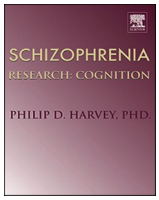
Schizophrenia Research: Cognition 37 (2024) 100310

Contents lists available at ScienceDirect

Schizophrenia Research: Cognition

journal homepage: www.elsevier.com/locate/scog



Research Paper

PsyCog: A computerised mini battery for assessing cognition in psychosis

George Gifford [a,*], Alexis E. Cullen [b,c], Sandra Vieira [d], Anja Searle [e], Robert A. McCutcheon [a,f], Gemma Modinos [g], William S. Stone [h], Emily Hird [i], Jennifer Barnett [e,j], Hendrika H. van Hell [k], Ana Catalan [l], Edward Millgate [e], Nick Taptiklis [e], Francesca Cormack [e], Margot E. Slot [k], Paola Dazzan [g], Arija Maat [k], Lieuwe de Haan [m], Benedicto Crespo Facorro [n,o], Birte Glenthøj [p,q], Stephen M. Lawrie [r], Colm McDonald [s], Oliver Gruber [t], Thérèse van Amelsvoort [u], Celso Arango [v], Tilo Kircher [w], Barnaby Nelson [x,y], Silvana Galderisi [z], Rodrigo A. Bressan [aa], Jun Soo Kwon [ab], Mark Weiser [ac], Romina Mizrahi [ad], Gabriele Sachs [ae], Matthias Kirschner [af,ag], Abraham Reichenberg [ah], PSYSCAN Consortium, René Kahn [k,ah], Philip McGuire [a]

[a] University of Oxford, Oxford, UK
[b] Department of Psychosis Studies, Institute of Psychiatry, Psychology and Neuroscience, KCL, London, UK
[c] Division of Insurance Medicine, Department of Clinical Neuroscience, Karolinska Institutet, Sweden
[d] Lausanne University Hospital and University of Lausanne, Lausanne, Switzerland
[e] Cambridge Cognition Ltd, Cambridge, UK
[f] Oxford Health NHS Foundation Trust, Oxford, UK
[g] Department of Psychological Medicine, Institute of Psychiatry, Psychology and Neuroscience, KCL, London, UK
[h] Harvard Medical School Department of Psychiatry at the Beth Israel Deaconess Medical Center and the Massachusetts Mental Health Center, United States of America
[i] Institute of Cognitive Neuroscience, UCL, London, UK
[j] Department of Psychiatry, University of Cambridge, Cambridge, UK
[k] University Medical Center, Division of Neurosciences, Department of Psychiatry, Heidelberglaan 100, 3584 CX Utrecht, the Netherlands
[l] Basurto University Hospital, Bilbo, Bizkaia, Spain
[m] Amsterdam UMC, University of Amsterdam, Psychiatry, Department Early Psychosis, Meibergdreef 9, Amsterdam, the Netherlands
[n] CIBERSAM, Centro Investigación Biomédica en Red Salud Mental, Sevilla, Spain
[o] University Hospital Virgen del Rocio, IBIS-CSIC, Department of Psychiatry, School of Medicine, University of Sevilla, Sevilla, Spain
[p] Centre for Neuropsychiatric Schizophrenia Research (CNSR), Centre for Clinical Intervention and Neuropsychiatric Schizophrenia Research (CINS), Mental Health Centre Glostrup, University of Copenhagen, Glostrup, Denmark
[q] University of Copenhagen, Faculty of Health and Medical Sciences, Dept. of Clinical Medicine, Copenhagen, Denmark
[r] Division of Psychiatry, University of Edinburgh, Royal Edinburgh Hospital, Edinburgh, UK
[s] Centre for Neuroimaging & Cognitive Genomics (NICOG), Galway Neuroscience Centre, University of Galway, H91 TK33 Galway, Ireland
[t] Section for Experimental Psychopathology and Neuroimaging, Department of General Psychiatry, Heidelberg University, Heidelberg, Germany
[u] Department of Psychiatry and Neuropsychology, Maastricht University, Maastricht, the Netherlands
[v] Servicio de Psiquiatría del Niño y del Adolescente, Hospital General Universitario Gregorio Marañon, Universidad Complutense Madrid, Spain, Centro de Investigación Biomédica en Red de Salud Mental, Madrid, Spain
[w] Dept of Psychiatry, University of Marburg, Rudolf-Bultmann-Straße 8, D-35039 Marburg, Germany
[x] Orygen, 35 Poplar Road, Parkville, Victoria, Melbourne, Australia
[y] Centre for Youth Mental Health, The University of Melbourne, Parkville, Victoria, Australia
[z] Department of Mental and Physical Health and Preventive Medicine, University of Campania Luigi Vanvitelli, Largo Madonna delle Grazie, 80138 Naples, Italy
[aa] Department of Psychiatry, Interdisciplinary Lab for Clinical Neurosciences (LiNC), Universidade Federal de Sao Paulo (UNIFESP), Sao Paulo, Brazil
[ab] Department of Psychiatry, Seoul National University College of Medicine, 101 Dahakno, Jongno-gu, Seoul, Republic of Korea
[ac] Department of Psychiatry, Sheba Medical Center, Tel Hashomer 52621, Sackler School of Medicine, Tel Aviv University, Tel Aviv, Israel
[ad] Department of Psychiatry, McGill University, Montreal, Canada
[ae] Department of Psychiatry and Psychotherapy, Medical University of Vienna, Währinger Gürtel 18-20, 1090 Vienna, Austria
[af] Department of Psychiatry, Psychotherapy and Psychosomatics, Psychiatric Hospital, University of Zurich, Switzerland
[ag] Division of Adult Psychiatry, Department of Psychiatry, University Hospitals of Geneva, Switzerland
[ah] Department of Psychiatry, Icahn School of Medicine at Mount Sinai, One Gustave L. Levy Place, Box 1230, New York, NY 10029-6574, United States of America

* Corresponding author at: University of Oxford, Department of Psychiatry, The Prince of Wales International Centre for SANE Research, Warneford Ln, Headington, Oxford OX3 7JX, UK.
E-mail address: George.gifford@psych.ox.ac.uk (G. Gifford).

https://doi.org/10.1016/j.scog.2024.100310
Received 15 February 2024; Received in revised form 20 March 2024; Accepted 23 March 2024
Available online 28 March 2024

ARTICLE INFO

Keywords:
Psychosis
Cognition
First episode psychosis
Clinical high risk for psychosis

ABSTRACT

Despite the functional impact of cognitive deficit in people with psychosis, objective cognitive assessment is not typically part of routine clinical care. This is partly due to the length of traditional assessments and the need for a highly trained administrator. Brief, automated computerised assessments could help to address this issue. We present data from an evaluation of PsyCog, a computerised, non-verbal, mini battery of cognitive tests. Healthy Control (HC) (N = 135), Clinical High Risk (CHR) (N = 233), and First Episode Psychosis (FEP) (N = 301) participants from a multi-centre prospective study were assessed at baseline, 6 months, and 12 months. PsyCog was used to assess cognitive performance at baseline and at up to two follow-up timepoints. Mean total testing time was 35.95 min (SD = 2.87). Relative to HCs, effect sizes of performance impairments were medium to large in FEP patients (composite score G = 1.21, subtest range = 0.52–0.88) and small to medium in CHR patients (composite score G = 0.59, subtest range = 0.18–0.49). Site effects were minimal, and test-retest reliability of the PsyCog composite was good (ICC = 0.82–0.89), though some practice effects and differences in data completion between groups were found. The present implementation of PsyCog shows it to be a useful tool for assessing cognitive function in people with psychosis. Computerised cognitive assessments have the potential to facilitate the evaluation of cognition in psychosis in both research and in clinical care, though caution should still be taken in terms of implementation and study design.

