2021). The instruments were administered digitally, in the classroom of the participants, during school hours. The pupils’ teacher and a university supervisor were present. The tests were programmed in Qualtrics (<https://www.qualtrics.com>), a commercial survey software and research platform.

After a general introduction, participants could work in silence at their own pace on the different tests. The subtests of the Ch-ICAR appeared in a fixed sequence: Verbal

Footnote 6 (continued)

and with parental agreement. Consequently, the predominant majority of pupils embark on the 1A track (87% in the academic year 2021–2022; Ministry of Education and Training, 2022). As pupils in 1B follow a distinct curriculum, we opted for the separate calculation of standardized scores for this subgroup within the school. B-groups with fewer than 10 pupils were also excluded from the corresponding analyses, resulting in the exclusion of 6 B-groups.

<sup>6</sup> The first year of secondary education in Flanders consists of two primary streams: 1A and 1B (Ministry of Education and Training, s.d.). Admission to 1A is automatic for those who possess a certificate of primary education, while entry into 1B is automatic for those without the certificate. However, pupils holding a certificate of primary education may gain admission to 1B through a favorable decision of the admissions class council and the student guidance center,

Reasoning, Matrix Reasoning, Number Series, and Figural Analogies. The items appeared one by one, in ascending difficulty (as defined in the pilot study). Once participants decided to move on to the next item, they could not go back to previous questions, for both the CDR and the Ch-ICAR. All items required a response. Participants were explicitly told not to ask content-related questions, nor could they use supplementary materials (e.g., calculator, pen and paper). Most participants finished the Ch-ICAR within 25 min.<sup>7</sup>

Data on school achievement were communicated to us at the end of the school year (June 2022) by the school principal.

## Analyses

Analyses were conducted in SPSS (version 29.0; IBM Corp., 2022) and R (version 4.3.3; R Core Team, 2024). All R analysis codes and the variance–covariance matrix are available at: [https://osf.io/6cwfs/?view\\_only=4a80feb83bd94c378d3bd06853820563](https://osf.io/6cwfs/?view_only=4a80feb83bd94c378d3bd06853820563).

To examine the internal structure of the test and the psychometric properties of individual items, we conducted a hierarchical (aligned with CHC theory) item response theory (IRT) analysis (Chalmers, 2012), using the mirt package in R (version 1.42; Chalmers, 2023). The expected structure based on CHC theory consists of two levels: several broad cognitive abilities at the first, lowest level (represented by the four Ch-ICAR subtests) and one general<sup>8</sup> cognitive ability at the second, highest level (Flanagan & McDonough, 2018). Items with standardized slopes below 0.20 were removed one at a time, starting with the item with the lowest loading. After each removal, the model was re-estimated. Subsequently, we conducted a differential item functioning (DIF) analysis on the fitted hierarchical IRT model, using score-based structural change tests (Merkle et al., 2014), as implemented in the scDIFtest package in R (version 0.1.1; Debeer, 2020). Items showing significant DIF, with a *p*-value below 0.05 after false discovery rate (FDR; Benjamini & Hochberg, 1995) correction, were removed. The final model was re-estimated, and the model fit was evaluated.

To examine the distribution of scores, mean scores and standard deviations per subtest were calculated and a histogram of the Ch-ICAR total score was plotted. For this plot, the raw total scores were transformed into *z*-scores ( $M = 0$ ,

$SD = 1$ ). To examine potential sex differences in the total score, we conducted an independent-samples *t*-test with sex as grouping variable and the Ch-ICAR total score as dependent variable.

The internal consistency of the different subtests and the Ch-ICAR as a whole was determined by calculating Cronbach's alpha and McDonald's omega<sup>9</sup> (Dunn et al., 2014; McDonald, 1999; Raykov, 1998) in R using the MBESS package (version 4.9.3; Kelley & Lai, 2012). To assess the reliability coefficients, we adhere to the COTAN guidelines for test quality evaluation (Evers et al., 2010). The COTAN rating system has established cutoff criteria for assessing reliability coefficients, which vary depending on the intended purpose of the test. COTAN distinguishes between three main purposes: tests for important decisions at the individual level, tests for relatively less important decisions at the individual level, and tests for research at the group level (Evers et al., 2010, p. 34). Since our primary goal is to develop an instrument suitable for research purposes, we apply the cutoff criteria designated for research at the group level. According to these criteria, reliability coefficients exceeding 0.70 are considered good, those ranging between 0.60 and 0.70 are deemed sufficient, and coefficients below 0.60 are deemed insufficient.

To examine the relationship with academic achievement, we calculated Pearson correlations and conducted mixed-effects models for the different measures of academic achievement with the lmerTest package (version 3.1.3; Kuznetsova et al., 2017) in R. To assess the unique contribution of the Ch-ICAR total score to the marginal explained variance in academic achievement, we contrasted the marginal explained variance between the full model and a model excluding the Ch-ICAR score (Nakagawa & Schielzeth, 2013; Shaw et al., 2023). The marginal explained variance was calculated via the MuMIn package (version 1.47.5; Bartoń, 2023).

## Results

### Internal structure and psychometric properties

In the initial hierarchical IRT model, with all items included, three items (MR5, MR8, and FA7) demonstrated low standardized slopes (i.e., < 0.200), with values of 0.191, 0.199, and 0.110, respectively. We removed FA7, the item with the lowest slope, and re-estimated the model. In the second

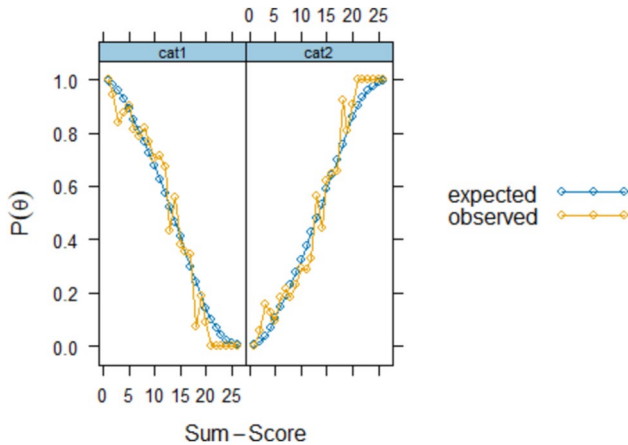
<sup>7</sup> Our time registration records encompassed the entire test administration, including the CDR test and inter-test breaks, rather than specific segments. As a result, we can only provide an approximation of the time needed for completing the Ch-ICAR.

<sup>8</sup> When cognitive ability is explicitly linked to the theoretical framework of the CHC model, we use the term “general cognitive ability” instead of “cognitive ability” (Flanagan & McDonough, 2018).

<sup>9</sup> When the assumption of tau-equivalence is violated (which is frequently the case in psychology), omega outperforms alpha (Dunn et al., 2014; Zinbarg et al., 2005). Omega has less risk of overestimation or underestimation of reliability, which makes it the preferred choice.

**Table 3** Item fit final hierarchical IRT model

Item	S- $\chi^2$ statistic	df	RMSEA	FDR-adjusted p-value
VR4	28.1	12	0.041	0.048
VR5	35.0	14	0.043	0.020
NS4	35.9	10	0.056	0.002

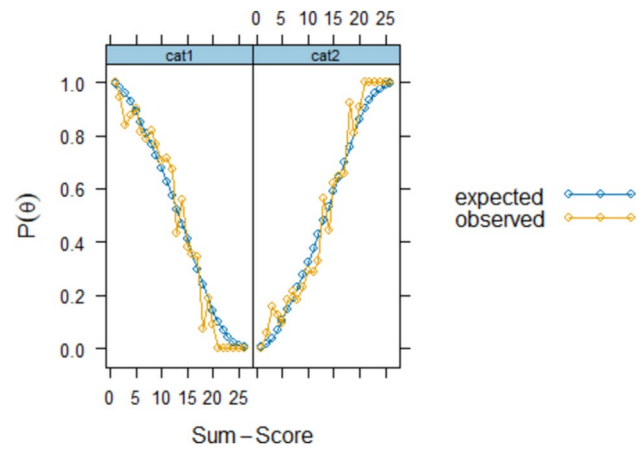


**Fig. 1** Item fit plot item VR4: Observed versus expected values

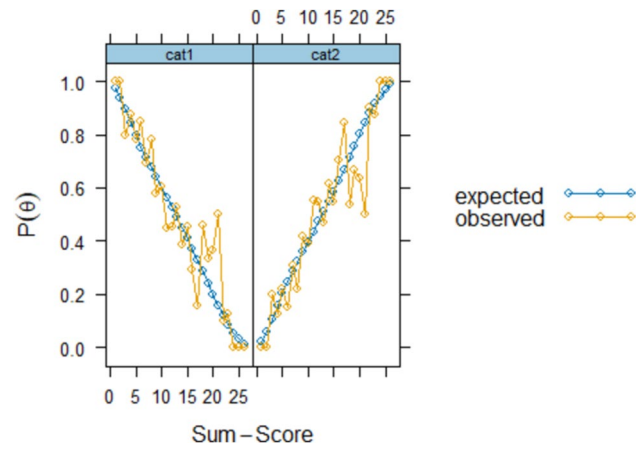
iteration, two items (MR5 and MR8) still had slopes below 0.200 (0.191 and 0.199, respectively), so MR5 was removed, and the model was estimated again. In the third iteration, MR8 alone exhibited a standardized slope below 0.200 (0.192) and was removed. By the fourth iteration, all remaining items had standardized slopes above the 0.200 threshold.

