Received: 21 February 2024 | Revised: 27 June 2024 | Accepted: 2 August 2024

DOI: 10.1002/mpr.2035

ORIGINAL ARTICLE

WILEY

Neurocognitive functioning during adolescence: Spanish validation of the Penn Computerized Neurocognitive Battery

Xacobe Fernández-García[1] | Félix Inchausti[2] | Alicia Pérez-Albéniz[3] | Javier Ortuño-Sierra[3] | Raquel Falcó[3] | Eduardo Fonseca-Pedrero[3]

[1]University Hospital of A Coruña, Health Service of Galicia, A Coruña, Spain

[2]Department of Mental Health, Health Service of La Rioja, Logroño, Spain

[3]Department of Educational Sciences, University of La Rioja, Logroño, Spain

Correspondence
Eduardo Fonseca-Pedrero, University of La Rioja, C/ Luis de Ulloa s/n - Edificio VIVES, 26002 Logroño, La Rioja, Spain.
Email: eduardo.fonseca@unirioja.es

Funding information
The Ministry of Science and Innovation of the Government of Spain, the State Research Agency, and the European Regional Development Fund, Grant/Award Number: PID2021-127301OB-I00

Abstract

Objectives: The Penn Computerized Neurocognitive Battery - Child Version (PennCNB-cv) is presented as a brief tool that allows comprehensive and automated assessment of 5 factors (via 14 performance tasks): Executive Control, Episodic Memory, Complex Cognition, Social Cognition, and Sensorimotor Speed. The literature links (dys)functions in these areas with psycho(patho)logical constructs, but evidence is scarce among Spanish-speaking youth. Therefore, this study aims to validate the PennCNB-cv in a community sample of Spanish adolescents.

Methods: After a process of (back)translation and adaptation by bilingual researchers, the PennCNB-cv was administered in 34 schools. The sample included 1506 students, ages 14–19, 44.28% were male. Preliminary treatment of the data included descriptive and correlational statistics. To provide evidence of structural validity, exploratory and confirmatory factor analyses were performed.

Results: Results from the exploratory and confirmatory factor analysis showed a four-factor model (Complex Cognition, Executive Control, Episodic Memory, and Social Cognition) as the most appropriate. These findings provide compelling evidence in favor of the a priori theory that underpinned the development of the CNB.

Conclusions: The study of the psychometric properties showed that the Spanish version of the PennCNB-cv, seems to be an adequate tool for assessing neurocognitive functioning during adolescence.

KEYWORDS
adolescence, assessment, neurocognitive battery, Penn CNB, validation

1 | INTRODUCTION

Cognitive psychology and neuroscience demand new methods to measure individual differences in cognitive domains that can be linked to brain systems. The goal of these demands is to deepen the fundamental underlying mechanisms of the brain-behavioral human interaction. Some initiatives like the Research Domain Criteria project (Cuthbert & Insel, 2013; Insel et al., 2010; Morris & Cuthbert, 2012) contemplate several levels of analysis (genetic, molecular, cellular, behavioral, physiological) to be linked to basic dimensions of human functioning like the cognitive system domain. Progressively, more objective, valid, and reliable measures are needed, as well as useful, brief, and easier tools, in order to assess neurocognitive functioning, in both clinical and non-clinical populations of the general population.

A quite important stage of human development is adolescence. In this phase, biological, psychological, and social changes occur (Dahl & Suleiman, 2017; Konrad et al., 2013). Adolescence is a key developmental stage for establishing a baseline assessment of typical or atypical development (Gur et al., 2019; Luciana et al., 2018). In addition, different mental health problems like schizophrenia (Gogtay et al., 2011), bipolar disorder (Van Rheenen et al., 2020), borderline personality (Biskin, 2015), eating disorders (Olivo et al., 2019), anxiety disorders (Zimmermann et al., 2019) or substance abuse (Luciana et al., 2018; Thorpe et al., 2020), among others, develop during this stage of life.

Pencil and paper assessment tools are useful for interpretation and semiology, but are not enough to analyze human behavior and cognitive functioning (Parsey & Schmitter-Edgecombe, 2013). Traditional neuropsychological batteries take several hours to administer and score, and need training and supervision. Furthermore, classical approaches need expert judgment to score, are difficult to standardize, and have the vulnerability of data-handling methods (Gur et al., 2001). These aspects explain why traditional neurocognitive batteries do not allow large-scale investigations. The tentative limitations burden new approximations to study cognitive processes, such as searching domains linked to brain systems available to serve as endophenotypes (Gottesman & Gould, 2003; Insel & Cuthbert, 2009).