1. Introduction

Cognitive dysfunction is a core component of psychosis (Bora et al., 2010; Bora and Murray, 2014; Catalan et al., 2021; Fusar-Poli et al., 2012; Heinrichs and Zakzanis, 1998) and predicts impairments in social and occupational functioning (Green, 1996; Bowie and Harvey, 2006; Fett et al., 2011; Cowman et al., 2021). This has led to an increased interest in the development of interventions to improve cognition for patients with psychosis (Cella et al., 2020; Marder, 2006; McGrath and Hayes, 2000; McCutcheon et al., 2023).

However, cognitive performance is not routinely evaluated as part of clinical care (McCutcheon et al., 2023). This is partly be due to the length of traditional cognitive assessments, which involve comprehensive batteries of tests that can take >1 h to administer (Vita et al., 2022). Patients with psychosis often find these assessments demanding and their administration may require an assessor that has been trained in their use. In addition, for people with psychosis, the completion of formal cognitive tasks may be made particularly challenging by the presence of symptoms such as reduced motivation and impaired concentration and attention, difficulties with understanding or remembering test instructions, or the sedative effects of medications (Barnett et al., 2010). In the context of multicentre studies, further requirements include tests that are non-language dependent and robust against site effects.

We describe initial findings from a computerised mini battery: PsyCog, which was administered in the PSYSCAN study: a multisite longitudinal study of first episode psychosis (FEP) patients and individuals at clinical high-risk (CHR) for psychosis (Tognin et al., 2020). PsyCog contains five non-language dependent tasks from the Cambridge Neuropsychological Test Automated Battery (CANTAB), chosen to capture the range of cognitive deficits typically seen in psychosis.

This study reports the reliability, validity, and practical utility of PsyCog by examining completion rates at baseline, 6 months, and 12 months; the distribution of tests scores (including floor / ceiling effects); effect sizes of impairment in patients, practice effects, site effects, and test-retest reliability.

2. Methods

2.1. PsyCog mini battery

PsyCog comprises four tests that were chosen from the larger CANTAB battery to assess the key cognitive deficits associated with psychosis, including learning and memory, emotion recognition, working memory, and attention (see Sections 2.1.1–2.1.4 and Table 1). Testing involves the participant following auditory and visual cues presented via an inexpensive tablet computer, and administration does not require specialised training. Scoring is automated, including

Table 1
PsyCog Battery subtest descriptions, describing cognitive domains, key measures in each subtest, direction of scores (sense), and range.

Task	Cognitive domain	Administration time	Key Measures	Acronym	Description	Sense	Range
Emotion Recognition Task	Emotion recognition / social cognition	6–10 min	ERT Overall Median Reaction Time (ms)	ERTOMDRT	Median latency for selection of an emotion word after stimulus presentation.	Lower is better	100 - ∞
			ERT Total Hits	ERTTH	Total number of correct responses (selection of correct emotion).	Higher is better	0–48
Paired Associated Learning	Associative learning, visual memory	8 min	PAL Total Errors Adjusted	PALTEA	Total incorrect responses adjusted for the estimated number of errors made on trials the participant did not reach.	Lower is better	0–70
			PAL First Attempt Memory Score	PALFAMS	The number of times the correct response was given on the first attempt.	Higher is better	0–20
Rapid Visual Information Processing	Sustained attention	7 min	RVP A'	RVPA	Participant sensitivity to the target sequence (sequence of three numbers), regardless of response tendency.	Higher is better	0–1
			RVP Median Response Latency (ms)	RVPMDL	Median response latency on trials where the correct response was given.	Lower is better	100–1900
Spatial Span (forward / reverse)	Visuospatial working memory	5 min	SSP Forward Span Length	SSPFSL	The longest sequence of boxes correctly recalled (forward variant).	Higher is better	3–9
			SSP Reverse Span Length	SSPRSL	The longest sequence of boxes correctly recalled in reverse.	Higher is better	3–9

calculation of summary measures from raw scores. Data hosting was implemented by Cambridge Cognition Ltd. (https://www.cambridgecognition.com/) and IXICO PLC (https://ixico.com/).

2.1.1. Task 1: emotion recognition task (ERT)

The ERT measures the recognition of emotion from facial expressions. Participants are shown a series of images of faces, each morphed to show one of six basic emotions (sadness, happiness, fear, anger, disgust, or surprise). Each face is shown for 200 ms, followed by a choice of 6 emotions, which the participant must identify as the correct emotion. Results can be summarised across the whole task or can be given for specific emotions.

2.1.2. Task 2: paired associated learning (PAL)

The PAL measures paired associated learning and visual episodic memory. Participants are presented with patterns within boxes, opened in a pseudo-randomised order by the software. One pattern is then displayed in the centre of the screen and the participants are asked to identify and touch the box where the pattern was shown. Participants are reshown the patterns if they choose incorrectly. Difficulty increases throughout the test, with the number of patterns increasing from one to eight.

2.1.3. Task 3 + 4: Spatial span (forward / reverse) (SSPF/R)

The SSP F/R measures visuospatial working memory capacity. Participants are shown white squares, which change colour in a variable sequence. The participant must then touch the boxes in the same sequence that they changed colour (forward mode) or in the reverse order (reverse mode). The difficulty of the task increases with the number of boxes (sequence lengths of 2–9). Sequence and box colour are changed throughout the task.

2.1.4. Task 5: rapid visual information processing (RVP)

The RVP test measures sustained attention. Participants are presented with a pseudo-random sequence of digits from 2 to 9, shown one at a time, at a rate of 100 digits per minute. Participants are asked to respond using a press pad when they detect target sequences of digits (3 digits long).

2.2. Procedures

Cognitive assessments using PsyCog were performed at baseline, 6 months, and 12 months. Full visit timepoints and procedures are summarised in the Supplementary Materials Tables S2.1–3. Follow-up visits with missing PsyCog assessments performed during the worldwide SARS-CoV-2 pandemic were excluded from analysis, as some sites were unable to administer PsyCog in this period depending on local restrictions (N removed: HC = 10, CHR = 40, FEP = 15). Detailed descriptions of inclusion /exclusion criteria, statistical analysis, global composite calculation, and data cleaning are given in the Supplementary Materials Section 1.

Participants (or caregivers for those <18 years of age) gave written informed consent. Ethical approval was given by local research ethics committees. *The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.*

3. Results

3.1. Sample characteristics

669 subjects were included in the study (HC = 135, CHR = 233, FEP = 301). Subjects were recruited from 19 sites (7 HC / 9 UHR / 16 FEP). Demographics and group differences are shown in Table 2. Proportions of gender ($X^2 = 11.03, p < 0.004$) were significantly different across the three cohorts; however, post-hoc chi-squared test suggested proportions of gender to be significantly different between the FEP and CHR ($X^2 = 10.35, p = 0.001$) but not FEP and HC ($X^2 = 2.18, p = 0.140$) or CHR and HC ($X^2 = 1.10, p = 0.293$), so gender was not a confounder for patient vs control group differences.

Table 2
Demographic and clinical variables for Healthy Control (HC), Clinical High Risk (CHR), and First Episode Psychosis (FEP) participants included in the PSYSCAN study.