We conducted a DIF analysis on the fitted hierarchical IRT model (excluding items MR5, MR8, and FA7), which revealed significant DIF only in item NS6, with a Lagrange multiplier (LM) statistic of 16.510 ( $df=2$ , FDR-corrected  $p=0.007$ ). After removing item NS6, we re-estimated the hierarchical IRT model and evaluated the final model. Although the S- $\chi^2$  statistic is not specifically designed for hierarchical IRT models, we used this statistic to assess item misfit, as the hierarchical structure of the model supports the use of summed item scores. The S- $\chi^2$  test for three items (VR4, VR5, and NS4) yielded FDR-adjusted  $p$ -values below 0.05 (Table 3). However, after visually inspecting the observed response curves, these items were retained (Figs. 1, 2, and 3). The S- $\chi^2$  test results for all items are provided in Appendix Table 21.

The standardized and unstandardized slopes for the final model are presented in Table 4, and the DIF statistics are shown in Table 5. The final model exhibited a good overall fit to the data: RMSEA: 0.027, 95% CI [0.022, 0.031]; SRMR: 0.040; CFI: 0.976; TLI: 0.973.<sup>10</sup> The estimated



**Fig. 2** Item fit plot item VR5: Observed versus expected values



**Fig. 3** Item fit plot item NS4: Observed versus expected values

regression weights for general cognitive ability on the four dimensions are as follows: Matrix Reasoning = 1.111, Verbal Reasoning = 1.390, Number Series = 1.845, and Figural Analogies = 0.654, indicating that general cognitive ability has a smaller load on the Figural Analogies dimension. Given the improved psychometric properties of this 27-item subset compared to the 31-item pilot version, we used this refined 27-item version for all further analyses.

**Internal consistency**

The full Ch-ICAR showed good internal consistency ( $\alpha=0.82$ ;  $\omega=0.82$ , 95% CI<sub>ω</sub> [0.81, 0.84]). At the subtest

<sup>10</sup> We use the cutoff values of Hu and Bentler (1999) to evaluate the goodness of fit: RMSEA < .06, SRMR < .08, and CFI & TLI > .95 indicate good fit.

**Table 4** Standardized and unstandardized slopes final hierarchical IRT model

Item	Unstd. Inter-cept	Unstd. MR slope	Std. MR slope	Unstd. VR slope	Std. VR slope	Unstd. NS slope	Std. NS slope	Unstd. FA slope	Std. FA slope
MR1	-0.530	0.465	0.231	0.000	0.000	0.000	0.000	0.000	0.000
MR2	-0.030	1.120	0.444	0.000	0.000	0.000	0.000	0.000	0.000
MR3	-1.316	0.595	0.285	0.000	0.000	0.000	0.000	0.000	0.000
MR4	-1.082	0.849	0.373	0.000	0.000	0.000	0.000	0.000	0.000
MR6	-1.036	0.618	0.294	0.000	0.000	0.000	0.000	0.000	0.000
MR7	-1.726	0.456	0.227	0.000	0.000	0.000	0.000	0.000	0.000
VR1	1.742	0.000	0.000	0.589	0.229	0.000	0.000	0.000	0.000
VR2	1.312	0.000	0.000	1.009	0.344	0.000	0.000	0.000	0.000
VR3	-0.075	0.000	0.000	0.956	0.332	0.000	0.000	0.000	0.000
VR4	-0.724	0.000	0.000	1.392	0.414	0.000	0.000	0.000	0.000
VR5	-0.362	0.000	0.000	0.838	0.303	0.000	0.000	0.000	0.000
VR6	-1.578	0.000	0.000	0.665	0.253	0.000	0.000	0.000	0.000
VR7	-1.532	0.000	0.000	0.532	0.210	0.000	0.000	0.000	0.000
VR8	-1.531	0.000	0.000	1.058	0.355	0.000	0.000	0.000	0.000
NS1	1.827	0.000	0.000	0.000	0.000	0.884	0.242	0.000	0.000
NS2	0.058	0.000	0.000	0.000	0.000	1.106	0.283	0.000	0.000
NS3	0.349	0.000	0.000	0.000	0.000	1.729	0.360	0.000	0.000
NS4	-0.671	0.000	0.000	0.000	0.000	2.274	0.397	0.000	0.000
NS5	-0.428	0.000	0.000	0.000	0.000	3.067	0.428	0.000	0.000
NS7	-1.572	0.000	0.000	0.000	0.000	1.331	0.316	0.000	0.000
NS8	-2.067	0.000	0.000	0.000	0.000	1.214	0.300	0.000	0.000
FA1	-0.370	0.000	0.000	0.000	0.000	0.000	0.000	1.651	0.729
FA2	-0.075	0.000	0.000	0.000	0.000	0.000	0.000	1.919	0.753
FA3	-0.164	0.000	0.000	0.000	0.000	0.000	0.000	2.344	0.778
FA4	0.174	0.000	0.000	0.000	0.000	0.000	0.000	1.218	0.665
FA5	-2.665	0.000	0.000	0.000	0.000	0.000	0.000	0.378	0.315
FA6	-1.756	0.000	0.000	0.000	0.000	0.000	0.000	0.626	0.467

VR Verbal Reasoning, MR Matrix Reasoning, NS Number Series, FA Figural Analogies.

level, two of the four subtests also showed good internal consistency: Number Series ( $\alpha=0.73$ ;  $\omega=0.75$ , 95%  $CI_{\omega}$  [0.72, 0.77]) and Figural Analogies ( $\alpha=0.77$ ;  $\omega=0.81$ , 95%  $CI_{\omega}$  [0.79, 0.83]). The internal consistency of the other two subtests was less favorable: Verbal Reasoning had  $\alpha=0.60$ ;  $\omega=0.61$ , 95%  $CI_{\omega}$  [0.57, 0.65] and Matrix Reasoning had  $\alpha=0.48$ ;  $\omega=0.48$ , 95%  $CI_{\omega}$  [0.42, 0.54].

### Distribution of Ch-ICAR scores

Table 6 presents the means and standard deviations of the Ch-ICAR (subtest) scores, with separate values provided for boys and girls. Notably, the maximum scores are 8 for Verbal Reasoning, 6 for both Matrix Reasoning and Figural Analogies, 7 for Number Series, and 27 for the full Ch-ICAR. Results of the independent-samples  $t$ -test showed no significant difference in Ch-ICAR total score between males ( $M=10.91$ ,  $SD=5.20$ ) and females

( $M=10.54$ ,  $SD=4.99$ ):  $t(812)=1.02$ ,  $p=0.31$ , Cohen's  $d=0.07$ . The histogram of the standardized Ch-ICAR total scores is depicted in Fig. 4.

### Relation with academic performance

All measures of academic performance were positively and significantly correlated with both the subtests and the full Ch-ICAR (Table 7). Correlations with CDR were consistently stronger than those with the other measures of academic performance. However, given that two out of four subtests demonstrate limited reliability, we recommend caution when interpreting individual subtest scores independently.