New neurocognitive batteries must incorporate recent technologies and condense several advances to solve the mentioned problems (Parsey & Schmitter-Edgecombe, 2013). For instance, computerized batteries allow large-scale administration and scoring without human factor involved in data-handling (Gualtieri, 2004). In addition, computerized testing allows, among other things, larger and more accurate databases, as well as standardization of administration and scoring procedures. These strengths are relevant to make adequate decisions (e.g., guide clinical decision) based on empirical data.

The potential of the physiologic neuroimaging can be boosted by these improvements, especially through "neurobehavioral probes" (Gur, Erwin, Gur, et al., 1992) capable of linking both types of information. The criteria to be a "neurobehavioral probe" are to: (1) measure a well-defined unitary psychology dimension, (2) be adaptable to the constraints of neuroimaging evaluation, (3) be brief and maintain good reliability, (4) accept alternative versions, (5) have comparable levels of difficulties, and (6) avoid the floor and ceiling effect (Gur, Erwin, Gur, et al., 1992; Schneider et al., 1995). The last point means that the instrument should not be too easy or too hard. That means that the instrument has to mantain adequate levels of discrimination, what will allow the use of these probes in both general and clinical populations.

In the previous literature, one of the most relevant instruments to reach these objectives is the Penn Computerized Neurocognitive Battery (PennCNB; Gur et al., 2001, 2010). The PennCNB consists of 14 computerized tasks grouped into five neurobehavioral functions: "Sensorimotor Speed", "Executive Control," "Episodic Memory," "Complex Cognition," and "Social Cognition". All constructs, except for "Sensorimotor Speed" which has a dual task, are measured through "speed" and "accuracy", the combination of which allows the computation of "efficiency". Executive Control includes mental flexibility, attentional capacity, and working memory. Episodic Memory is structured at three levels: verbal, face, and spatial memory. Complex Cognition comprises language reasoning, nonverbal reasoning, and spatial ability. Finally, Social Cognition involves emotion identification and differentiation, and their differentiation by age.

Roalf et al. (2013) tested directly the PennCNB with functional neuroimaging and associated its scores to different brain systems in the context of schizophrenia research. The PennCNB reliability, standardization, and validation is an ongoing challenge (Gur et al., 2001, 2010). In this sense, the PennCNB has been studied in different populations, as well as in clinical and research contexts. For example, the study of neurocogitive performance in schizophrenia (Calkins et al., 2013; Gur, Braff et al., 2015; Gur, March, et al., 2015; Thomas et al., 2017, 2018; Tsuang et al., 2014), or the 22q11.2 deletion syndrome, a common genetic copy variation associated to schizophrenia (Gao et al., 2018; Tang et al., 2017, 2018; Weiberger et al., 2016, 2018; Yi et al., 2016). Obsessive-compulsive disorder (Aigner et al., 2007), suicidal ideation (Barzilay et al., 2019), and mood and anxiety disorders (de Vito et al., 2019; Merikangas et al., 2017) have also been studied. Furthermore, the PennCNB has been used in other contexts like, for instance, the study of traumatic brain injuries (Kalkstein et al., 2017), hepatitis C (Ibrahim et al., 2016), levels of iron in blood (Ji et al., 2017), chronic kidney disease (Hartung et al., 2016), or midday napping (Ji et al., 2019), among others. In addition, the external validity has been tested in previous studies. For example, Roalf et al. (2013), studied the correlation between the PennCNB speed scores and the White Matter density in the left cingulum bundle and the inferior front-occipital fasciculus, observing a negative correlation in healthy controls, but no correlation at all in people with schizophrenia diagnosis.

Gur's group also developed a child and adolescent version (PennCNB-cv; Gur et al., 2012). This adaptation has similar characteristics and adaptations to the adult's version, but with a reduced number of tasks. Moore et al. (2015), using a large sample of youth (*N* = 9138; age range 8–21), tested the theoretical structure of the PennCNB-cv, finding an adequate structural fit for a four-factor model solution: Complex Cognition, Executive Control, Memory, and Social Cognition. To date, we have little information about the validity of the PennCNB-cv scores in adolescent samples from other countries. For instance, and to the best of our knowledge, no previous studies have adapted and validated this battery in large and representative samples of Spanish-speaking youth. Therefore, the main purpose of the present study was to validate the PennCNB-cv in a community-derived sample of Spanish adolescents. Arising from this general goal are two specific objectives: (a) to study the efficiency, accuracy, and speed scores of the neurocognitive tasks;

and (b) to analyze the factorial structure of the PennCNB-cv scores throughout exploratory and confirmatory factor analyses.