	HC	CHR	FEP	T / F / X2	*P* value
N	135	233	301		
Age (SD)	23.6 (4.03)	22.54 (4.59)	25.28 (5.6)	20.27	< 0.001
Male (%) / Female (%) / Non-binary (%)*	80 (59.26) / 55 (40.74)	123 (52.79) / 109 (46.78)	202 (67.11) / 99 (32.89)	11.03	0.004
Years of education (SD)	16.01 (3.0)	14.21 (3.24)	14.2 (3.07)	17.75	< 0.001
IQ (SD)	112.15 (16.01)	104.6 (17.56)	90.7 (18.52)	77.16	< 0.001
PANSS Positive	6.73 (1.62)	–	12.91 (5.7)	11.98	< 0.001
PANSS Negative	6.9 (1.78)	–	14.16 (6.41)	12.57	< 0.001
CAARMS Positive	1.74 (2.97)	43.12 (19.46)	–	13.86	< 0.001
CAARMS Negative	9.58 (18.39)	62.44 (37.75)	–	13.13	< 0.001

T = *t*-test, F = ANOVA, X2 = chi-squared test.
* The non-binary gender category was not included in chi-squared tests of group difference due to low cell count.

Mean age was significantly different across the three cohorts (F (DF) = 20.27 (2) = $p < 0.001$). Tukey HSD tests showed differences in age to be significant between CHR vs FEP (p = 0.001, 95 % CI = 1.71, 3.77) and HC vs FEP ($p = 0.004$, 95 % CI = 0.46, 2.89). Years of education was significantly different across cohorts (F (DF) = 17.75 (2), $p < 0.001$), which was driven by differences between HC vs CHR (p = 0.001, 95 % CI = 1.00, 2.60) and HC vs FEP differences (p = 0.001, 95 % CI = 1.04, 2.57). Group comparisons were repeated using normative scores made in reference to age, gender, and years of education matched HCs, which removed potential confounding effects of age and educational level. Level of estimated IQ was significantly different across cohorts, following the pattern of disease severity (FEP < CHR < HC) (F (DF) = 77.16 (2), $p < 0.001$) (see Table 2).

3.2. Adherence

Seven PsyCog assessments were removed as they ran for longer than 45 min ($N = 7$; HC = 1, CHR = 4, FEP = 2), which indicated non-adherence to the battery. In the remaining participants the mean total test time was 35.95 (SD = 2.87, range = 25.12, 44.75). The numbers of tests removed on the basis of researcher observations are shown in Fig. S3. Two RVP tests were removed as 0 attempts were made on the RVP (N CHR = 1, FEP = 1). All subjects reached at least 2 patterns in the PAL and made >0 attempts in the ERT and SSPF/R tasks.

3.3. Completion rates

Completion rates are shown in Table 3. The PsyCog was judged to be complete if 4/5 tests were completed, allowing for computation of the global composite score. Completion rates were as follows: HC = 96.30 %, 91.75 %, 94.44 %, CHR = 84.12 %, 85.09 %, 88.70 %, FEP = 89.04 %, 87.16 %, 89.57 % (at baseline, 6 months, 12 months). Rates of completion of the entire battery (5/5 tests complete) were as follows:

Table 3
The number and proportion of PsyCog subtests completed at each timepoint for Healthy Control (HC), Clinical High Risk (CHR), and FEP (First Episode Psychosis) subjects, for subjects who attended each visit and for subjects who were administered the battery. The global composite score was calculated if 4/5 tests were complete. Global composite score if PsyCog initiated and PsyCog complete if initiated include only those who were administered the PsyCog.

	Healthy Control			Clinical High Risk			First Episode Psychosis		
	Baseline	Month 6	Month 12	Baseline	Month 6	Month 12	Baseline	Month 6	Month 12
N	135	97	90	233	161	115	301	218	211
PsyCog administered (%)	130 (96.30)	89 (91.75)	85 (94.44)	200 (85.84)	140 (86.96)	102 (88.70)	280 (93.02)	199 (91.28)	192 (91.00)
ERT complete (%)	130 (96.30)	89 (91.75)	85 (94.44)	200 (85.84)	139 (86.34)	101 (87.83)	277 (92.03)	196 (89.91)	191 (90.52)
PAL complete (%)	130 (96.30)	89 (91.75)	85 (94.44)	196 (84.12)	140 (86.96)	101 (87.83)	275 (91.36)	193 (88.53)	191 (90.52)
SSPF complete (%)	129 (95.56)	89 (91.75)	85 (94.44)	195 (83.69)	138 (85.71)	102 (88.70)	274 (91.03)	192 (88.07)	187 (88.63)
SSPR complete (%)	129 (95.56)	88 (90.72)	85 (94.44)	191 (81.97)	134 (83.23)	101 (87.83)	268 (89.04)	186 (85.32)	181 (85.78)
RVP complete (%)	128 (94.81)	88 (90.72)	83 (92.22)	186 (79.83)	132 (81.99)	100 (86.96)	235 (78.07)	180 (82.57)	182 (86.26)
Global composite score (%)	130 (96.30)	89 (91.75)	85 (94.44)	196 (84.12)	137 (85.09)	102 (88.70)	268 (89.04)	190 (87.16)	189 (89.57)
Global Composite Score if PsyCog initiated (%)	130 (100.00)	89 (100.00)	85 (100.00)	196 (98.00)	137 (97.86)	102 (100.00)	268 (95.71)	190 (95.48)	189 (98.44)

ERT = Emotional Recognition Test, PAL = Paired Associates Learning, SSPF/R = Spatial Span Forward / Reverse, RVP = Rapid Visual Processing.

HC = 94.81 %, 90.72 %, 92.22 %, CHR = 79.83 %, 81.99 %, 86.96 %, FEP = 78.07 %, 82.57 %, 86.26 % (baseline, 6 months, 12 months). Completion rates were higher for tests earlier in the battery with the last test, the RVP, reporting the lowest completion rates (Table 3).

3.4. Distributions of PsyCog variables

There were moderate ceiling effects for the PAL, RVP, and SSP tasks in the HC group (Fig. 1). Several tests had relatively high proportions of those with maximum scores in the HC cohort (SSP-Forward Span Length = 41.19 %, SSP-Reverse Span Length = 28.15 %) (see Table S4). Tendency towards ceiling effects inversely followed illnesses severity (FEP < CHR < HC), suggesting task difficulty to be most appropriate for measuring cognition in the patient groups.

3.5. Test-retest reliability

ICC values for composite scores and individual tests were computed only for subjects with both baseline and follow up PsyCog data (month 6 and month 12 respectively). Composite score test-retest reliability was 'good' (Koo and Li, 2016) across timepoints / cohorts (ICC = 0.82–0.89). Individual score test-retest reliability was poor to moderate (ICC = 0.36–0.77), though on average tests showed moderate reliability (mean ICC = 0.54, SD = 0.09). Full results are shown in Table S5.