Subsequently, we conducted three mixed-effects models, each with a different dependent variable: GPA, mathematics score and CDR score. In each model, we included the Ch-ICAR total score (continuous), sex (categorical),

**Table 5** Item-wise score-based DIF detection final hierarchical IRT model

Item	Item type	Number of est. parameters	LM test statistic	p-value	FDR-adjusted p-value
MR1	2PL	2	1.962	0.375	0.562
MR2	2PL	2	2.401	0.301	0.562
MR3	2PL	2	2.256	0.324	0.562
MR4	2PL	2	1.268	0.531	0.677
MR6	2PL	2	5.239	0.073	0.328
MR7	2PL	2	0.379	0.827	0.894
VR1	2PL	2	0.563	0.755	0.849
VR2	2PL	2	2.771	0.250	0.562
VR3	2PL	2	0.235	0.889	0.896
VR4	2PL	2	7.652	0.022	0.147
VR5	2PL	2	1.101	0.577	0.677
VR6	2PL	2	3.157	0.206	0.506
VR7	2PL	2	2.031	0.362	0.562
VR8	2PL	2	10.624	0.005	0.069
NS1	2PL	2	3.911	0.142	0.382
NS2	2PL	2	5.808	0.055	0.296
NS3	2PL	2	4.216	0.121	0.382
NS4	2PL	2	10.047	0.007	0.069
NS5	2PL	2	2.090	0.352	0.562
NS7	2PL	2	9.731	0.008	0.069
NS8	2PL	2	4.370	0.112	0.382
FA1	2PL	2	1.515	0.469	0.666
FA2	2PL	2	4.027	0.134	0.382
FA3	2PL	2	0.219	0.896	0.896
FA4	2PL	2	1.105	0.575	0.677
FA5	2PL	2	1.124	0.570	0.677
FA6	2PL	2	2.144	0.342	0.562

**Table 6** Means and standard deviations of the Ch-ICAR (subtest) scores

(Sub)test	M (SD)	M (SD) Boys	M (SD) Girls
Verbal Reasoning	3.49 (1.81)	3.64 (1.86)	3.28 (1.74)
Matrix Reasoning	1.86 (1.42)	1.79 (1.45)	1.94 (1.39)
Number Series	3.19 (1.99)	3.41 (2.00)	2.93 (1.95)
Figural Analogies	2.22 (1.85)	2.07 (1.81)	2.40 (1.88)
Full Ch-ICAR	10.76 (5.11)	10.91 (5.20)	10.54 (4.99)

and all four SES indicators<sup>11</sup> (all categorical) as fixed effects. Additionally, school was included as a random factor in each model to account for the multilevel nature

<sup>11</sup> All SES indicators were significantly correlated with GPA, math score, and CDR score, with the exception of *Educational Level Parent 1*, which showed no correlation with GPA and math score. See Appendix Table 22 for the full correlation table.

of the data. To address potential multicollinearity concerns, we assessed the variance inflation factor (VIF) for all predictors. All VIF values ranged from 1.01 to 1.30, which is well below the commonly cited thresholds<sup>12</sup> for problematic multicollinearity in the model (Marcoulides & Raykov, 2019; O’Brien, 2007). Table 8 includes the results of the mixed-effects models. The models achieved a marginal  $R^2$  of 0.32, 0.34, and 0.40 for GPA, mathematics score, and CDR score as dependent variable, respectively, indicating that up to 40% of the variance in academic performance is explained by the fixed-effects portion of the model (Nakagawa & Schielzeth, 2013; Shaw et al., 2023). The Ch-ICAR total score uniquely explained 18%, 26%, and 35% of the within-school variance in GPA, math score, and CDR score, respectively, via its fixed effects.

### Discussion

In Study 1, we aimed to evaluate the psychometric properties of the Ch-ICAR by examining four key aspects of the test. Results from the final hierarchical IRT analysis, excluding four items (MR5, MR8, NS6, and FA7), provided support for the Ch-ICAR’s psychometric robustness. All remaining items demonstrated adequate discriminatory power, and no DIF was detected. Furthermore, the good model fit aligns with expectations based on CHC theory, which posits several broad cognitive abilities at the first, lower level and general cognitive ability at the second, higher level (Flanagan & McDonough, 2018). We thus utilized the 27-item subset in all subsequent analyses and recommend that future research also adopt this subset when using the Ch-ICAR.

Regarding internal consistency, analyses revealed that the full Ch-ICAR shows good internal consistency, which contributes to the quality of the test. At the subtest level, however, reliability estimates are mixed: While Number Series and Figural Analogies demonstrate good internal consistency, Matrix Reasoning and Verbal Reasoning exhibit insufficient and marginally sufficient reliability respectively. These findings align with prior research on the original ICAR16, where similar<sup>13</sup> reliability challenges were reported for Matrix Reasoning ( $\omega = 0.55$ ) and Verbal Reasoning ( $\omega = 0.61$ ; Condon & Revelle, 2014; Young et al., 2019). The consistent pattern of low reliability across studies suggests that these two subtests may be capturing multiple underlying factors rather than a single dimension. Given that two out of four subtests demonstrate limited reliability, we

<sup>12</sup> “Not uncommonly a VIF of 10 or even one as low as 4 have been used as rules of thumb to indicate excessive or serious multicollinearity” (O’Brien, 2007, p. 674).

<sup>13</sup> Of course, reliability is influenced by the length of a test, so comparisons between tests of differing lengths should be made with careful consideration and nuance.

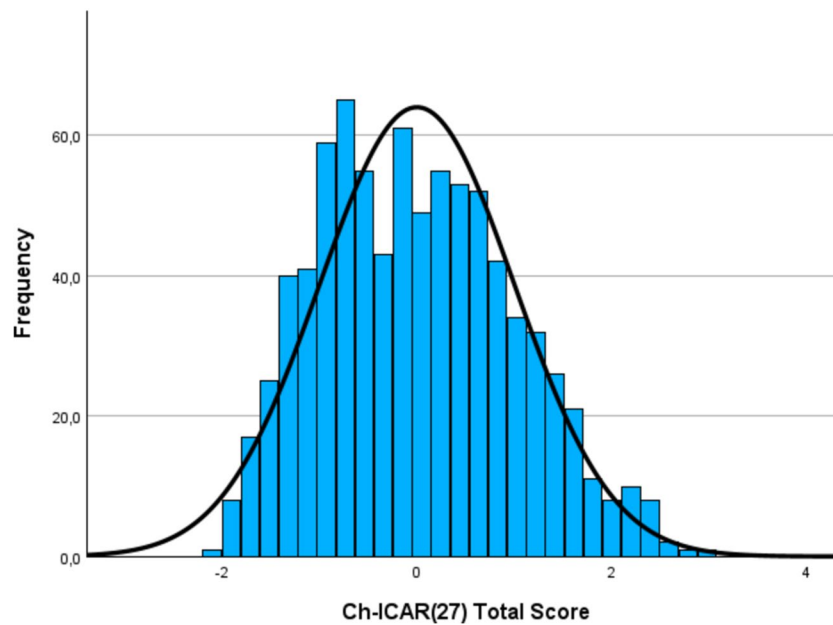


Fig. 4 Histogram of standardized Ch-ICAR total scores

Table 7 Correlations between academic performance and the Ch-ICAR (sub)tests

Academic performance	Verbal Reasoning	Matrix Reasoning	Number Series	Figural Analogies	Full Ch-ICAR
GPA	0.35**	0.27**	0.29**	0.28**	0.42**
Dutch	0.33**	0.23**	0.28**	0.25**	0.38**
Mathematics	0.40**	0.29**	0.38**	0.32**	0.49**
Natural sciences	0.34**	0.23**	0.30**	0.25**	0.40**
Technics	0.20**	0.21**	0.14**	0.20**	0.26**
CDR	0.58**	0.31**	0.54**	0.34**	0.63**

\*\*  $p < 0.01$

Table 8 Estimates, standard errors,  $t$ -values, and  $p$ -values for the fixed and random effects of the three linear mixed-effect models

	GPA				Mathematics score				CDR score			
	$\beta$	SE	$t$	$p$	$\beta$	SE	$t$	$p$	$\beta$	SE	$t$	$p$
Fixed effects												
Intercept	-0.99	0.11	-8.94	<0.001	-1.07	0.11	-9.42	<0.001	-1.27	0.09	-13.73	<0.001
Ch-ICAR	0.08	0.01	11.94	<0.001	0.10	0.01	14.40	<0.001	0.12	0.01	18.38	<0.001
Sex	0.50	0.07	7.03	<0.001	0.14	0.07	1.98	0.05	0.18	0.06	2.83	<0.01
Language	-0.06	0.14	-0.40	0.69	-0.13	0.14	-0.90	0.37	-0.24	0.13	-1.94	0.05
Bursary	-0.47	0.08	-5.68	<0.001	-0.45	0.08	-5.39	<0.001	-0.06	0.07	-0.80	0.42
Education, parent 1	0.18	0.14	1.25	0.21	0.22	0.14	1.56	0.12	-0.10	0.12	-0.84	0.40
Education, parent 2	-0.31	0.15	-2.08	0.04	-0.15	0.15	-1.04	0.30	-0.24	0.12	-2.03	0.04
Random effects												
School												
(Intercept)	0.04	0.19			0.05	0.21			0.01	0.10		

Reference level for Sex = boys; reference level for Language = Dutch as home language; reference level for Bursary = no bursary; reference level for Education parents 1 and 2 = highest attained degree is secondary education or higher.

recommend caution when interpreting individual subtest scores independently. However, reliability and validity are always a function of both the instrument and the specific population being tested (Bannigan & Watson, 2009), so future research is essential to assess whether these subtests might perform more reliably in other populations.

