Psychological Medicine

www.cambridge.org/psm

A network approach exploring the effects of cognitive remediation on cognition, symptoms, and functioning in early psychosis

Andrew J Watson[1,2], Dominic Stringer[1], Andrew Pickles[1], Paul McCrone[3], Clare Reeder[1], Max Birchwood[4], David Fowler[5], Kathryn Greenwood[5], Sonia Johnson[6], Jesus Perez[7], Andrew Thompson[4], Rachel Upthegrove[8], Jon Wilson[9], Alex Kenny[1], Iris Isok[1], Balaji Suseendrabose[1], Eileen M Joyce[10], Til Wykes[1,2] and Matteo Cella[1,2]

[1]Institute of Psychiatry, Psychology and Neuroscience, King's College London, London, UK; [2]South London and Maudsley NHS Foundation Trust, London, UK; [3]School of Health Sciences, University of Greenwich, London, UK; [4]Warwick Medical School, University of Warwick, Coventry, UK; [5]School of Psychology, University of Sussex, Brighton, UK; [6]Faculty of Brain Sciences, University College London, London, UK; [7]Institute of Biomedical Research of Salamanca (IBSAL), University of Salamanca, Salamanca, Spain; [8]School of Psychology, University of Birmingham, Birmingham, UK; [9]Norfolk and Suffolk NHS Foundation Trust, Norwich, UK and [10]UCL Queen Square Institute of Neurology, University College London, London, UK

Original Article

Cite this article: Watson, A. J., Stringer, D., Pickles, A., McCrone, P., Reeder, C., Birchwood, M., Fowler, D., Greenwood, K., Johnson, S., Perez, J., Thompson, A., Upthegrove, R., Wilson, J., Kenny, A., Isok, I., Suseendrabose, B., Joyce, E. M., Wykes, T., & Cella, M. (2025). A network approach exploring the effects of cognitive remediation on cognition, symptoms, and functioning in early psychosis. *Psychological Medicine*, **55**, e66, 1–10
https://doi.org/10.1017/S0033291725000212

Received: 20 September 2024
Revised: 13 January 2025
Accepted: 24 January 2025

Keywords:
Early Intervention; Cognitive Training; Network Analysis; Psychosis; Recovery

Corresponding author:
Matteo Cella;
Email: matteo.cella@kcl.ac.uk

Abstract

Background. Although cognitive remediation (CR) improves cognition and functioning, the key features that promote or inhibit its effectiveness, especially between cognitive domains, remain unknown. Discovering these key features will help to develop CR for more impact.
Aim. To identify interrelations between cognition, symptoms, and functioning, using a novel network analysis approach and how CR affects these recovery outcomes.
Methods. A secondary analysis of randomized controlled trial data (N = 165) of CR in early psychosis. Regularized partial correlation networks were estimated, including symptoms, cognition, and functioning, for pre-, post-treatment, and change over time. Pre- and post-CR networks were compared on global strength, structure, edge invariance, and centrality invariance.
Results. Cognition, negative, and positive symptoms were separable constructs, with symptoms showing independent relationships with cognition. Negative symptoms were central to the CR networks and most strongly associated with change in functioning. Verbal and visual learning improvement showed independent relationships to improved social functioning and negative symptoms. Only visual learning improvement was positively associated with personal goal achievement. Pre- and post-CR networks did not differ in structure ($M = 0.20$, $p = 0.45$) but differed in global strength, reflecting greater overall connectivity in the post-CR network ($S = 0.91$, $p = 0.03$).
Conclusions. Negative symptoms influenced network changes following therapy, and their reduction was linked to improvement in verbal and visual learning following CR. Independent relationships between visual and verbal learning and functioning suggest that they may be key intervention targets to enhance social and occupational functioning.

Introduction

Using traditional approaches, robust findings from longitudinal studies demonstrate that cognitive impairments and negative symptoms are the best predictors of poor social and occupational functioning following the onset of psychosis (Cowman et al., 2021; Dickinson & Coursey, 2002; Fett et al., 2011; Lindgren, Holm, Kieseppä, & Suvisaari, 2020; Milev, Ho, Arndt, & Andreasen, 2005). A limiting factor for durable intervention effects is the heterogeneous illness presentations and trajectories (Joyce, Hutton, Mutsatsa, & Barnes, 2005; Salagre et al., 2020; Tandon, Nasrallah, & Keshavan, 2009) and the dynamic interplay between symptoms and functioning difficulties (Esfahlani, Sayama, Visser, & Strauss, 2017).