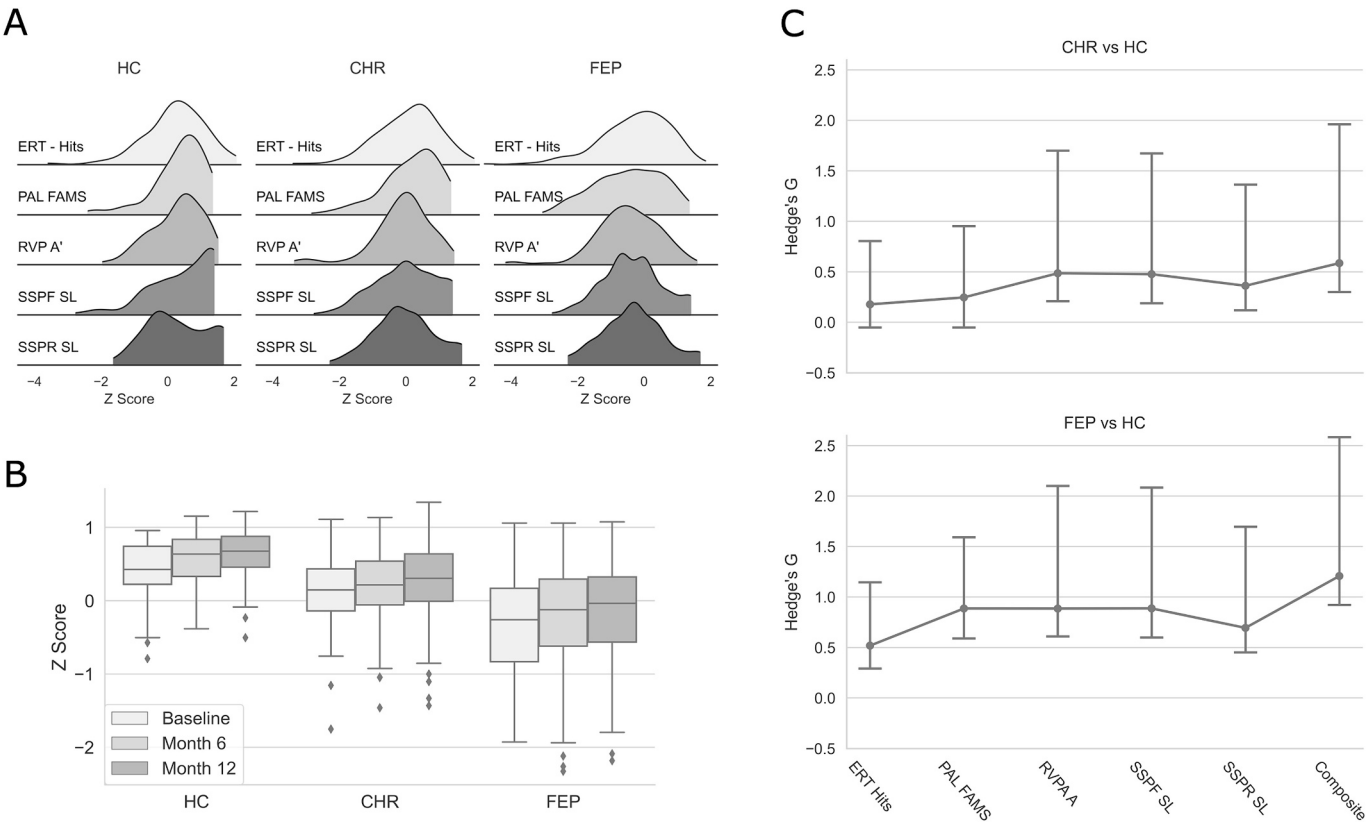


Fig. 1. A) Distribution of test scores for Healthy Control (HC), Clinical High Risk (CHR), and First Episode Psychosis (FEP) subjects across timepoints. B) Boxplots showing distributions of PsyCog composite scores for HC, CHR, and FEP groups at each timepoint. C) Hedge's G effect sizes of cognitive deficit for CHR < HC and FEP < HC for each test. Error bars show bootstrapped 95 % confidence intervals (2000 permutations). ERT - Hits = ERT Total Hits, PALFAMS = PAL First Attempt Memory Score, SSPF SL = SSP Forward Span Length, SSPR SL = SSP Reverse Span Length. *Z*-scores were computed over all cohorts / timepoints.

3.6. Patient vs control group differences

Effect sizes were computed between HC vs CHR, and HC vs FEP. Results are shown in Table 4 and Fig. 1. Effect sizes ranged from medium-to-large in HC vs FEP comparisons (composite score Hedge's g = 1.21, subtests = 0.52–0.88) and small-to-medium in HC vs CHR comparisons (composite score Hedges' g = 0.59, subtests 0.18–0.49). All group differences were statistically significant, except for the comparisons between CHR vs HC for accuracy (total hits) in the Emotion Recognition Task ($p = 0.116$).

Normative scores of performance variables (*Z*-scores in reference to external healthy populations with matched age, gender, and years of education) yielded similar results in terms of statistical significance and effect sizes of group difference (Table S6). On average, the FEP group showed lower than normal performance across all PsyCog tests (Fig. S6). Normative scores indicated better than expected performance in the HC group. The CHR group performed worse than the normative reference group on the RVP and SSP tasks but at a comparable level to normal on the ERT and PAL tasks.

3.7. Practice effects

Practice effects were explored in the subset of participants who completed all three assessment timepoints (Fig. 1; Table S7). Practice effects were below the suggested optimal level of <0.2 standard deviation units of difference (Standard Deviation Index: SDI) in the CHR and FEP groups, though in the HC group the RVPA, PAL, and SSPF were > 0.2 SDI (Barch and Carter, 2008). Typically, a greater increase in performance was seen between baseline vs month 6 visits compared to month 6 vs month 12 visits (composite score SDI baseline vs month 6 / month 6 vs month 12: HC = 0.38 / 0.24, CHR 0.16 / 0.10, FEP = 0.19 / 0.11) suggesting a stabilization of performance after the second visit (Fig. 1). Practice effects were greatest in the HC group.

3.8. Site effects

Mean test scores were compared across sites for a subset of sites with HC subjects ($N > 5$, sample described in Supplementary Materials Section 8). The only PsyCog test with significantly different mean scores across sites was the ERT (Total Hits) (F (DF) = 3.24 (7), $p = 0.003$).

4. Discussion

This study assessed the reliability, validity, and practical utility of an automated cognitive mini battery in a large sample of HC, CHR, and FEP participants. Measures of these factors were within acceptable ranges for the aims of the PSYSCAN study (Tognin et al., 2020). Patient vs HC group differences were similar in nature and magnitude to those previously reported using larger cognitive batteries, suggesting the tool to successfully measure psychosis related cognitive deficit. Moderate ceiling effects were observed only for the HC subjects, suggesting the PsyCog to be suited to patient groups but unable to capture some variability for high performing HCs. Validity, acceptability, reliability, and site effects are discussed in detail below.

4.1. Validity

Effect sizes of cognitive deficit were medium-to-large for FEP participants (composite score Hedge's g = 1.21, subtests range = 0.52, 0.89) and small-to-medium for CHR participants (composite score Hedges' g = 0.59, subtest range = 0.18, 0.49), which is similar to those reported in both FEP (Mesholam-Gately et al., 2009; Aas et al., 2014) and CHR groups (Catalan et al., 2021). Similar results have also been found when performance was assessed using the same tasks as were used in PsyCog in people with FEP (Saleem et al., 2013; Haring et al., 2015; Bakker et al., 2018), CHR (Wood et al., 2003; Glenthøj et al., 2016, 2019), and schizophrenia (for reviews see: Barnett et al., 2010; Levaux et al., 2007). Collectively, these results suggest that PsyCog generates valid cognitive data, and add to evidence of the utility of computerised tests in assessing cognition in participants with psychosis (Ritsner et al., 2006; Pietrzak et al., 2009; Benoit et al., 2015; van Erp et al., 2015).