2 | METHOD

2.1 | Participants

Stratified random cluster sampling was conducted at the classroom level, in an approximate population of 15,000 students selected from La Rioja, a region located in the north of Spain. The students belonged to different public and concerted Educational Centers of Compulsory Secondary Education and Vocational Training, as well as to different socio-economic levels. The layers were created as a function of the geographical zone and the educational stage.

There were 1845 students in the initial sample, although some participants were excluded due to their high scores on the infrequency scale (>3; $n = 104$), being older than 19 years of age ($n = 170$), or not completing all the administered tasks ($n = 65$). Thus, the sample was composed of 1506 students, 667 males (44.28%) from 34 centers and 98 classrooms. The mean age was 16.14 years ($SD = 1.36$), with an age range between 14 and 19 years. The distribution by age was: 14 year olds ($n = 200$), 15 year olds ($n = 313$), 16 year olds ($n = 281$), 17 year olds ($n = 365$), and 18/19 year olds ($n = 248$).

With regards to nationality, the distribution was as follows: 89.9% Spanish, 3.7% Latin American (Bolivia, Argentina, Colombia, and Ecuador), 0.7% Portuguese, 2.4% Romanian, 1% Moroccan, 0.7% Pakistani, and 2% other nationalities.

2.2 | Instruments

2.2.1 | The Penn Computerized Neurocognitive Battery-Child version

Pennsylvania Computerized Neurocognitive Battery - Child Version (PennCNB-cv; Gur et al., 2010, 2012). PennCNB-cv was administered using a software developed by original authors. The 1-h computerized neurocognitive battery (Calkins et al., 2014; Gur et al., 2010, 2012, 2014) included 14 tasks used to measure accuracy and response time over five domains: executive control, episodic memory, complex cognition, social cognition, and sensorimotor speed (the last one without accuracy measures). The Spanish version of the PennCNB-CV was used in previous studies (Aritio-Solana et al., 2022).

Executive control

The PennCNB-cv includes Penn Conditional Exclusion Test (PCET; Kurtz et al., 2004), Penn Continuous Performance Test (PCPT; Kurtz et al., 2001), and Letter N-Back Test (LNB; Braver et al., 1997; Ragland et al., 2002) to assess executive control. During PCET, individuals decide which of four objects does not belong to the other three based on one of three sorting principles (e.g., shape, size, line thickness). Sorting principles change after 10 successive correct responses, and feedback is used to guide discovery of the principle and indicate its change. PCPT is a version of the computerized CPT paradigm (Conners & Sitarenios, 2011) where participant responds if the stimulus is the letter or digit target. LNB consists in responds to identical targets in particular conditions. In the 0-back condition, participants responded to a single target (i.e., X). During the 1-back condition, participant responds if the consonant was identical to the one preceding it. In the 2-back condition, participant responds if the letter was identical to one presented two trials back.

Episodic memory

The PennCNB-cv contains Penn Word Memory Test (PWMT; Gur et al., 1997, 2001, 2010), Penn Face Memory Test (PFMT; Gur et al., 1997, 2001, 2010), and Visual Object Learning Test (VOLT; Glahn et al., 1997; Gur et al., 2001, 2010) to explore episodic memory. In PWTMT the participants are asked to memorize the target words, and after the presentation of mixed list (target and distracting words) they are asked to indicate whether a word presented was included in the target list. PFMT uses the same paradigm than before but with faces instead of words, that is, some target faces to identify them in a mixed list. VOLT used Euclidean shapes in the same memory paradigm. Some target shapes to identify them in presence of distractors.

Complex cognition

The PennCNB-cv includes Children's version of the Penn Verbal Reasoning Test (PVRT; Gur et al., 1982, 2001, 2010), Computerized Ravens Progressive Matrices (CRPM; Gur et al., 2010), and Computerized Judgment of Line Orientation (JOLO; Gur et al., 2010) to examine complex cognition. PVRT consists of verbal analogy problems with simplified instructions and vocabulary. CRPM is based on Raven's paradigms (Raven & Raven, 2003) of reasoning by geometric analogy and contrast principles. JOLO presents a modification of the Benton's paradigm (Benton et al., 1983), where the participant must put a line in an identical angle than the target, and locations and length change across essays.