One evidence-based intervention shown to improve cognition, functioning, and negative symptoms is cognitive remediation (CR) (Cella, Preti, Edwards, Dow, & Wykes, 2017; Vita et al., 2021; Wykes, Huddy, Cellard, McGurk, & Czobor, 2011). CR for schizophrenia is a psychological, behavioral training-based intervention that aims to enhance functioning by targeting cognitive impairments (Bowie et al., 2020), and a large randomized controlled trial has shown its effectiveness in improving outcomes for people early in the course of illness (Wykes et al., 2023). A White Paper identified the key ingredients of CR (Bowie et al., 2020) likely to produce a positive outcome; an active therapist, cognitive exercise, development of problem-solving strategies, and

© The Author(s), 2025. Published by Cambridge University Press. This is an Open Access article, distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike licence (http://creativecommons.org/licenses/by-nc-sa/4.0), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the same Creative Commons licence is used to distribute the re-used or adapted article and the original article is properly cited. The written permission of Cambridge University Press must be obtained prior to any commercial use.

facilitation of transfer to real-world functioning, but a mechanistic understanding of how cognitive skills influence functioning is lacking. The current proposed model for CR is that cognition improvement will affect functional outcome, but few studies have tested this mediational model, and when they have, the result is only a partial effect. A recent analysis by our group (Tinch-Taylor et al., 2024) found that cognitive improvements were correlated with functional improvements but did not fully explain the positive impact of increased therapy hours on functioning. There was, however, evidence that the translation of global cognition improvement to functional benefit was affected by negative symptoms (a moderated-mediational relationship). This analysis used a composite measure of global cognition and was therefore not able to evaluate how specific cognitive difficulties may relate to improvements in symptoms and functioning.

Uncovering potential pathways between improvement in specific cognitive domains and areas of real-world functioning is important to understanding how to bolster the different components of CR. Novel network intervention analyses and network comparison techniques using longitudinal data have recently been introduced to surface these potential mechanisms (Contreras, Nieto, Valiente, Espinosa, & Vazquez, 2019). Network analysis (NA) considers mental disorders as emerging from dynamic causal interactions among symptoms and processes rather than a singular underlying common cause or mechanism (Borsboom & Cramer, 2013; Bringmann et al., 2022; Cramer, Waldorp, van der Maas, & Borsboom, 2010; Henry, Robinaugh, & Fried, 2021). In contrast to traditional causal models, NA uses a data-driven approach to produce spatially ordered networks that accommodate the unique interplay between variables (Borsboom, 2017; Borsboom & Cramer, 2013) and can identify central features considered to be most influential to the networks.

Conventional approaches have found that cognitive difficulties and negative symptoms predict functioning, and two cross-sectional NA studies in people with long-standing schizophrenia support social and non-social cognition being linked to functional capacity and that negative symptoms have multiple connections between symptoms and functioning (Galderisi et al., 2018; Hajdúk, Penn, Harvey, & Pinkham, 2021). NA studies in early psychosis are emerging but have focused largely on positive and negative symptoms and on cross-sectional data (Betz et al., 2020; Chang et al., 2019; Griffiths et al., 2021; Hasson-Ohayon, Goldzweig, Lavi-Rotenberg, Luther, & Lysaker, 2018; Herniman et al., 2021; Izquierdo et al., 2021; Piao et al., 2021). Only two have included cognitive measures, with one demonstrating a central role (Hasson-Ohayon et al., 2018) and the other highlighting the importance of motivation (Chang et al., 2019). Hasson-Ohayon et al. (2018) additionally found that metacognition (particularly self-reflectivity) had high strength centrality in the network. These results suggest that therapies targeting both cognition, motivation, and metacognition may be most effective in promoting recovery. No study has explored how psychopathology networks change following a psychological intervention in people with early psychosis.