With respect to the distribution of the Ch-ICAR scores, our analysis showed no evidence of sex bias. This result aligns with previous research, which suggests that although small sex differences in specific cognitive skills may exist, overall cognitive ability is generally equal across sexes (e.g., Deary et al., 2007; Fergusson & Horwood, 1997; Nisbett et al., 2012).

Regarding the relation with academic performance, we found that cognitive ability as measured by the Ch-ICAR uniquely explained about 18% of the within-school variance in GPA, 26% of the within-school variance in the score for the school subject mathematics, and 35% of the within-school variance in the score on the CDR. The proportion of explained variance in school achievement is somewhat lower than what is commonly reported for educational tests (i.e., medium to high, depending on the way academic performance is measured and analyzed, see for instance Kort et al., 2002; Deary et al., 2007; Koenig et al., 2008), but acceptable considering the rather short nature of the Ch-ICAR. Moreover, it is crucial to highlight that we have controlled for SES and sex, and accounted for the nested structure of our data, enhancing the robustness of the results. Furthermore, the correlations in our study are similar to the magnitude of the correlations with academic achievement found in the initial validation study of the ICAR16 (Condon & Revelle, 2014), which confirms the present set as a useful contribution to the ICAR project.

In conclusion, the Ch-ICAR seems promising as a quick, cost-efficient (i.e., free to use), and useful tool for researchers to obtain a reliable and valid, sex-neutral assessment of cognitive ability.

## Study 2: Cross-validation of the Children's ICAR

Study 2 sought to cross-validate the Ch-ICAR with two established intelligence tests: the Raven's 2 Progressive Matrices (RPM; McLeod & McCrimmon, 2021) and the CoVaT-CHC Basic Version (CoVaT; Magez et al., 2015). We examined the relation between the Ch-ICAR and cognitive ability, estimated by RPM. Additionally, we examined the relations between the Ch-ICAR subtests and three broad cognitive abilities estimated by the CoVaT, namely fluid intelligence (Gf), visuospatial processing (Gv), and crystallized intelligence (Gc), as well as the relation between the Ch-ICAR and the CoVaT total score. A priori we expected

significant correlations of the Ch-ICAR with on the one hand RPM and on the other CoVaT.

As mentioned in the general introduction, the ICAR project does not start from an a priori theoretical framework of cognitive ability. Only one study explored the connection between the original four ICAR(sub)tests and the CHC model (Young & Keith, 2020). Results showed a strong correlation between the ICAR16 total score and general cognitive ability, estimated by the Wechsler Adult Intelligence Scale, Fourth Edition (WAIS-IV). At subtest level, Young and Keith (2020) found that Letter-Number Series correlated most strongly with tests of Gf, whereas the remaining three subtests (Verbal Reasoning, Three-dimensional Rotation, and Matrix Reasoning) showed the strongest correlations with tests of Gv. Regarding Verbal Reasoning, Young and Keith (2020) themselves expressed surprise at the results given the inconsistency with CHC theory. They considered it highly plausible that the results stemmed from a statistical artifact or the small sample size, and hence pleaded for replications. Regarding Matrix Reasoning, the authors suggested that it is likely that it calls on both Gf and Gv but recommended caution in interpretation given the low internal consistency.

Building on cognitive ability theory, we anticipated that the Ch-ICAR Number Series and Matrix Reasoning subtests would mainly tap into Gf, that Figural Analogies would draw on both Gf and Gv, and that Verbal Reasoning would call on Gf and Gc, since this subtest requires both mathematical operations and general knowledge. However, we did not rule out the possibility that the results regarding Verbal Reasoning and Matrix Reasoning would be in line with the earlier research of Young and Keith (2020), and primarily assess Gv. It is important to note here that the Ch-ICAR does not aspire to measure IQ like the Wechsler scales. Instead, the Ch-ICAR strives to be a concise, open-source measure of cognitive ability for research purposes, in line with the overarching aim of the ICAR project (Condon & Revelle, 2014).

## Method

### Participants

Data for cross-validation with RPM were collected from 91 pupils ( $N_{\text{RPM}} = 91$ , male 40%), who were in their second year of secondary education ( $M_{\text{age}} = 12.99$ ,  $SD_{\text{age}} = 0.57$ ). In this sample, 3% of the participants had a home language other than Dutch. Data for cross-validation with the CoVaT were collected from 96 pupils ( $N_{\text{CoVaT}} = 96$ , male 50%), who were in their last year of primary education ( $M_{\text{age}} = 11.05$ ,  $SD_{\text{age}} = 0.27$ ). In this sample, 3% of the participants had a home language other than Dutch. Table 2 offers a comprehensive overview of the demographics and associated statistics for each sample.

**Table 9** Means and standard deviations of the Ch-ICAR (subtest) scores for CoVaT sample

(Sub)test	<i>M (SD)</i>	<i>M (SD)</i> Boys	<i>M (SD)</i> Girls
Verbal Reasoning	3.93 (1.78)	4.17 (2.01)	3.69 (1.49)
Matrix Reasoning	2.55 (1.52)	2.46 (1.52)	2.65 (1.54)
Number Series	3.58 (1.98)	4.13 (1.94)	3.04 (1.88)
Figural Analogies	2.22 (1.80)	1.98 (1.76)	2.46 (1.82)
Full Ch-ICAR	12.28 (5.32)	12.73 (5.53)	11.83 (5.12)

The maximum scores are 8 for Verbal Reasoning, 6 for both Matrix Reasoning and Figural Analogies, 7 for Number Series, and 27 for the full Ch-ICAR

**Table 10** Means and standard deviations of the Ch-ICAR (subtest) scores for RPM sample

(Sub)test	<i>M (SD)</i>	<i>M (SD)</i> Boys	<i>M (SD)</i> Girls
Verbal Reasoning	3.98 (1.99)	3.61 (1.78)	4.22 (2.10)
Matrix Reasoning	2.51 (1.34)	2.42 (1.50)	2.56 (1.23)
Number Series	4.12 (2.06)	4.11 (2.05)	4.13 (2.08)
Figural Analogies	2.98 (1.71)	2.47 (1.87)	3.31 (1.53)
Full Ch-ICAR	13.58 (5.09)	12.61 (5.40)	14.22 (4.83)

The maximum scores are 8 for Verbal Reasoning, 6 for both Matrix Reasoning and Figural Analogies, 7 for Number Series, and 27 for the full Ch-ICAR.

## Materials

**Children's ICAR** All pupils completed the Ch-ICAR (see Study 1 for a detailed description of the instrument). Based on recommendations from Study 1, we utilized the 27-item subset for all analyses. The means and standard deviations of the Ch-ICAR (subtest) scores for the CoVaT and RPM samples are presented in Tables 9 and 10, respectively, with separate values reported for boys and girls.<sup>14</sup> The full Ch-ICAR showed good internal consistency in both samples, with McDonald's omega values of 0.81 in the RPM sample

<sup>14</sup> In Flanders, primary education is comprehensive, with no ability grouping and open access, while secondary education is specialized and ability-based (Seghers et al., 2019). Study 2 focused on examining the Ch-ICAR's correlation with other cognitive ability tests, rather than sampling a representative population. Consequently, sex balance across ability groups in the RPM sample was not specifically monitored, as this was not a focus of the study. Nevertheless, independent-samples *t*-tests showed no significant difference in Ch-ICAR total scores between males and females in either sample: CoVaT sample:  $t(94) = .82, p = .41, \text{Cohen's } d = .17$ ; RPM sample:  $t(89) = -1.48, p = .14, \text{Cohen's } d = -.32$ . Furthermore, no DIF was detected in any items in the refined hierarchical IRT model (excluding items MR5, MR8, NS6, and FA7).

and 0.84 in the CoVaT sample. At subtest level, internal consistency was sufficient to good for three of the four subtests (Number Series, Figural Analogies, and Verbal Reasoning) in both samples, with McDonald's omega values ranging from 0.60 to 0.77. However, internal consistency for the Matrix Reasoning subtest was insufficient ( $\omega = 0.31$  in the RPM sample;  $\omega = 0.52$  in the CoVaT sample). Comprehensive internal consistency statistics, including both McDonald's omega and Cronbach's alpha, are provided in Appendix Tables 23 and 24.