Social cognition

The PennCNB-cv contains Penn Emotion Identification Test (EMI; Carter et al., 2008; Gur, Erwin, Gur, et al., 1992, 2001; Mathersul et al., 2009), Penn Emotion Differentiation Test (EMD; Gur et al., 2010), and Penn Age Differentiation Test (AGD; Gur et al., 2010) to assess social cognition. During EMI participants have to identify what emotion is expressing the face of the stimuli. The facial stimuli are balanced for sex, age, and ethnicity. In EMD, subjects must choose the most intense expression of a pair of faces with same emotion. AGD requires the participants to select which one of the two presented faces appears older, or if they are the same age.

Sensorimotor speed

The PennCNB-cv includes Mouse Practice (MP; Gur et al., 2001, 2010) and Computerized Finger Tapping Test (CTAP; Gur et al., 2001, 2010) to explore sensorimotor speed. MP requires moving the mouse and clicking on a green square that disappears after the click. In CTAP, the participant is expected to tap on the spacebar as quickly as possible for 10 s with the index finger, alternating between dominant and non-dominant hand for five trials.

2.2.2 | The Oviedo Infrequency Scale (INF-OV)

The Oviedo Infrequency Scale (INF-OV; Fonseca-Pedrero et al., 2009). INF-OV was administered to detect participants who responded in a random, pseudorandom, or dishonest manner. The INF-OV is a self-reported instrument composed of 12 items in a 5-point Likert- scale format (1 = completely disagree; 5 = completely agree) which has been developed following guidelines for test construction. Items of the INF-OV included questions like for instance: "The distance between Madrid and New York is higher than the distance between Madrid and Barcelona". Students with more than three incorrect responses on the INF-OV scale were eliminated from the sample. This measuring instrument has been administered in previous works (Fonseca-Pedrero et al., 2009, 2011).

2.3 | Procedure

The research was approved by the General Directorate of Education of the Government of La Rioja and the Ethical Committee of Clinical Research of La Rioja.

Translation of the PennCNB-cv was performed using a back-translation procedure in accordance with international guidelines for translation of psychological measures (Muñiz & Fonseca-Pedrero, 2019). A panel of experts in the subject matter translated the American English original version of the PennCNB-cv into Spanish. Subsequently, this version was translated into English by another bilingual researcher who was familiar with American culture. A third panel of researchers compared the two English versions (original and translated). Instructions and vocabulary for verbal stimuli were simplified from the adult PennCNB. The process was supported by the Brain Behavior Laboratory, Department of Psychiatry, University of Pennsylvania Perelman School of Medicine, Philadelphia, USA.

The neurocognitive battery tasks were administered collectively, in groups of 10 to 30 students, during normal school hours and in a classroom specially prepared for this purpose. Administration took place under the supervision of the researchers. The PennCNB-cv was administered by assessors trained in a standard protocol. No incentive was provided for their participation. For participants under 18, parents were asked to provide a written informed consent in order for their child to participate in the study. Participants were informed of the confidentiality of their responses and of the voluntary nature of the study.

The following platform was used: https://webcnp.med.upenn.edu/. According to previous works (Gur et al., 2012), the web-based platform for the PennCNB was developed using Perl CGI, HTML, a mySQL database and the Apache web server; tests were developed using Adobe Flash®. Scoring is fully automated.

2.4 | Data analysis

First, we calculated descriptive statistics of the PennCNB-cv tasks' scores. In order to calculate efficiency scores, raw accuracy and speed values were transformed to their standard equivalents (z-scores), based on means and standard deviations for the entire sample. The speed scores were transformed, so a higher score reflects better performance; the transformation consisted in multiplied the reaction time by −1.

Second, we examined the psychometric properties of the PennCNB-cv scores. An efficiency score is the sum of individuals standardized accuracy and speed scores. Thus, we randomly split the whole sample in order to make a cross-validation study of the internal structure. With the purpose of analyzing the internal structure of the battery, an Exploratory Factor Analysis (EFA) and a Confirmatory Factor Analysis (CFA) were performed (Ferrando et al., 2022). With the first subsample ($n = 753$) an EFA was carried out using the principal axis factoring analysis method with oblimin rotation. Sensorimotor Speed domain was measured by two tests that only provide speed measures and, therefore, were not included in the current analysis. Parallel analysis and very simple structure (Revelle & Rocklin, 1979) were computed.