The Internal validity of PsyCog was evidenced by group differences that were similar to those computed from normative scores (Table S5). Normative scores additionally provided a benchmark of how far participant performance deviated from that in an external healthy population (Fig. S6). For several tests (the ERT and PAL), normative scores showed better than expected performance for HC participants, and normal performance in the CHR group. Normative samples were recruited and acquired in different settings (Palan and Schitter, 2018) and used different versions of the PAL (the present study had 8 rather than 12 difficulty levels in order to better target the difficulty of the PAL to patient groups).

4.2. Acceptability

Whilst computerised testing is highly beneficial in offering a standardised test administration, adherence may be lower in comparison to researcher administered tests, where the researcher can supervise and encourage participants. In the present study, the number of tests that were removed due to distraction, poor understanding of test instructions, or refusal was highest in patients (FEP > CHR > HC). Completion rates were lowest in the RVP, which measures sustained attention. Poor sustained attention is a feature of psychosis (Chen and Faraone, 2000; Liu et al., 2002; Ojeda et al., 2002), which may suggest a bias towards non-completion in participants with psychosis. Similar to the present results, a previous study reported relatively lower completion of an attention / vigilance task in a sample of schizophrenia patients (Pietrzak et al., 2009) using the MATRICS Consensus Cognitive Battery (MCCB) (Nuechterlein et al., 2008), though other studies have reported high completion rates across MCCB tasks (Keefe et al., 2011; Georgiades et al., 2017).

Higher completion rates have been reported for other computerised cognitive batteries in psychosis samples, such as the Brief Assessment of Cognition in Schizophrenia app (Atkins et al., 2017) and CogState

Table 4
Means, SD (Standard Deviation), t-test, and Hedges G effect sizes (bootstrapped 95 % Confidence Intervals, 2000 permutations), for HC vs CHR / FEP group differences computed for baseline PsyCog assessments.

	HC mean (SD)	CHR mean (SD)	FEP mean (SD)	T-test (p val) CHR vs HC	G (B.S. 95 % CIs) CHR < HC	T-test (p val) FEP vs HC	G (B.S. 95 % CIs) FEP < HC
ERTTH	31.08 (4.48)	30.27 (4.56)	28.52 (5.12)	1.58 (0.116)	0.18 (−0.05, 0.45)	4.87 (<0.001)	0.52 (0.28, 0.78)
PALFAMS	15.61 (3.53)	14.67 (3.92)	11.8 (4.64)	2.18 (0.030)	0.25 (−0.05, 0.46)	8.28 (<0.001)	0.88 (0.59, 1.04)
RVPA	0.92 (0.05)	0.89 (0.06)	0.87 (0.06)	4.24 (<0.001)	0.49 (0.21, 0.73)	8.04 (<0.001)	0.88 (0.76, 1.20)
SSPFSL	7.71 (1.38)	7.05 (1.38)	6.53 (1.32)	4.21 (<0.001)	0.48 (0.19, 0.72)	8.26 (<0.001)	0.88 (0.57, 1.10)
SSPRSL	6.98 (1.42)	6.46 (1.42)	5.99 (1.44)	3.18 (0.002)	0.36 (0.12, 0.64)	6.41 (<0.001)	0.69 (0.39, 0.96)
Composite Score	0.34 (0.44)	0.02 (0.58)	−0.36 (0.63)	5.19 (<0.001)	0.59 (0.30, 0.79)	11.30 (<0.001)	1.21 (0.87, 1.32)

ERTTH = ERT Total Hits, PALFAMS = PAL First Attempt Memory Score, RVPA = RVPA A' (prime), SSPFSL = SSP Forward Span Length, SSPRSL = SSP Reverse Span Length. HC = Healthy Control, CHR = Clinical High Risk, FEP = First Episode Psychosis.

(Pietrzak et al., 2009), as well as for the MCCB (Keefe et al., 2011; Georgiades et al., 2017). Additionally, shorter computerised cognitive tests may be better tolerated by patients (Velligan et al., 2004; Atkins et al., 2017; Hurford et al., 2018). However, a high completion rate was achieved in a study of FEP participants who were administered a 1-h CANTAB battery that included the PAL, SSP, and RVP (Haring et al., 2015). This suggests factors other than test design may affect completion rates, for example fatigue from extensive testing, the testing environment, or selection bias. It would be beneficial to compare PsyCog with alternative cognitive batteries within psychosis samples and under identical conditions.

4.3. Reliability

We found PsyCog composite score test-retest reliability to be good (ICC range = 0.82, 0.89) and individual test reliability to be poor-moderate (ICC range = 0.36, 0.77). Previous research in a healthy sample showed a similar range of test-retest reliability for the same tasks (Karlsen et al., 2022).

Good test-retest reliability of the PsyCog composite in the current study may reflect the stability of cognitive deficit in CHR / FEP populations, which has been demonstrated in previous studies (Bora and Murray, 2014; Hedges et al., 2022). However, some evidence suggests the progression of cognitive deficit to be heterogenous in psychosis populations (Karson et al., 2016; Allott et al., 2022). Additionally, the use of cognitive remediation in psychosis patients suggests a degree of plasticity for cognitive skills (Barlati et al., 2013). The stability of cognitive deficit in psychosis therefore remains an open question.

Non-comprehension of task instructions in some participants, as well as a relatively larger practice effects between time points 1 and 2, suggests that a familiarisation session could be beneficial, as has been implemented in similar computerised batteries (Turner et al., 2003; Pietrzak et al., 2009). However, this would increase participant burden and practice effects were below the suggested threshold of 0.2 SDs of improvement in the patient groups (Barch and Carter, 2008), though some tests were > 0.2 SDs of improvement in the HC group.

4.4. Site effects

Site effects were observed only for the ERT task, which appeared to have been driven by relatively poor performance at a Korean site, which may reflect the use of Caucasian faces in this task, suggesting the ERT to be sensitive to cultural or exposure related differences in emotion recognition (Elfenbein and Ambady, 2002).

4.5. Limitations

Ideally, convergent validity would have been used to validate the cognitive tests in the present study, however careful management of visit burden precluded the use of additional cognitive tests. Those attending follow up assessments may have been more likely to complete PsyCog, which likely accounts for the slightly higher completion rates at follow up relative to baseline.

4.6. Conclusions

PsyCog is a computerised non-verbal mini battery for assessing cognition that is easy to administer. Computerised test batteries are attractive as randomisation, administration, and scoring of tasks can be delivered automatically (Barnett et al., 2010). The present study is unique in providing a detailed description of the acceptability, reliability, and validity of a computerised cognitive battery in the context of a large, longitudinal, multi-centre neuroimaging study.

Funding sources

The PSYSCAN project is funded by the European Commission within its 7th Framework Programme under grant agreement number 603196: PSYSCAN – Translating neuroimaging findings from research into clinical practice.