**Raven's 2 Progressive Matrices** We used the Raven's 2 Digital Short Form (McLeod & McCrimmon, 2021). The test starts with three example items followed by three practice items. The actual test consists of 24 items and has a time limit of 20 min. Each participant received a unique but comparable subset of items, automatically generated from the Raven's 2 item bank. The marginal reliability coefficient of the Raven's 2 Digital Short Form, based on American data, is 0.80 (Dimitrov, 2003). Per participant, a score report was obtained via Q-Global (Pearson, 2023). The report describes among others, a total raw score (TRS), a skill score (SkS), and a scaled score (ScS). For our analyses we used the ScS.<sup>15</sup> In our sample, the mean ScS was  $M = 96.44, SD = 12.18$ .

**CoVaT-CHC Basic Version** The full CoVaT (Magez et al., 2015) encompasses five broad cognitive abilities (BCA): fluid intelligence (Gf), visuospatial processing (Gv), crystallized intelligence (Gc), short-term memory (Gsm), and processing speed (Gs). Each BCA is measured by two subtests, except Gs, which is measured by only one. The CoVaT offers strong psychometric properties (Magez, 2019) and has received the highest quality label of the Belgian Federation of Psychologists (BFP, 2020). The complete CoVaT administration takes two and a half to three hours, but individual administration may be shorter. Due to time constraints, we only administered the six subtests measuring Gf, Gv, and Gc.

Gf is assessed by the subtests Point Sequences and Figure Sequences. Point Sequences comprises 15 items, where participants have to draw points to complete a sequence. Figure Sequences comprises 25 items and requires participants to draw figures to complete a sequence. Gc is measured via the

<sup>15</sup> The skill score converts each participant's test performance to a common and equal interval scale, regardless of test version or differences between item sets (Pearson, 2023). Skill scores can be directly compared with each other. The scaled score is based on the skill score and the participant's age. The scaled score is a standardized score with a mean of 100 and a standard deviation of 15, and can be compared to the score on other intelligence tests.

**Table 11** Means and standard deviations of the CoVaT (BCAs)

CoVaT (BCA)	<i>M</i> ( <i>SD</i> )
Gv	54.76 (17.59)
Gf	67.32 (14.97)
Gc	54.42 (9.86)
CoVaT weighted overall score <sup>a</sup>	298.24 (54.84)

**Table 12** Correlations between the Ch-ICAR and RPM

(Sub)test	1	2	3	4	5	6
1. RPM: ScS	1					
2. Ch-ICAR: VR	0.59**	1				
3. Ch-ICAR: MR	0.43**	0.46**	1			
4. Ch-ICAR: NS	0.48**	0.47**	0.33**	1		
5. Ch-ICAR: FA	0.39**	0.30**	0.34**	0.19	1	
6. Full Ch-ICAR	0.67**	0.80**	0.69**	0.74**	0.62**	1

ScS = Scaled Score, VR = Verbal Reasoning, MR = Matrix Reasoning, NS = Number Series, FA = Figural Analogies.

\*\**p* < 0.01.

subtests Shifts and Opposites, each consisting of 35 items. In Shifts, participants have to select the word that does not fit in a series, while Opposites requires participants to select the opposite word from a target word. Gv is evaluated using the Rotated Figs. (20 items) and Folding Boxes (26 items) subtests, assessing participants’ ability to identify equal, albeit rotated, figures and match folded with unfolded boxes, respectively. Each subtest has a specified time limit outlined in the manual. The reliability coefficients of Gf, Gv, and Gc are 0.96, 0.91, and 0.87 respectively.<sup>16</sup> The means and standard deviations of the BCAs in our sample are shown in Table 11. We used the pen-and-paper version and administered the instrument in group.

**Procedure**

For cross-validation with RPM, participants completed RPM and the Ch-ICAR on the same day. For cross-validation with the CoVaT, participants completed the CoVaT and the Ch-ICAR on different days, with a minimum of 7 and maximum of 35 days between the two tests (*M*<sub>days</sub> = 16.33, *SD*<sub>days</sub> = 16.17). We introduced a time delay specifically for the Ch-ICAR-CoVaT test-taking to prevent pupils from experiencing cognitive overload before beginning the subsequent test, given that the CoVaT spanned about three hours.

<sup>16</sup> The reliability of the BCA indices was estimated based on the formula of Lienert (Stinissen et al., 1975), which uses the observed standard deviations ( $\sigma$ ) per subtest and the observed intercorrelations between subtests.

Since the Raven only lasted 20 min, no time delay was deemed necessary between the Raven and the Ch-ICAR. The order of testing alternated between classes, in both samples.

**Analyses**

Analyses were conducted in SPSS (version 29.0; IBM Corp., 2022) and R (version 4.3.3; R Core Team, 2024). All R anal-

ysis codes as well as the variance–covariance matrix are available at: [https://osf.io/6cwfs/?view\\_only=4a80feb83bd94c378d3bd06853820563](https://osf.io/6cwfs/?view_only=4a80feb83bd94c378d3bd06853820563).

To examine the relationship between the Ch-ICAR and cognitive ability, we calculated Pearson correlations between the observed Ch-ICAR (subtest) scores and the scaled score derived from the RPM, as well as between the observed Ch-ICAR (subtest) scores and the CoVaT’s weighted overall score, and its measures of the broad cognitive abilities Gf, Gv, and Gc. In line with Young and Keith’s (2020) cross-validation research, we also tested a final integrated CFA model informed by the theoretical expected relationships. The CFA was conducted using the lavaan package (version 0.6.17; Rosseel, 2012), with maximum likelihood (ML) as estimator and the Satorra-Bentler correction for non-normality. The model allowed for correlations between the broad cognitive abilities to account for the positive manifold (i.e., the psychometric phenomenon that all (sub)tests that measure facets of cognitive ability correlate; Burgoyne et al., 2022), and for correlated errors for the Ch-ICAR subtests to account for potential method covariance (Young & Keith, 2020).

**Results**

**Cross-validation with the RPM**

The correlations between the Ch-ICAR subtests and the ScS range from *r* = 0.39 to *r* = 0.59 (Table 12). The Ch-ICAR total score showed the largest correlation with the ScS: *r* = 0.67.

### Cross-validation with the CoVaT

The correlations between the Ch-ICAR and CoVaT scores are depicted in Table 13. Number Series, Verbal Reasoning, and Matrix Reasoning showed the strongest correlation with Gf, while Figural Analogies correlated most strongly with Gv, when considering all BCAs. However, given that two out of four subtests demonstrate limited reliability, we recommend caution when interpreting individual subtest scores independently.