CFAs were carried out in the second subsample ($n = 753$). Different dimensional models were tested. The first model considered the presence of a single general dimension. The second model proposed a two-factor structure: executive control/complex cognition and episodic memory/social cognition. The third model postulated a four-factor structure: executive control, complex cognition, episodic memory, and social cogniticion. The fourth model proposed the same four dimensions plus the addition of correlated error terms. All CFAs were performed using Maximum Likelihood estimator. The following goodness-of-fit index were used: Chi-Square test (χ^2), Tucker-Lewis Index (TLI), Comparative Fit Index (CFI), Root Mean-Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR). Hu and Bentler (1999) suggested that RMSEA should be 0.06 or less for a good model fit. CFI and TLI should be 0.95 or more (Hair et al., 2010), though any value over 0.90 tends to be considered acceptable.

The analyses were conducted with JASP, IBM SPSS Statistics for Windows, Version 27.0, and *R* (R Core Team, 2014) using the "lavaan" package (Rosseel, 2012) and "psych" package (Revelle, 2018).

3 | RESULTS

3.1 | Descriptive statistics for the PennCNB-cv

The completion of all tasks of the battery has been possible in large percentage, from 94% in PCPT to 99% in EMD. The descriptive statistics for each task are provided in Table 1. The scores in MP and

TABLE 1 Descriptive statistics for PennCNB-cv tasks.

	Accuracy (total correct)				Speed (Median RT, ms)			
Test	*n*	Mdn	*M*	SD	*n*	Mdn	*M*	SD
1. PCET	1448	2.34	2.17	0.81	1426	1582.00	1651.04	377.60
2. PCPT	1417	56	53.05	7.72	1390	459.00	464.95	45.71
3. LNB	1434	28	27.39	2.95	1436	422.00	430.97	59.73
4. PWMT	1490	37	36.45	2.83	1469	1185.50	1209.94	152.73
5. PFMT	1499	31	30.09	4.16	1465	1473.50	1517.28	276.22
6. VOLT	1488	16	15.98	2.25	1462	1365.50	1381.37	253.23
7. PVRT	1495	13	12.2	1.72	1478	5677.75	5966.94	1565.45
8. CRPM	1472	14	13.94	4.68	1475	7479.50	8940.03	5520.78
9. JOLO	1492	12	11.95	3.89	1489	7311.00	7680.64	2017.79
10. EMI	1500	36	35.24	3.05	1496	1674.25	1717.59	273.04
11. EMD	1501	27	26.22	4.12	1493	2721.00	2825.01	722.80
12. AGD	1498	26	25.13	4.06	1491	1737.50	1829.61	458.74
13. MP	--	--	--	--	1491	556.00	568.53	78.84
14. CTAP	--	--	--	--	1384	62.67	64.45	14.34

Note: *n* = sample; Mdn = median; M = mean; *SD* = standard deviation.

Abbreviations: AGD, Penn Age Differentiation Test; CRPM, Computerized Ravens Progressive Matrices; CTAP, Computerized Finger Tapping Test; EMD, Penn Emotion Differentiation Test; EMI, Penn Emotion Identification Test; JOLO, Judgment of Line Orientation; LNB, Letter N-Back; MP, Mouse Practice Task; PCET, Penn Conditional Exclusion Test; PCPT, Penn Continuous Performance Test; PFMT, Penn Face Memory Test; PVRT, Penn Verbal Reasoning Test; PWMT, Penn Word Memory Test; RT (ms), Reaction Time (milliseconds); VOLT, Visual Object Learning Test.

TABLE 2 Intercorrelation between the tasks of the PennCNB-cv.