The current study will offer the first insights into the interrelations (edge-weights) among psychopathological and cognitive variables early in the course of illness and evaluate networks of change after CR to examine paths by which symptoms and cognition may lead to improvements in functioning. Strength centrality, which identifies the most influential nodes within the network, will highlight which variables (e.g., negative symptoms, specific cognitive domains) play a pivotal role in driving changes across the network and infer the features that need emphasis in CR. Network Connectivity and Global Strength measures will reflect the overall integration of the networks and the strength of interactions between variables, with changes in connectivity and global strength after cognitive remediation suggesting enhanced interplay between cognitive and symptom domains and offering insights into the impact of the intervention.

Methods

This is a secondary analysis of data from a large randomized controlled trial (RCT) in early psychosis (Wykes et al., 2018, 2023). Only participants who received CR and completed both baseline (pre-CR) and 3-month follow-up (post-CR) assessments were included from two arms of the trial (one-to-one and group treatment). In the initial analysis, there was no difference between these two therapist-supported arms, so they were combined as stated in the pre-specified analysis plan (Wykes et al., 2023). Both groups were allocated the same number of therapist-supported sessions, and there was no difference between groups in the proportion of missing data.

Participants

Participants were recruited from six sites across the United Kingdom: Birmingham, Coventry and Warwickshire, Sussex, East Anglia, South London, and North London. The inclusion criteria were: attending an early intervention service for at least 3 months, being aged between 16 and 45, having a diagnosis of non-affective psychosis, being clinically stable as judged by the clinical team, and having the ability to give informed consent. The exclusion criteria were: an underlying organic or neurological condition affecting cognition, a comorbid diagnosis of intellectual disability, or an inability to communicate in English sufficiently to participate in cognitive testing. Participants were included if they had pre and post-therapy measures (165 participants). At baseline, participants had a mean score of 64.4 on the SOFAS and 12.84 and 14.39, respectively, on the PANSS positive and negative sub-scales. Demographic data are detailed in Table 1.

Intervention

This RCT used a therapist-supported computerized CR, CIRCuiTS™ (Reeder et al., 2017), a new-generation training program focusing on cognition and metacognition by encouraging participants to monitor and manage their cognitive performance, with the aim of improving the transfer of cognitive skills to daily living. All intervention participants were offered 42 therapy sessions, either in a small group or one-to-one and had similar amounts of contact with a therapist. The therapy was delivered over 12 weeks by graduate-level assistant psychologists who had received 25–30 hours of online training and received weekly supervision from an experienced clinical psychologist.

Measures

The measures are described in Table 2. For a more detailed description of each measure, see the supplementary materials.

Statistical analysis and network estimation

The included data: Data imputation can be used reliably in network analysis (Boschloo et al., 2019; Cervin et al., 2020; Griffiths et al.,

https://doi.org/10.1017/S0033291725000212 Published online by Cambridge University Press

Table 1. Sample demographics

Variable	All cases (n = 165) Mean (SD)/N (%)
Age	26.34 (6.64)
Gender	
Male	122 (73.1%)
Female	43 (25.7%)
Ethnicity	
White	73 (43.7%)
Black (African/Caribbean)	52 (31.3%)
Asian (i.e., Bangladeshi, Indian, Pakistani)	20 (12.0%)
Other (Other – mixed; Other – mixed White and Black Caribbean)	19 (11.4%)
Missing	1 (1.6%)
Employment	
Unemployed	143 (85.6%)
Part-time employed	11 (6.6%)
In full-time education	7 (4.2%)
Employed	3 (1.8%)
Missing	1 (1.6%)
Relationship Status	
Single	111 (66.5%)
Living with partner	26 (15.6%)
Married	15 (9.0%)
Separated/divorced	12 (7.2%)
Missing	1 (1.6%)

2021) and imputed networks compare well with non-imputed networks, so we used the Markov-Chain Monte Carlo technique to generate plausible missing values drawn from a distribution specifically modeled for each missing item, using a predictor matrix (Buuren & Groothuis-Oudshoorn, 2011) – the MICE process for pre- and post-CR networks (n = 165). To eliminate the possibility of bias, we carried out a sensitivity analysis of complete cases.