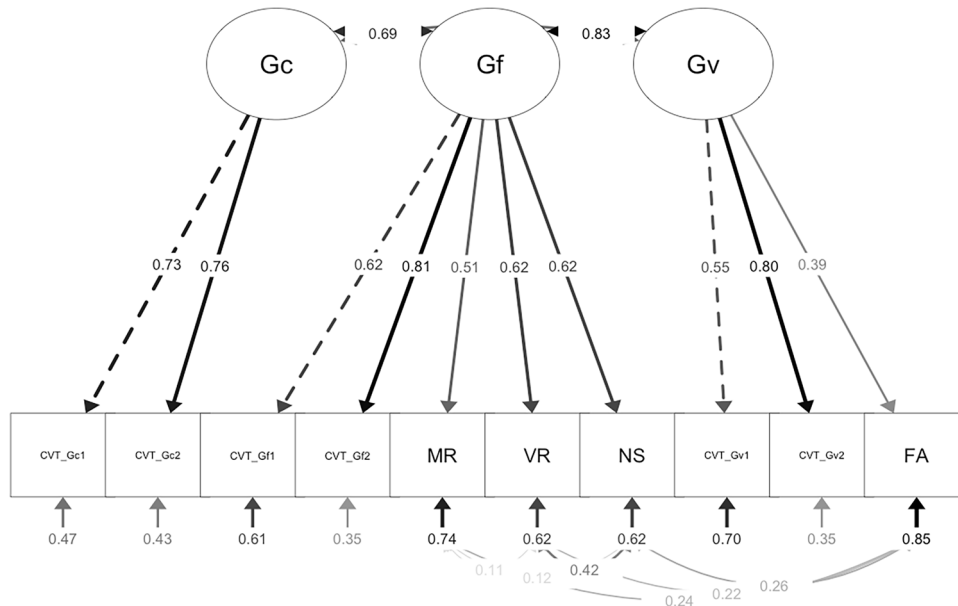
The final integrated CFA model (Fig. 5) showed a moderate fit for the data:  $\chi^2(26): 41.305$ ; RMSEA = 0.081, 90% CI [0.026, 0.125]; CFI = 0.944, TLI = 0.904, SRMR = 0.060. Given that we a priori expected Verbal Reasoning and Figural Analogies to show equally high correlations with Gf and Gc and with Gf and Gv, respectively, we initially allowed those two subtests to cross-load on both. However, compared to the final integrated model, cross-loading Verbal Reasoning did not significantly improve the model fit:  $\chi^2(25): 39.574$ ; RMSEA = 0.081, 90% CI [0.024, 0.126]; CFI = 0.947,

**Table 13** Correlations between the Ch-ICAR (sub)tests, the CoVaT overall score, and three broad cognitive abilities estimated by the CoVaT

(Sub)test	1	2	3	4	5	6	7	8	9
1. CoVaT weighted overall score	1								
2. CoVaT: Gv	0.79**	1							
3. CoVaT: Gf	0.90**	0.63**	1						
4. CoVaT: Gc	0.71**	0.35**	0.43**	1					
5. Ch-ICAR: VR	0.54**	0.28**	0.53**	0.45**	1				
6. Ch-ICAR: MR	0.47**	0.38**	0.40**	0.37**	0.40**	1			
7. Ch-ICAR: NS	0.55**	0.35**	0.51**	0.44**	0.62**	0.39**	1		
8. Ch-ICAR: FA	0.31**	0.29**	0.26*	0.21*	0.34**	0.35**	0.40**	1	
9. Full Ch-ICAR	0.62**	0.43**	0.57**	0.49**	0.79**	0.68**	0.82**	0.70**	1

VR = Verbal Reasoning, MR = Matrix Reasoning, NS = Number Series, FA = Figural Analogies.

\* $p < 0.05$ , \*\* $p < 0.01$ .



**Fig. 5** Final integrated CFA model. *Note.* CVT\_... = CoVaT subtest, VR = Verbal Reasoning scale score, MR = Matrix Reasoning scale score, NS = Number Series scale score, FA = Figural Analogies scale score

TLI = 0.904, SRMR = 0.058;  $\Delta\chi^2(1) = 1.774$ ,  $p = 0.183$ . Similarly, cross-loading Figural Analogies also had no significant impact:  $\chi^2(25) = 40.667$ ; RMSEA = 0.084, 90% CI [0.030, 0.129]; CFI = 0.942, TLI = 0.896, SRMR = 0.061,  $\Delta\chi^2(1) = 0.085$ ,  $p = 0.771$ . Therefore, we opted for the more parsimonious model without cross-loadings.

## Discussion

In Study 2, we cross-validated the Ch-ICAR with the RPM in a sample of 91 pupils in secondary education, and with the CoVaT in a sample of 96 pupils in primary education. Analyses revealed high correlations between the Ch-ICAR total score and cognitive ability, estimated by RPM and CoVaT. The magnitude of the relationships is in line with prior cross-validation research with the ICAR16 (Young & Keith, 2020). As expected, the Ch-ICAR is mainly a measure of Gf, making it a viable measure specifically for non-verbal cognitive ability.

At the subtest level, the correlation matrix in combination with the integrated CFA model suggests that the subtests tend to measure what we theoretically expected. We found Verbal Reasoning to predominantly assess Gf and, to a somewhat lesser extent, Gc. These results are consistent with the theory and support the statement by Young and Keith (2020) that their findings (Verbal Reasoning mainly tapping into Gv) are presumably a statistical artifact or a product of the small sample.

Regarding Figural Analogies, it is notable that this subtest shows rather small correlations with the CoVaT across the board. When we take a closer look, several reasons emerge as to why this subtest does not function as expected. First, the scores on this subtest are not normally distributed at all (Appendix Fig. 6); many participants get either four questions right or none at all. Secondly, and related to the first reason, there appears to be an issue with increasing difficulty: While about half of the participants answered items 1–4 correctly, the correct response rate dropped to 11% for item 5 and 20% for item 6 (Appendix Table 25 displays the proportion of correct responses for each item across all samples). Additionally, as we aimed for standardization in the testing procedure, we presented the subtests in a fixed sequence, with Figural Analogies as the final subtest. While this procedure adheres to common practice (Flanagan & Alfonso, 2017; Weiss et al., 2019), it introduces the potential for fatigue effects to impact test performance. To address these issues, we recommend conducting further research to assess the validity of Figural Analogies with other items of the subtest that vary in difficulty.

The subtest Matrix Reasoning correlates most strongly with Gf, as expected; however, its low reliability requires careful interpretation. Future research should explore ways

to enhance the quality of Matrix Reasoning, as its validity issues reflect broader challenges within the ICAR project (Condon & Revelle, 2014, p. 57; Young et al., 2019, p. 2). For the Ch-ICAR specifically, developing a larger set of easier items and incorporating simple, nonverbal instructions may enhance the subtest's internal consistency and further improve the overall quality of the Ch-ICAR. Additionally, one could consider replacing Matrix Reasoning items with alternative item types, such as Progressive Matrices items, as those use a similar task paradigm but offer much stronger reliability.

In conclusion, the Ch-ICAR total score exhibits a strong correlation with cognitive ability, establishing itself as a valid and freely available measure for assessing children's cognitive abilities in research settings. Nonetheless, at this stage, we advise against using and interpreting subtests independently.

As the sample sizes of Study 2 are rather small, the current results should be interpreted with caution, and replications in larger samples are needed. Nevertheless, the results of both cross-validations yield the same conclusions, which removes part of the potential bias risk.

## General conclusion

In developing the Ch-ICAR, our aim was to expand the scope of the ICAR project, considering that its suitability for children had not been previously assessed (Dworak et al., 2021; The International Cognitive Ability Resource Team, 2014). Additionally, we sought to address the dearth of psychometrically robust cognitive ability measures that are freely accessible, brief in administration time, and tailored to children.

The results of Study 1 and 2 provide support for the utility of the full Ch-ICAR as a measure for children's cognitive abilities within a research context. This was demonstrated by the observed correlations between the Ch-ICAR and the RPM and CoVaT, two established intelligence tests (Magez et al., 2015; McLeod & McCrimmon, 2021), and by the established relationship with academic performance. The magnitude of the correlation coefficients is in line with prior validation research of the ICAR16 (Condon & Revelle, 2014; Young & Keith, 2020).

At this point, however, we advise against the use of the Ch-ICAR subtests in isolation, in contrast to the use of the battery as a whole. Further research should ascertain whether the subtests can reliably stand alone and yield meaningful interpretations. Therefore, replications of the relations with the broad cognitive abilities are necessary, as well as improvements in the Matrix Reasoning and Figural Analogies subtests.

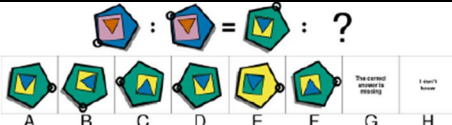
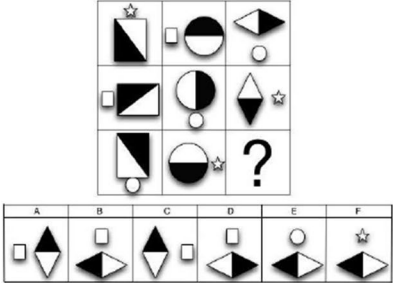
The primary constraint of this investigation pertains to the restricted scope of the Ch-ICAR, which solely assessed a limited subset of ICAR items in children. Consequently, the possibility cannot be dismissed that an alternative or more extensive item selection may yield superior performance as a child-adapted version of the ICAR. Another consideration involves the absence of established norms for the Ch-ICAR.