RAMs work is funded by a Wellcome Trust Clinical Research Career Development (224625/Z/21/Z)

CRediT authorship contribution statement

George Gifford: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alexis E. Cullen:** Writing – review & editing, Project administration, Data curation, Conceptualization. **Sandra Vieira:** Writing – review & editing, Data curation, Conceptualization. **Anja Searle:** Writing – review & editing, Software, Conceptualization. **Robert A. McCutcheon:** Writing – review & editing, Conceptualization. **Gemma Modinos:** Writing – review & editing, Project administration, Conceptualization. **William S. Stone:** Writing – review & editing, Conceptualization. **Emily Hird:** Writing – review & editing, Conceptualization. **Jennifer Barnett:** Writing – review & editing, Software, Conceptualization. **Hendrika H. van Hell:** Writing – review & editing, Project administration. **Ana Catalan:** Writing – review & editing. **Edward Millgate:** Writing – review & editing, Software. **Nick Taptiklis:** Software. **Francesca Cormack:** Software. **Margot E. Slot:** Writing – review & editing. **Paola Dazzan:** Writing – review & editing. **Arija Maat:** Writing – review & editing. **Lieuwe de Haan:** Writing – review & editing. **Benedicto Crespo Facorro:** Writing – review & editing. **Birte Glenthøj:** Writing – review & editing. **Stephen M. Lawrie:** Writing – review & editing. **Colm McDonald:** Writing – review & editing. **Oliver Gruber:** Writing – review & editing. **Thérèse van Amelsvoort:** Writing – review & editing. **Celso Arango:** Writing – review & editing. **Tilo Kircher:** Writing – review & editing. **Barnaby Nelson:** Writing – review & editing. **Silvana Galderisi:** Writing – review & editing. **Rodrigo A. Bressan:** Writing – review & editing. **Jun Soo Kwon:** Writing – review & editing. **Mark Weiser:** Writing – review & editing. **Romina Mizrahi:** Writing – review & editing. **Gabriele Sachs:** Writing – review & editing. **Matthias Kirschner:** Writing – review & editing. **Abraham Reichenberg:** Writing – review & editing, Conceptualization. **René Kahn:** Writing – review & editing, Funding acquisition, Conceptualization. **Philip McGuire:** Writing – review & editing, Funding acquisition, Conceptualization.

Declaration of competing interest

The following conflicts of interest are declared: Robert A. McCutcheon has received speaker/consultancy fees from Karuna, Janssen, Boehringer Ingelheim, and Otsuka, and co-directs a company that designs digital resources to support treatment of mental illness. Gemma Modinos has received consultancy fees from Boehringer Ingelheim for work unrelated to this study. Silvana Galderisi received advisory board/consultant fees, or honoraria/expenses from the following drug companies: Angelini, Boehringer Ingelheim, Gedeon Richter-Recordati, Innova Pharma-Recordati Group, Janssen, Lundbeck, Otsuka, Recordati Pharmaceuticals, Rovi Pharma and Sunovion Pharmaceuticals outside the submitted work.

Acknowledgements

Collaborators

Stefania Tognin[1], Paolo Fusar-Poli[1,2], Matthew Kempton[1], Kate Merritt[1], Andrea Mechelli[1], Natalia Petros[1], Mathilde Antoniades[1], Andrea De Micheli[1], Sandra Vieira[1], Tom J Spencer[1], Cristina Scarpazza[1], Inge Winter[3], Wiepke Cahn[3], Hugo Schnack[3], Dieuwke Siegmann[5], Jana Barkhof[5], Lotte Hendriks[5], Iris de Wit[5], Diana Tordesillas-

Gutierrez[6,7], Esther Setien-Suero[6,7], Rosa Ayesa-Arriola[6,7], Paula Suarez-Pinilla[6,7], MariaLuz Ramirez-Bonilla[6,7], Victor Ortiz Garcia-de la foz[6,7], Mikkel Erlang Sørensen[8], Karen Tangmose[8,9], Helle Schæbel[8], Brian Broberg[8], Egill Rostrup[8,10], Brian Hallahan[12], Dara Cannon[12], James McLoughlin[12], Martha Finnegan[12], Danny Deckers[14,15], Machteld Marcelis[14,15], Claudia Vingerhoets[14], Covadonga M. Díaz-Caneja[16], Miriam Ayora[16], Joost Janssen[16], Roberto Rodríguez-Jiménez[17], Marina Díaz-Marsá[18], Irina Falkenberg[19], Florian Bitsch[19], Philipp Berger[19], Jens Sommer[19,20], Kyeon Raab[19], Babette Jakobi[19], Barnaby Nelson[21,22], Paul Amminger[21,22], Meredith McHugh[21,22], Silvana Galderisi[23], Armida Mucci[23], Paola Bucci[23], Giuseppe Piegari[23], Daria Pietrafesa[23], Alessia Nicita[23], Sara Patriarca[23], André Zugman[24], Ary Gadelha[24], Graccielle Rodrigues da Cunha[24], Kang Ik Kevin Cho[25], Tae Young Lee[25], Minah Kim[25], Yoo Bin Kwak[25], Wu Jeong Hwang[25], Michael Kiang[27,28,29], Cory Gerritsen[28,29], Margaret Maheandiran[28], Sarah Ahmed[27,28], Ivana Prce[28], Jenny Lepock[27,28], Matthäus Willeit[30], Marzena Lenczowski[30], Ullrich Sauerzopf[30], Ana Weidenauer[30], Julia Furtner-Srajer[31], Anke Maatz[32], Achim Burrer[32], Philipp Stämpfli[32], Naemi Huber[32], Stefan Kaiser[34,35], Wolfram Kawohl[36], Michael Brammer[38], Jonathan Young[39,1], Edward Bullmore[40], and Sarah Morgan[40].

Affiliations

1. Department of Psychosis Studies, Institute of Psychiatry, Psychology & Neuroscience, King's College London, De Crespigny Park, Denmark Hill, London SE5 8AF, UK.

2. National Institute for Health Research, Maudsley Biomedical Research Centre, South London and Maudsley NHS Foundation Trust, London, UK.

3. University Medical Center, Division of Neurosciences, Department of Psychiatry, Heidelberglaan 100, 3584 CX Utrecht, The Netherlands.

4. Department of Psychiatry and Behavioral Health System, Icahn School of Medicine at Mount Sinai, One Gustave L. Levy Place, Box 1230, New York, NY 10029–6574.

5. Amsterdam UMC, University of Amsterdam, Psychiatry, Department Early Psychosis, Meibergdreef 9, Amsterdam, The Netherlands.

6. CIBERSAM, Department of Psychiatry, University Hospital Virgen del Rocío, Sevilla; Marqués de Valdecilla University Hospital, IDIVAL. School of Medicine, University of Cantabria, Santander, Spain.

7. CIBERSAM, Centro Investigación Biomédica en Red Salud Mental, Spain.

8. Centre for Neuropsychiatric Schizophrenia Research (CNSR) & Centre for Clinical Intervention and Neuropsychiatric Schizophrenia Research (CINS), Mental Health Centre Glostrup, University of Copenhagen, Glostrup, Denmark.

9. University of Copenhagen, Faculty of Health and Medical Sciences, Dept. of Clinical Medicine, Copenhagen, Denmark.

10. Functional Imaging Unit (FIUNIT), Rigshospitalet Glostrup, University of Copenhagen, Glostrup, Denmark.

11. Division of Psychiatry, University of Edinburgh, Royal Edinburgh Hospital, Edinburgh EH10 5HF, UK.

12. Centre for Neuroimaging & Cognitive Genomics (NICOG), NCBES Galway Neuroscience Centre, National University of Ireland Galway, H91 TK33 Galway, Ireland.

13. Section for Experimental Psychopathology and Neuroimaging, Department of General Psychiatry, Heidelberg University, Heidelberg, Germany.

14. Department of Psychiatry and Neuropsychology, Maastricht University, Maastricht, The Netherlands.

15. GGZE Mental Health Care, Eindhoven, the Netherlands.

16. Servicio de Psiquiatría del Niño y del Adolescente, Hospital General Universitario Gregorio Marañon, Universidad Complutense Madrid, Spain; Centro de Investigación Biomédica en Red de Salud Mental, Madrid, Spain.

17. Departmento de Psiquiatría, Instituto de Investigación Sanitaria Hospital 12 de Octubre (imas12), Madrid, Spain; CIBERSAM (Biomedical Research Networking Centre in Mental Health), Spain.