All analyses were conducted using the statistical software R (version 4.0.4). Descriptive statistics and t-tests were performed to identify variables that significantly changed between pre- and post-CR and identify the cognitive variables to be included in the change networks.

Pre-CR and post-CR networks were created to establish the network structures at presentation and follow-up. Additional networks were estimated using the difference in scores (pre – post-therapy), including only the cognitive items that showed significant improvement (<0.05) and either SOFAS or GAS as the outcome measure – referred to hereafter as "change networks." These networks were used to establish changes in interactions following CR. Networks were estimated using the "*Bootnet*" package (Epskamp & Fried, 2018), which uses the Extended Bayesian Information Criterion (EBIC) in combination with the least absolute shrinkage and selection operator (LASSO) to construct a network of partial correlations, controlling for all other variables. The LASSO procedure applies a penalty to small associations (considered to be spurious), shrinking these to zero, and leaving a sparse network of meaningful associations (Tibshirani, 1996).

To maximize the discovery of associations, the EBIC tuning hyperparameter was set to 0. To assess the influence variables, strength centrality was calculated for each variable by summing the weighted connections to all other items in the network (the degree to which each node is connected to other nodes in the network). Those items with more and stronger connections to others are considered to have the highest network "strength."

Networks represent models of a series of variables referred to as "nodes" (represented as circles) and their associations, referred to as "edges" (represented by lines connecting nodes). Thicker edges denote stronger associations between nodes. Networks were plotted using the "*Qgraph*" package (Epskamp, Cramer, Waldorp, Schmittmann, & Borsboom, 2012) with blue edges representing positive partial correlations and red edges indicating negative partial correlations. The layout of networks was set using the Fruchterman–Reingold algorithm (Fruchterman & Reingold, 1991) for the pre-CR network, and the post-CR network layout was set to match for ease of comparison. The length of edges has no specific meaning in the network visualizations.

Network comparisons, accuracy, and stability

To compare differences statistically in network structure following CR, pre- and post-CR networks were compared on global strength, global structure, edge invariance, and centrality invariance, using the Network Comparison Test (NCT) (van Borkulo et al., 2022). The NCT is a permutation-based test that randomly regroups individuals 1000 times to create a distribution under the null hypothesis that groups are equal and then tests for network differences. "Global structure" is calculated by comparing the distributions of edge weights in the network, and "global strength" tests the weighted sum of the absolute connections in each network.

In limited sample sizes, it is important to ensure that networks are estimated accurately and, therefore, the interpretation of networks is valid. Accuracy and stability of networks were calculated following best practice guidelines (Epskamp, Borsboom, & Fried, 2018). Bootstrapping routines (n = 1000) were used to test the correlation stability for different edge weights and centrality indices, and bootstrapped confidence intervals (CIs) for edge parameters were reported.

Inclusion of lived experience

CIRCuiTS™ therapy was co-developed with service users. For the ECLIPSE trial, people with experience in using mental health services were consulted at every stage of the trial, from study question, design, choice of outcome measures, protocol, and all patient-facing document wording, We continue to involve service users as advisors, with members of the Patient Advisory Board (PAB) being invited as critical reviewers and authors of this analysis.

Results

Demographic and clinical data

Data for 165 participants allocated to either the "one-to-one" (n = 77) or "group" (n = 88) arms were included. A total of 6.6% of data was missing (across all measures), 1.6% at baseline, and 11.7% at follow-up. Ninety-six participants had complete data on

https://doi.org/10.1017/S0033291725000212 Published online by Cambridge University Press