	1	2	3	4	5	6	7	8	9	10	11	12
1. PCET		0.14**	0.21**	0.11**	0.18**	0.15**	0.24**	0.30**	0.20**	0.16**	0.14**	0.16**
2. PCPT	0.09**		0.24**	0.18**	0.10**	0.19**	0.18**	0.28**	0.21**	0.15**	0.17**	0.19**
3. LNB	0.08**	0.50**		0.23**	0.21**	0.27**	0.31**	0.36**	0.24**	0.19**	0.21**	0.19**
4. PWMT	0.19**	0.23**	0.21**		0.32**	0.23**	0.24**	0.28**	0.24**	0.22**	0.18**	0.21**
5. PFMT	0.19**	0.10**	0.05	0.43**		0.29**	0.29**	0.31**	0.24**	0.29**	0.26**	0.23**
6. VOLT	0.11**	0.08**	0.01	0.41**	0.49**		0.20**	0.32**	0.24**	0.18**	0.16**	0.17**
7. PVRT	0.16**	0.15**	0.06*	0.23**	0.22**	0.19**		0.49**	0.35**	0.26**	0.30**	0.29**
8. CRPM	0.05*	−0.08**	−0.14**	0.04	0.24**	0.32**	0.21**		0.43**	0.25**	0.31**	0.29**
9. JOLO	0.22**	0.07*	0.02	0.22**	0.28**	0.32**	0.26**	0.33**		0.18**	0.27**	0.27**
10. EMI	0.16**	0.22**	0.11**	0.38**	0.37**	0.26**	0.32**	0.16**	0.22**		0.26**	0.20**
11. EMD	0.19**	0.09**	0.02	0.25**	0.38**	0.29**	0.38**	0.23**	0.33**	0.39**		0.50**
12. AGD	0.19**	0.08**	−0.01	0.27**	0.41**	0.39**	0.28**	0.34**	0.35**	0.36**	0.41**	
13. MP	0.17**	0.24**	0.20**	0.42**	0.15**	0.16**	0.12**	−0.10**	0.12**	0.23**	0.10**	0.09**
14. CTAP	−0.03	−0.13**	−0.08**	−0.10**	−0.06*	−0.04	−0.04	0.05	−0.06*	−0.09**	−0.06*	−0.04

Note: The upper diagonal shows correlations with accuracy (hence non available for MP and CTAP), and the lower diagonal shows correlations for Speed.

Abbreviations: AGD, Penn Age Differentiation Test; CRPM, Computerized Ravens Progressive Matrices; CTAP, Computerized Finger Tapping Test; EMD, Penn Emotion Differentiation Test; EMI, Penn Emotion Identification Test; JOLO, Judgment of Line Orientation; LNB, Letter N-Back; MP, Mouse Practice Task; PCET, Penn Conditional Exclusion Test; PCPT, Penn Continuous Performance Test; PFMT, Penn Face Memory Test; PVRT, Penn Verbal Reasoning Test; PWMT, Penn Word Memory Test; VOLT, Visual Object Learning Test.

$^{*}p < 0.05$, $^{**}p < 0.01$.

CTAP are not presented in accuracy because they are a pure reaction time measure with not possible errors.

Table 2 presents the intercorrelations among the PennCNB-cv tasks. There is a high correlation between PennCNB-cv scores both on accuracy (upper triangle) and speed (lower triangle).

3.2 | Evidence of internal structure of the PennCNB-cv: Explorory factor analysis

Using the first subsample (n = 753), an EFA for the PennCNB-cv efficiency scores was performed. Bartlet's test was statistically significant ($p < 0.05$), and Kaiser-Meyer-Olkin (KMO) was 0.79. To determinate the numbers of factors, several parallel analyses and very simple structure were conducted. According to the results found, the four factor solution was retained as the most satisfactory. These four factors explained the 34.6% of the total variance.

Then, we studied if the different tasks belonged to the original proposed dimensions Table 3 shows the factor loadings for this four-dimensional model: Complex Cognition composed of PCET, PVRT, CRPM, and JOLO; Executive Control composed of PCPT and LNB; Episodic Memory composed of PWMT, PFMT, and VOLT; and Social Cognition composed of EMI, EMD, and AGD.

TABLE 3 EFA factor loadings for PennCNB-cv efficiency scores.

	F I	F II	F III	F IV
1. PCET			0.31	
2. PCPT		0.62		
3. LNB		0.59		
4. PWMT	0.52			
5. PFMT	0.68			
6. VOLT	0.36			
7. PVRT			0.35	
8. CRPM			0.70	
9. JOLO			0.36	
10. EMI				0.32
11. EMD				0.76
12. AGD				0.39
Eigenvalues	3.15	1.26	1.15	1.01
Proportion explained	0.21	0.05	0.05	0.04

Note: The upper diagonal shows correlations with accuracy (hence non available for MP and CTAP), and the lower diagonal shows correlations for Speed.

Abbreviations: AGD, Penn Age Differentiation Test; CRPM, Computerized Ravens Progressive Matrices; EMD, Penn Emotion Differentiation Test; EMI, Penn Emotion Identification Test; JOLO, Judgment of Line Orientation; LNB, Letter N-Back; PCET, Penn Conditional Exclusion Test; PCPT, Penn Continuous Performance Test; PFMT, Penn Face Memory Test; PVRT, Penn Verbal Reasoning Test; PWMT, Penn Word Memory Test; VOLT, Visual Object Learning Test.