Given the dynamic developmental changes in cognitive processing efficiency during childhood and adolescence (Flanagan & McDonough, 2018), it is imperative to consider factors such as age or grade level when interpreting and comparing Ch-ICAR results. Therefore, we underscore the significance of future research endeavors aimed at establishing age- or grade-based norms to ensure precise interpretation and comparison of Ch-ICAR outcomes.

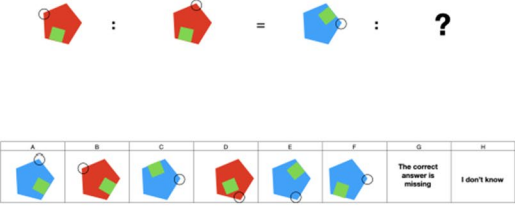
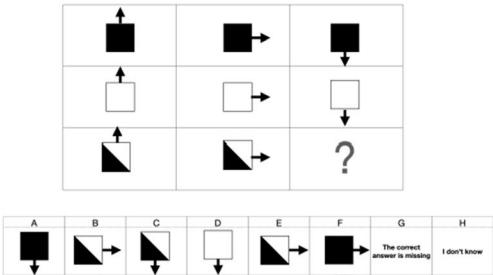
### Appendix

See Tables 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25 and Fig. 6

**Table 14.** Specimen of Each Item Type of the Ch-ICAR (Loe et al., 2018; The International Cognitive Ability Resource Team, 2014)

Verbal Reasoning	If the day after tomorrow is two days before Thursday then what day is it today? (1) Friday (2) Monday (3) Wednesday (4) Saturday (5) Tuesday (6) Sunday (7) None of these (8) I don't know	Figural Analogies	
Matrix Reasoning		Number Series	34,150,35,160,36,170, ...

**Table 15.** Example Items of the Subtest Figural Analogies and Matrix Reasoning

Figural Analogies	Matrix Reasoning
	

**Table 16** Overview Test Statistics Verbal Reasoning Items (Pilot Study, N = 46)

Cronbach's alpha full item set (16 items): 0.50  
Cronbach's alpha final item selection (8 items): 0.65

ICAR item number	PC	Mean response time (in sec)	PC boys	PC girls
VR18	0.91	24	0.91	0.92
VR31	0.56	42	0.52	0.58
VR39	0.77	23	0.90	0.65
VR11	0.12	19	0.10	0.13
VR14	0.42	37	0.50	0.35
VR17	0.37	41	0.25	0.48
VR42	0.42	18	0.40	0.43
VR04	0.10	22	0.16	0.04
VR19	0.52	35	0.53	0.52
VR32	0.43	39	0.53	1. 0.35
VR09	0.03	22	0.00	0.04
VR16	0.21	37	0.35	0.09
VR36	0.03	18	0.06	0.00
VR23	0.26	19	0.41	0.14
VR26	0.00	17	0.00	0.00
VR13	0.15	40	0.18	0.14

The numbers of the items refer to the numeration in the ICAR database (The International Cognitive Ability Resource Team, 2014). PC=proportion of correct responses in the full sample; PC boys=proportion of correct responses in boys subsample; PC girls=proportion of correct responses in girls subsample.

**Table 17** Overview Test Statistics Matrix Reasoning Items (Pilot Study, N = 66)

Cronbach's alpha full item set (11 items): 0.63  
Cronbach's alpha final item selection (8 items): 0.69

ICAR item number	PC	Mean response time (in sec)	PC boys	PC girls
Figure 12043	0.52	62	0.64	0.41
Figure 12044	0.52	41	0.56	0.49
Figure 12047	0.36	36	0.41	0.33
Figure 12046	0.30	33	0.33	0.28
Figure 12053	0.26	39	0.30	0.23
Figure 12045	0.29	28	0.30	0.28
Figure 12048	0.23	34	0.33	0.15
Figure 12054	0.17	31	0.22	0.13
Figure 12056	0.31	27	0.33	0.30
Figure 12055	0.16	29	0.22	0.11
Figure 12050	0.13	26	0.11	0.14

The numbers of the items refer to the numeration in the ICAR database (The International Cognitive Ability Resource Team, 2014). PC=proportion of correct responses in the full sample; PC boys=proportion of correct responses in boys subsample; PC girls=proportion of correct responses in girls subsample.

**Table 18** Overview Test Statistics Number Series Items (Pilot Study, N = 71)

Cronbach's alpha full item set (23 items): 0.88  
Cronbach's alpha final item selection (8 items): 0.85

ICAR item number	PC	Mean response time (in sec)	PC boys	PC girls
8	0.83	33	0.83	0.83
6	0.90	20	0.90	0.90
2	0.66	34	0.79	0.56
7	0.89	18	0.86	0.90
1	0.63	28	0.79	0.51
3	0.51	35	0.66	0.39
4	0.63	28	0.79	0.51
5	0.52	28	0.61	0.44
10	0.44	33	0.52	0.39
12	0.49	28	0.62	0.40
9	0.20	46	0.19	0.20
25	0.22	45	0.19	0.24
19	0.25	41	0.23	0.26
26	0.32	41	0.31	0.33
27	0.37	45	0.46	0.30
11	0.09	56	0.13	0.06
33	0.00	44	0.00	0.00
42	0.09	49	0.20	0.03
13	0.08	37	0.05	0.09
16	0.10	39	0.05	0.12
44	0.08	34	0.11	0.06
40	0.06	38	0.11	0.03
28	0.04	22	0.06	0.03

The numbers of the items refer to the numeration in the ICAR database (The International Cognitive Ability Resource Team, 2014). PC=proportion of correct responses in the full sample; PC boys=proportion of correct responses in boys subsample; PC girls=proportion of correct responses in girls subsample.

**Table 19** Overview Test Statistics Figural Analogies Items (Pilot Study, N=56)

Cronbach's alpha full item set (20 items): 0.77  
 Cronbach's alpha final item selection (7 items): 0.83

ICAR item number	PC	Mean response time (in sec)	PC boys	PC girls
q18005	0.36	68	0.30	0.41
q18019	0.38	35	0.31	0.45
q18020	0.44	28	0.36	0.52
q18006	0.51	25	0.52	0.50
q18002	0.26	24	0.16	0.36
q18001	0.25	20	0.16	0.32
q18004	0.25	36	0.24	0.25
q18009	0.26	24	0.13	0.37
q18010	0.31	19	0.17	0.42
q18003	0.27	22	0.13	0.38
q18012	0.29	28	0.39	0.19
q18011	0.19	31	0.26	0.12
q18014	0.15	20	0.14	0.16
q18018	0.13	21	0.14	0.12
q18013	0.33	18	0.29	0.38
q18017	0.07	21	0.05	0.08
q18016	0.24	19	0.19	0.29
q18015	0.22	21	0.19	0.25
q18008	0.05	16	0.05	0.04
q18007	0.09	20	0.15	0.04

The numbers of the items refer to the numeration in the ICAR database (The International Cognitive Ability Resource Team, 2014). PC=proportion of correct responses in the full sample; PC boys=proportion of correct responses in boys subsample; PC girls=proportion of correct responses in girls subsample.

**Table 21** Item Fit Final Hierarchical IRT Model (Study 1, N=820)

Item	S_ $\chi^2$ Statistic	df	RMSEA	FDR adjusted p-value
MR1	12.5	15	0.000	0.719
MR2	24.4	13	0.033	0.105
MR3	20.2	14	0.023	0.258
MR4	12.9	14	0.000	0.632
MR6	11.8	15	0.000	0.719
MR7	8.4	15	0.000	0.906
VR1	15.3	13	0.015	0.433
VR2	23.9	11	0.038	0.060
VR3	16.7	13	0.019	0.382
VR4	28.1	12	0.041	0.048
VR5	35.0	14	0.043	0.020
VR6	17.0	14	0.016	0.431
VR7	16.5	14	0.015	0.433
VR8	17.2	13	0.020	0.363
NS1	19.2	12	0.027	0.215
NS2	26.8	13	0.036	0.060
NS3	10.9	10	0.011	0.509
NS4	35.9	10	0.056	0.002
NS5	16.6	9	0.032	0.169
NS7	14.0	13	0.009	0.509
NS8	12.5	13	0.000	0.601
FA1	11.2	11	0.005	0.546
FA2	17.7	11	0.027	0.215
FA3	19.3	11	0.030	0.169
FA4	18.7	12	0.026	0.215
FA5	11.1	14	0.000	0.719
FA6	30.0	14	0.037	0.052

**Table 20** Included ICAR Items in the Children's ICAR

Subtest	ICAR item number
Verbal Reasoning	VR39, VR31, VR19, VR14, VR32, VR16, VR11, VR04
Matrix Reasoning	12,044, 12,043, 12,056, 12,046, 12,053, 12,048, 12,055, 12,050
Number Series	8, 5, 3, 12, 10, 27, 25, 13
Figural Analogies	q18005, q18020, q18019, q18006, q18015, q18009, q18016

The numbers of the items refer to the numeration in the ICAR database (The International Cognitive Ability Resource Team, 2014).