18. Hospital Clínico de San Carlos, Universidad Complutense, Centro de Investigación Biomédica en Red de Salud Mental (CIBERSAM), Madrid, España.

19. Dept of Psychiatry, University of Marburg, Rudolf-Bultmann-Straße 8, D-35039, Marburg, Germany.

20. Core-Facility Brainimaging, Faculty of Medicine, University of Marburg.

21. Orygen, The National Centre of Excellence in Youth Mental Health, 35 Poplar Road, Parkville, Victoria, Melbourne, Australia.

22. Centre for Youth Mental Health, The University of Melbourne, Melbourne, Australia.

23. Department of Psychiatry, University of Campania Luigi Vanvitelli, Largo Madonna delle Grazie, 80138, Naples, Italy.

24. Department of Psychiatry, Interdisciplinary Lab for Clinical Neurosciences (LiNC), Universidade Federal de Sao Paulo (UNIFESP), Sao Paulo, Brazil.

25. Department of Psychiatry, Seoul National University College of Medicine, 101 Dahakno, Jongno-gu, Seoul, Korea.

26. Department of Psychiatry, Sheba Medical Center, Tel Hashomer 52621, Israel; Sackler School of Medicine, Tel Aviv University, Tel Aviv, Israel.

27. Institute of Medical Science, University of Toronto, 1 King's College Circle Room 2374, Toronto, Ontario, Canada M5S 1A8.

28. Centre for Addiction and Mental Health, 250 College Street, Toronto, Ontario, Canada M5T 1R8.

29. Department of Psychiatry, University of Toronto, 250 College Street 8th Floor, Toronto, Ontario, Canada M5T 1R8.

30. Department of Psychology, University of Toronto, 100 St. George Street 4th Floor, Toronto, Ontario, Canada M5S 3G3.

31. Department of Psychiatry and Psychotherapy, 1090 Vienna, Austria.

32. Medical University of Vienna, Department of Biomedical Imaging and Image-guided Therapy Währingergürtel 18–20, 1090 Vienna.

33. Department of Psychiatry, Psychotherapy and Psychosomatics, Psychiatric Hospital, University of Zurich, Switzerland.

34. Montreal Neurological Institute, McGill University, Montreal, Quebec, Canada.

35. Clinical and Experimental Psychopathology Laboratory, Faculty of Medicine, University of Geneva, Switzerland.

36. Adult Psychiatry Division, Department of mental health and psychiatry, University Hospitals of Geneva, Switzerland.

37. Department for Psychiatry and Psychotherapy, Psychiatric Services Aargau, Brugg, Switzerland.

38. Department of Neuroimaging, Centre for Neuroimaging Sciences, Institute of Psychiatry, Psychology & Neuroscience, King's College London, De Crespigny Park, Denmark Hill, London SE5 8AF, UK.

39. IXICO plc, London, UK.

40. Department of Psychiatry, University of Cambridge, Cambridge CB2 0SZ, UK.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scog.2024.100310.

References

Aas, M., et al., 2014. A Systematic Review of Cognitive Function in First-Episode Psychosis, Including a Discussion on Childhood Trauma, Stress, and Inflammation. Front. Psychiatry 4. https://doi.org/10.3389/fpsyt.2013.00182. Available at:. (Accessed: 7 September 2022).

Allott, K., et al., 2022. Twelve-month cognitive trajectories in individuals at ultra-high risk for psychosis: a latent class analysis. Schizophrenia Bulletin Open 3 (1). https://doi.org/10.1093/schizbullopen/sgac008 p. sgac008. Available at:

Atkins, A.S., et al., 2017. Validation of the tablet-administered brief assessment of cognition (BAC app). Schizophr. Res. 181, 100–106. Available at: https://doi.org/10.1016/j.schres.2016.10.010.

Bakker, G., et al., 2018. Relationship between muscarinic M1 receptor binding and cognition in medication-free subjects with psychosis. NeuroImage: Clinical 18, 713–719. Available at: https://doi.org/10.1016/j.nicl.2018.02.030.

Barch, D.M., Carter, C.S., 2008. Measurement issues in the use of cognitive neuroscience tasks in drug development for impaired cognition in schizophrenia: a report of the second consensus building conference of the CNTRICS initiative. Schizophr. Bull. 34 (4), 613–618. Available at: https://doi.org/10.1093/schbul/sbn037.

Barlati, S., et al., 2013. Cognitive remediation in schizophrenia: current status and future perspectives. Schizophrenia Research and Treatment e156084. Available at: https://doi.org/10.1155/2013/156084.

Barnett, J.H., et al., 2010. Assessing cognitive function in clinical trials of schizophrenia. Neurosci. Biobehav. Rev. 34 (8), 1161–1177.

Benoit, A., et al., 2015. Cognitive deficits characterization using the CogState research battery in first-episode psychosis patients. Schizophrenia Research: Cognition 2 (3), 140–145. Available at: https://doi.org/10.1016/j.scog.2015.03.006.

Bora, E., Murray, R.M., 2014. Meta-analysis of cognitive deficits in ultra-high risk to psychosis and first-episode psychosis: do the cognitive deficits progress over, or after, the onset of psychosis? Schizophr. Bull. 40 (4), 744–755. Available at: https://doi.org/10.1093/schbul/sbt085.

Bora, E., Yücel, M., Pantelis, C., 2010. Cognitive impairment in schizophrenia and affective psychoses: implications for DSM-V criteria and beyond. Schizophr. Bull. 36 (1), 36–42. Available at: https://doi.org/10.1093/schbul/sbp094.

Bowie, C.R., Harvey, P.D., 2006. Cognitive deficits and functional outcome in schizophrenia. Neuropsychiatr. Dis. Treat. 2 (4), 531.

Catalan, A., et al., 2021. Neurocognitive functioning in individuals at clinical high risk for psychosis: a systematic review and meta-analysis. JAMA Psychiatry 78 (8), 859–867. Available at: https://doi.org/10.1001/jamapsychiatry.2021.1290.

Cella, M., et al., 2020. Cognitive remediation for inpatients with psychosis: a systematic review and meta-analysis. Psychol. Med. 50 (7), 1062–1076.

Chen, W.J., Faraone, S.V., 2000. Sustained attention deficits as markers of genetic susceptibility to schizophrenia. Am. J. Med. Genet. 97 (1), 52–57. Available at: doi:10.1002/(SICI)1096-8628(200021)97:1<52::AID-AJMG7>3.0.CO;2-6.

Cowman, M., et al., 2021. Cognitive predictors of social and occupational functioning in early psychosis: a systematic review and meta-analysis of cross-sectional and longitudinal data. Schizophr. Bull. 47 (5), 1243–1253. Available at: https://doi.org/10.1093/schbul/sbab033.

Elfenbein, H.A., Ambady, N., 2002. On the universality and cultural specificity of emotion recognition: a meta-analysis. Psychol. Bull. 128, 203–235. Available at: https://doi.org/10.1037/0033-2909.128.2.203.

van Erp, T.G.M., et al., 2015. Neuropsychological profile in adult schizophrenia measured with the CMINDS. Psychiatry Res. 230 (3), 826–834. Available at: https://doi.org/10.1016/j.psychres.2015.10.028.

Fett, A.-K.J., et al., 2011. The relationship between neurocognition and social cognition with functional outcomes in schizophrenia: a meta-analysis. Neurosci. Biobehav. Rev. 35 (3), 573–588. Available at: https://doi.org/10.1016/j.neubiorev.2010.07.001.