3.3 | Evidence of internal structure of the PennCNB-cv: Confirmatory factor anlaysis

With the second subsample we analyzed four different models by means of CFA. Table 4 shows the goodness-of-fit indices for the theoretical models tested. As can be seen, the model that presented the best goodness-of-fit indeces was the four-factor. The fit of this four-factor solution was acceptable by conventional standards for RMSEA and SRMR indices. For this model, substantial modification indices were found. Thus, error correlations between tasks (PCET-PCPT, PCP-TLNB, and LNB-PWMT) were allowed. The inclusion of these correlated errors produced a significant increase in the fit of the four-factor model (χ^2 = 131.00, df = 45, CFI = 0.94, TLI = 0.91, RMSEA = 0.050, CI 90% RMSEA = 0.04–0.06, SRMR = 0.039). The resulting standardized factor loadings are shown in Table 5. All standardized factor loadings estimated were statistically significant ($p < 0.01$). The inter-factor correlations were moderate (from 0.41 to 0.73).

TABLE 4 Goodness-of-fit indices of the factorial models tested.

Model	χ^2 (df)	CFI	TLI	RMSEA (CI 90%)	SRMR
One factor	326.04 (54)	0.81	0.76	0.08 (0.07–0.09)	0.06
Two factors	260.80 (53)	0.85	0.82	0.07 (0.06–0.08)	0.05
Four factors	199.49 (48)	0.89	0.85	0.06 (0.05–0.07)	0.04

4 | DISCUSSION

The main purpose of the present study was to validate the PennCNB-cv in a community-derived sample of Spanish adolescents. The present psychometric study supports the Spanish version of the PennCNB-cv as a feasible, useful, and brief neurocognitive battery to assess neurocognitive domains in samples of adolescents of the general population.

First, the descriptive statistics and Pearson's correlation matrix were adequate and congruent with previous studies (Swagerman et al., 2016). For instance, Moore et al. (2015) found the same results about the dimensional structure in a sample of 9138 participants.

Second, EFA and CFA studies revealed a four-dimensional structure as the most satisfactory. The EFA almost reproduced the theoretical PennCNB-cv structure. It is worth noting that the results of our EFA indicated that PCET had a higher load in Complex Cognition than in Executive Control. There seems to be a fine line

TABLE 5 Standardized factor loadings for the four-factor solution (with correlated errors).

	Executive control	Episodic memory	Complex cognition	Social cognition
1. PCET	0.50			
2. PCPT	0.69			
3. LNB	0.54			
4. PWMT		0.52		
5. PFMT		0.52		
6. VOLT		0.63		
7. PVRT			0.54	
8. CRPM			0.62	
9. JOLO			0.57	
10. EMI				0.40
11. EMD				0.37
12. AGD				0.59

Abbreviations: AGD, Penn Age Differentiation Test; CRPM, Computerized Ravens Progressive Matrices; EMD, Penn Emotion Differentiation Test; EMI, Penn Emotion Identification Test; JOLO, Judgment of Line Orientation; LNB, Letter N-Back; PCET, Penn Conditional Exclusion Test; PCPT, Penn Continuous Performance Test; PFMT, Penn Face Memory Test; PVRT, Penn Verbal Reasoning Test; PWMT, Penn Word Memory Test; VOLT, Visual Object Learning Test.

$p < 0.01$.

between "control" and "reasoning". Moore et al. (2015) used "poor interpretability" related to the PCET behavior in their study.

The CFA confirmed the EFA results . Worth mentioning, some of the goodnes-of-fit indices of the four-factor model were adequate (RMSEA and SRMR); however, the CFI and TLI were below the recommended cut-off points. Therefore, error correlations between several tasks that measured the same cognitive processes were allowed. The inclusion of these correlated errors produced an increase in the fit of the four-factor model. It should be noted the coherence between the two subsamples of our data between themselves and other studies with the same battery (Gur et al., 2010; Moore et al., 2015). For instance, Moore et al. (2015) found that a four-factor model (correlated factors model) showed acceptable fit by conventional standards. Additionally, and as found in the present study, all factor loadings were moderate or strong and in the hypothesized direction. However, they found a high correlation (0.94) between Executive Functioning and Complex Cognition. In this study, correlations between latent factors ranged from 0.41 to 0.73. Thus, it could be concluded that the underlying dimensional structure of the PennCNB-cv is better represented by a correlated four-factor model. These findings provide compelling evidence in favor of the a priori theory that underpinned the creation of the CNB.