**Table 22** Correlations Between Academic Performance and SES Indicators (Study 1, N = 820)

	1	2	3	4	5	6	7
1. GPA	1						
2. Mathematics	0.86**	1					
3. CDR	0.37**	0.40**	1				
4. Home language	-0.11**	-0.10**	-0.14**	1			
5. Bursary	-0.27**	-0.27**	-0.23**	0.20**	1		
6. Education parent 1	-0.02	-0.02	-0.15**	0.29**	0.24**	1	
7. Education parent 2	-0.11**	-0.10*	-0.18**	0.29**	0.28**	0.46**	1

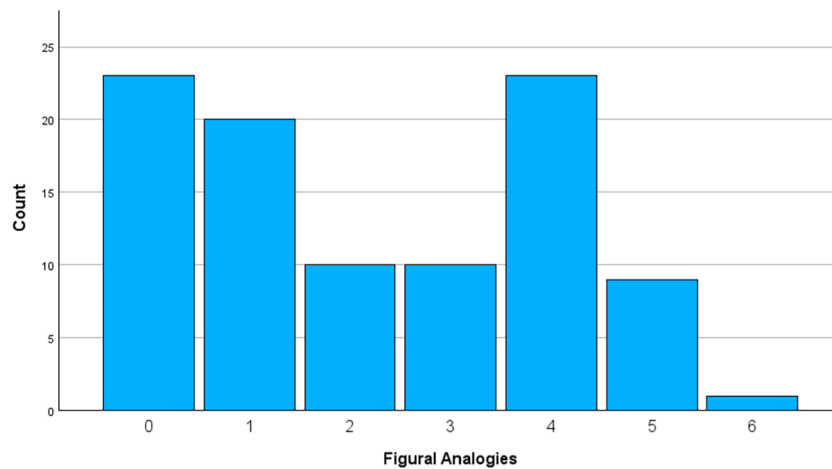
\* <0.05; \*\* <0.01

**Table 23** Internal Consistency of Ch-ICAR (sub)tests in CoVaT Sample (Study 2, N = 96)

(sub)test	McDonald’s omega ( $\omega$ )	Cronbach’s alpha ( $\alpha$ )
Verbal Reasoning	0.60	0.58
Matrix Reasoning	0.52	0.49
Number Series	0.76	0.74
Figural Analogies	0.77	0.73
Full Ch-ICAR	0.84	0.83

**Table 24** Internal Consistency of Ch-ICAR (sub)tests in RPM Sample (Study 2, N = 91)

(sub)test	McDonald’s omega ( $\omega$ )	Cronbach’s alpha ( $\alpha$ )
Verbal Reasoning	0.66	0.66
Matrix Reasoning	0.31	0.31
Number Series	0.77	0.75
Figural Analogies	0.75	0.70
Full Ch-ICAR	0.81	0.81



**Fig. 6** Distribution of Figural Analogies Scores (Study 2, CoVaT sample, N = 96)

**Table 25** Proportion of Correct Responses per Item (Study 1 & Study 2)

Item	PC (SD) Study 1, N=820	PC (SD) Study 2 CoVaT sample, N=96	PC (SD) Study 2 RPM sample, N=91
VR1	0.83 (0.38)	0.89 (0.32)	0.78 (0.42)
VR2	0.73 (0.44)	0.84 (0.37)	0.87 (0.34)
VR3	0.48 (0.50)	0.53 (0.50)	0.52 (0.50)
VR4	0.38 (0.49)	0.44 (0.50)	0.41 (0.49)
VR5	0.43 (0.50)	0.43 (0.50)	0.47 (0.50)
VR6	0.20 (0.40)	0.21 (0.41)	0.35 (0.48)
VR7	0.20 (0.40)	0.29 (0.46)	0.33 (0.47)
VR8	0.24 (0.43)	0.30 (0.46)	0.25 (0.44)
MR1	0.38 (0.49)	0.44 (0.50)	0.47 (0.50)
MR2	0.49 (0.50)	0.73 (0.45)	0.71 (0.45)
MR3	0.24 (0.43)	0.31 (0.47)	0.32 (0.47)
MR4	0.30 (0.46)	0.35 (0.48)	0.33 (0.47)
MR5	0.30 (0.46)	0.49 (0.50)	0.32 (0.47)
MR6	0.29 (0.45)	0.36 (0.48)	0.46 (0.50)
MR7	0.17 (0.37)	0.35 (0.48)	0.21 (0.41)
MR8	0.14 (0.34)	0.18 (0.38)	0.18 (0.38)
NS1	0.82 (0.38)	0.87 (0.33)	0.89 (0.31)
NS2	0.51 (0.50)	0.56 (0.50)	0.55 (0.50)
NS3	0.56 (0.50)	0.67 (0.47)	0.70 (0.46)
NS4	0.42 (0.49)	0.44 (0.50)	0.55 (0.50)
NS5	0.46 (0.50)	0.59 (0.49)	0.68 (0.47)
NS6	0.19 (0.39)	0.20 (0.40)	0.20 (0.40)
NS7	0.25 (0.43)	0.21 (0.41)	0.42 (0.50)
NS8	0.17 (0.38)	0.24 (0.43)	0.33 (0.47)
FA1	0.45 (0.50)	0.42 (0.50)	0.59 (0.49)
FA2	0.49 (0.50)	0.51 (0.50)	0.67 (0.47)
FA3	0.48 (0.50)	0.49 (0.50)	0.68 (0.47)
FA4	0.52 (0.50)	0.49 (0.50)	0.66 (0.48)
FA5	0.08 (0.27)	0.11 (0.32)	0.13 (0.34)
FA6	0.20 (0.40)	0.20 (0.40)	0.24 (0.43)
FA7	0.15 (0.36)	0.21 (0.41)	0.26 (0.44)

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**Authors' contributions** The authors confirm contribution to the paper as follows. Study conception and design: Derous Eva, Dirix Nicolas, Dutry Merel, Duyck Wouter, Schelfhout Stijn, Schittekatte Mark, Vereeck Alexandra. Data collection: Merel Dutry. Analysis and interpretation of results: Derous Eva, Dirix Nicolas, Dutry Merel, Duyck Wouter, Schelfhout Stijn, Schittekatte Mark, Szmalec Arnaud, Vereeck Alexandra, Woumans Evy, Dries Debeer. Draft manuscript preparation: Dutry Merel, Vereeck Alexandra. All authors reviewed the results and approved the final version of the manuscript.

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**Data availability** For now (pre-peer review), the Ch-ICAR can be accessed via this link: <https://ap.ic/UXMoM>, with this access data: Username: PeerReviewChICAR; Password: 2HE2wiA1. Upon acceptance, the Ch-ICAR will be available via the homepage, users will only need to create a user account. The variance-covariance matrices are available at [https://osf.io/6cwfs/?view\\_only=4a80feb83bd94c378d3bd06853820563](https://osf.io/6cwfs/?view_only=4a80feb83bd94c378d3bd06853820563); the complete dataset is available upon request; none of the studies were preregistered.

**Code availability** Analysis codes are available at [https://osf.io/6cwfs/?view\\_only=4a80feb83bd94c378d3bd06853820563](https://osf.io/6cwfs/?view_only=4a80feb83bd94c378d3bd06853820563)

## Declarations

**Conflicts of interest/Competing interests** The authors have no relevant financial or non-financial interests to disclose.

**Ethics approval** This research was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of the Faculty of Psychology and Educational Sciences of Ghent University (2 September 2021/ No 2021/59).

**Consent to participate** Written informed consent was obtained from the parents.

**Consent for publication** Not applicable.

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