Fusar-Poli, P., et al., 2012. Cognitive functioning in prodromal psychosis. Arch. Gen. Psychiatry 69 (6), 562–571. Available at: https://doi.org/10.1001/archgenpsychiatry.2011.1592.

Georgiades, A., et al., 2017. Psychometric characteristics of the MATRICS consensus cognitive battery in a large pooled cohort of stable schizophrenia patients. Schizophr. Res. 190, 172–179. Available at: https://doi.org/10.1016/j.schres.2017.03.040.

Glenthøj, L.B., et al., 2016. Social cognition in patients at ultra-high risk for psychosis: what is the relation to social skills and functioning? Schizophrenia Research: Cognition 5, 21–27.

Glenthøj, L.B., et al., 2019. Emotion recognition latency, but not accuracy, relates to real life functioning in individuals at ultra-high risk for psychosis. Schizophr. Res. 210, 197–202.

Green, M.F., 1996. What are the functional consequences of neurocognitive deficits in schizophrenia? Am. J. Psychiatry 153 (3), 321–330. Available at: https://doi.org/10.1176/ajp.153.3.321.

Haring, L., et al., 2015. Factorial validity, measurement equivalence and cognitive performance of the Cambridge Neuropsychological Test Automated Battery (CANTAB) between patients with first-episode psychosis and healthy volunteers. Psychol. Med. 45 (9), 1919–1929. Available at: https://doi.org/10.1017/S0033291714003018.

Hedges, E.P., et al., 2022. Meta-analysis of longitudinal neurocognitive performance in people at clinical high-risk for psychosis. Psychol. Med. 52 (11), 2009–2016. Available at: https://doi.org/10.1017/S0033291722001830.

Heinrichs, R.W., Zakzanis, K.K., 1998. Neurocognitive deficit in schizophrenia: a quantitative review of the evidence. Neuropsychology 12 (3), 426–445. Available at: https://doi.org/10.1037/0894-4105.12.3.426.

Hurford, I.M., et al., 2018. A 10-minute measure of global cognition: validation of the brief cognitive assessment tool for schizophrenia (B-CATS). Schizophr. Res. 195, 327–333. Available at: https://doi.org/10.1016/j.schres.2017.08.033.

Karlsen, R.H., et al., 2022. Examining 3-month test-retest reliability and reliable change using the Cambridge neuropsychological test automated battery. Appl. Neuropsychol. Adult 29 (2), 146–154. Available at: https://doi.org/10.1080/23279095.2020.1722126.

Karson, C., et al., 2016. Long-term outcomes of antipsychotic treatment in patients with first-episode schizophrenia: a systematic review. Neuropsychiatr. Dis. Treat. 12, 57–67. Available at: https://doi.org/10.2147/NDT.S96392.

Keefe, R.S.E., et al., 2011. Characteristics of the MATRICS consensus cognitive battery in a 29-site antipsychotic schizophrenia clinical trial. Schizophr. Res. 125 (2), 161–168. Available at: https://doi.org/10.1016/j.schres.2010.09.015.

Koo, T.K., Li, M.Y., 2016. A guideline of selecting and reporting Intraclass correlation coefficients for reliability research. J. Chiropr. Med. 15 (2), 155–163. Available at: https://doi.org/10.1016/j.jcm.2016.02.012.

Levaux, M.-N., et al., 2007. Computerized assessment of cognition in schizophrenia: promises and pitfalls of CANTAB. Eur. Psychiatry 22 (2), 104–115. Available at: https://doi.org/10.1016/j.eurpsy.2006.11.004.

Liu, S.K., et al., 2002. Deficits in sustained attention in schizophrenia and affective disorders: stable versus state-dependent markers. Am. J. Psychiatry 159 (6), 975–982. Available at: https://doi.org/10.1176/appi.ajp.159.6.975.

Marder, S.R., 2006. The NIMH-MATRICS project for developing cognition-enhancing agents for schizophrenia. Dialogues Clin. Neurosci. 8 (1), 109–113.

McCutcheon, R.A., Keefe, R.S.E., McGuire, P.K., 2023. Cognitive impairment in schizophrenia: aetiology, pathophysiology, and treatment. Mol. Psychiatry 1–17. Available at: https://doi.org/10.1038/s41380-023-01949-9.

McGrath, J., Hayes, R.L., 2000. Cognitive rehabilitation for people with schizophrenia and related conditions. Cochrane Database Syst. Rev. 2000 (3) https://doi.org/10.1002/14651858.CD000968 p. CD000968. Available at:

Mesholam-Gately, R.I., et al., 2009. Neurocognition in first-episode schizophrenia: a meta-analytic review. Neuropsychology 23 (3), 315–336. Available at: https://doi.org/10.1037/a0014708.

Nuechterlein, K.H., et al., 2008. The MATRICS consensus cognitive battery, part 1: test selection, reliability, and validity. Am. J. Psychiatry 165 (2), 203–213. Available at: https://doi.org/10.1176/appi.ajp.2007.07010042.

Ojeda, N., et al., 2002. Functional neuroanatomy of sustained attention in schizophrenia: contribution of parietal cortices. Hum. Brain Mapp. 17 (2), 116–130. Available at: https://doi.org/10.1002/hbm.10055.

Palan, S., Schitter, C., 2018. Prolific.ac—A subject pool for online experiments. Journal of Behavioral and Experimental Finance 17, 22–27. Available at: https://doi.org/10.1016/j.jbef.2017.12.004.

Pietrzak, R.H., et al., 2009. A comparison of the CogState schizophrenia battery and the measurement and treatment research to improve cognition in schizophrenia (MATRICS) battery in assessing cognitive impairment in chronic schizophrenia. J. Clin. Exp. Neuropsychol. 31 (7), 848–859. Available at: https://doi.org/10.1080/13803390802592458.

Ritsner, M.S., et al., 2006. The detection of neurocognitive decline in schizophrenia using the Mindstreams computerized cognitive test battery. Schizophr. Res. 82 (1), 39–49. Available at: https://doi.org/10.1016/j.schres.2005.10.014.

Saleem, M.M., et al., 2013. First episode psychosis patients show impaired cognitive function – a study of a south Asian population in the UK. J. Psychopharmacol. 27 (4), 366–373. Available at: https://doi.org/10.1177/0269881113477746.

Tognin, S., et al., 2020. Towards precision medicine in psychosis: benefits and challenges of multimodal multicenter studies—PSYSCAN: translating neuroimaging findings from research into clinical practice. Schizophr. Bull. 46 (2), 432–441. Available at: https://doi.org/10.1093/schbul/sbz067.

Turner, D.C., et al., 2003. Relative lack of cognitive effects of methylphenidate in elderly male volunteers. Psychopharmacology 168 (4), 455–464. Available at: https://doi.org/10.1007/s00213-003-1457-3.

Velligan, D.I. *et al.* (2004) 'A brief cognitive assessment for use with schizophrenia patients in community clinics', Schizophr. Res., 71(2–3), pp. 273–283. Available at: doi:https://doi.org/10.1016/j.schres.2004.02.027.

Vita, A., et al., 2022. European psychiatric association guidance on assessment of cognitive impairment in schizophrenia. Eur. Psychiatry 65 (1), e58. Available at: https://doi.org/10.1192/j.eurpsy.2022.2316.

Wood, S.J., et al., 2003. Spatial working memory ability is a marker of risk-for-psychosis. Psychol. Med. 33 (7), 1239–1247. Available at: https://doi.org/10.1017/s0033291703008067.