One of the most interesting advances is the efficiency measure of the PennCNB-cv. Previous neuropsychological batteries do not permit differentiating reaction time and accuracy measures. The PennCNB-cv allows to research in accuracy and reaction time (speed), and then in efficiency, as a result of the combination of accuracy and speed. This, permit exploring how speed and accuracy interact and how some traits (like impulsiveness) modify them and in which particular way. Some of these new markers (Roalf et al., 2014) could be endophenotypes and contribute to this strategy. These issues and others similar must be addressed in future investigations.

This adaptation of the PennCNB-cv allows its use in Spanish-speaking countries. The PennCNB-cv is a brief battery with adequate evidences of internal consistency of the scores that, in addition, does not present data-handling errors. Aside clinical benefits, the translation and adaptation of the PennCNB-cv allow to compare neurocognitive domains between cultures and populations. Furthermore, thanks to the computerized evaluation, it was feasible the evaluation of a large sample of healthy participants. The pencil and paper approach might need a huge effort of human and money resources. (e.g., scoring, interpretation).

It is worth mentioning that the study presents some limitations. First, no external informants, interviews or even bio-behavioral and/or biological markers were used. Second, no information was gathered regarding the participants' psychiatric morbidity, an aspect that may partially influence the results found. Third, we used a random sample of adolescents from a single region of Spain (La Rioja), so we must be cautious with the generalization of data to other populations of interest. Finally, the cross-sectional nature of this study prevents establishing cause-effect relations.

The influence of gender or/and age on the performance of PennCNB-cv has to be studied in future research. It is necessary to determine how these sociodemographic variables interact with the PennCNB-cv scores in other countries and samples (Gur & Gur, 2016; Roalf et al., 2014; Swagerman et al., 2016). In addition, future research could analyze the PennCNB-cv scores with other psychometric models (e.g., Items Response Theory or network model) as well as analyzing the links with protective and risk factors (e.g., bullying, suicidal behaviors) (Fonseca-Pedrero et al., 2024). Finally, another line of research is the application of the technology to neuropsychology through smartphones or tablets in the real life (e.g., ambulatory assessment; Elosua et al., 2023; Trull & Ebner-Priemer, 2013). In this sense, automatic evaluations allow generating an electronic data repository that can be shared, internationally even, making it possible to study multicultural samples (Docherty et al., 2018).

AUTHOR CONTRIBUTIONS

Xacobe Fernández-García: Conceptualization, writing – original draft. **Félix Inchausti**: Writing – original draft, supervision. **Alicia Pérez-Albéniz**: Project administration, investigation, supervision, validation. **Javier Ortuño-Sierra**: Methodology, writing – review & editing. **Raquel Falcó**: Methodology, writing – review & editing. **Eduardo Fonseca-Pedrero**: Investigation, funding acquisition, conceptualization, supervision, validation.

ACKNOWLEDGMENTS

This research was co-funded by the Ministry of Science and Innovation of the Government of Spain, the State Research Agency, and the European Regional Development Fund (Project "PID2021-127301OB-I00" funded by MCIN/AEI/10.13039/501100011033 FEDER, EU).

CONFLICT OF INTEREST STATEMENT

The authors report there are no competing interests to declare.

DATA AVAILABILITY STATEMENT

Data are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The procedures used in this study adhere to the tenets of the Declaration of Helsinki. Prior approval was obtained from the General Directorate of Education of the Government of La Rioja and the Ethical Committee of Clinical Research of La Rioja (CEICLAR). Written informed consent was compiled from all parents or legal guardians.

ORCID

Xacobe Fernández-García https://orcid.org/0000-0002-6145-5864
Félix Inchausti https://orcid.org/0000-0003-0610-8170
Alicia Pérez-Albéniz https://orcid.org/0000-0002-7182-060X
Javier Ortuño-Sierra https://orcid.org/0000-0003-4867-0946
Raquel Falcó https://orcid.org/0000-0003-1426-5934
Eduardo Fonseca-Pedrero https://orcid.org/0000-0001-7453-5225

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How to cite this article: Fernández-García, X., Inchausti, F., Pérez-Albéniz, A., Ortuño-Sierra, J., Falcó, R., & Fonseca-Pedrero, E. (2024). Neurocognitive functioning during adolescence: Spanish validation of the Penn Computerized Neurocognitive Battery. *International Journal of Methods in Psychiatric Research*, e2035. https://doi.org/10.1002/mpr.2035