Table 2. Study measures

Measure (Minimum score – maximum score)		
Social and Occupational Functioning Assessment Scale (SOFAS) (0–100)	Participants were rated by the assessor from 1 (unable to function without considerable support) to 100 (superior functioning in a wide range of activities)	Higher scores are interpreted as better
Goal Attainment Scale (GAS)	Goal Attainment Scale weighted T-score was scored as per the Goal Attainment Scale guide.	A higher score interpreted as a better
Positive and negative syndrome scale; positive symptom (PPos) (7–49)	Sum total of the scores for the 7 "positive" items on the PANSS scale (delusions, conceptual disorganization, hallucinations, excitement, grandiosity, suspiciousness/persecution, hostility)	A lower score interpreted as better
Positive and negative syndrome scale: negative symptoms (PNeg) (7–49)	Sum total of the scores for the 7 "negative" items on the PANSS scale (blunted affect, emotional withdrawal, poor rapport, passive/ apathetic social withdrawal, difficulty in abstract thinking, lack of spontaneity and flow of conversation, stereotyped thinking)	Lower score interpreted as better
Clinical assessment interview for negative symptoms; motivation and pleasure (MAP) (0–44)	Sum total of the CAINS MAP scale, which includes items on motivation for social, recreational, and vocational life, each scored 0–4.	Lower score interpreted as better
Clinical Assessment Interview for Negative Symptoms Experiential Scale (EXP) (0–16)	Sum total of the CAINS EXP scale, which is scored based on observation of facial, vocal, and expressive gestures and quantity of speech, each scored 0–4.	Lower score interpreted as better
The Measure of Insight Into Cognition (MIC-SR) (0–36)	Total of the MIC-SR, which has 12 statements about self-perceived cognitive ability, self-rated by the participant based on the frequency it occurs: 0 (never), 1 (once a week or less), 2 (twice a week), or 3 (almost daily).	Lower score interpreted as better functioning
Digit Span Backward (DS-B)	The total of digit span backward	Higher scores interpreted as better
Auditory Verbal Learning Test (AVLT) (0–75)	Total words correctly recalled across trials (1–5)	Higher scores interpreted as better
Cambridge Neuropsychological Test Automated Battery (CANTAB)		
Attention switching task (AST)	Attention Switching Task Total Correct. Measures attention switching and multitasking.	Higher scores interpreted as better
Emotion recognition task (*ERT*)	The total number of correct emotional selection responses across all assessed trials. Measures ability to identify six basic emotions in facial expressions along a continuum.	Higher scores interpreted as better
One-touch stockings of Cambridge (OTSC)	One touch stockings of Cambridge problems solved on the first choice. Measures executive functioning, including spatial planning and working memory subdomains.	Higher scores interpreted as better
Paired associates learning (PAL)*	Paired associates learning total errors (Adjusted). The number of times the participant chose an incorrect box for a patterned stimulus, with an additional adjustment for the estimated number of errors they would have made on any problems, attempts, and recalls they did not reach. Measures visual memory and new learning.	Higher scores interpreted as better (after reverse scoring)
Reaction time (RT) (measured in milliseconds)	Median duration it took for a participant to release the response button after the presentation of a target stimulus – calculated across correct, assessed trials in which the stimulus could appear in any one of five locations. Measures motor and mental response speed.	Higher scores interpreted as better
Rapid visual processing (RVP)* (0.00–1.00)	Sensitivity to the target sequence (a string of three numbers), regardless of response tendency (the expected range is 0.00 to 1.00). Measures sustained attention	Higher scores interpreted as better
Spatial working memory (SWM) (errors)*	Spatial working memory number of errors – number of times the participant incorrectly revisits a box in which a token has previously been found. Measures spatial working memory.	Higher scores interpreted as better (after reverse scoring)

https://doi.org/10.1017/S0033291725000212 Published online by Cambridge University Press

all measures (see supplementary materials for complete-cases sensitivity analysis), and imputation was performed for the remaining 69. Participants had a mean age of 26.3, 73.1% were male, 43.7% were white, and at the time of the study, 85.6% were unemployed, and 66.5% described themselves as single.

Mean pre- and post-CR scores for each variable included in the network analyses are detailed in the Supplementary Material (Table 1). The pre- and post-CR networks differed significantly (p = < 0.05) on SOFAS, GAS, PANSS positive, PANSS negative, CAINS MAP, AVLT, PAL, and SWM, representing a post-CR improvement in each case.

Pre-CR network

The pre-CR network and centrality indices are shown in Figure 1. The network was dense, with 57% of possible edges. The different variable domains were well separated, with connectivity evident within the cognitive and symptom domains. The most central nodes in the network were PNeg, OTSC, AST, SOF, and AVLT. As expected, social and occupational functioning (SOF) showed the strongest association with negative symptoms (MAP and PNeg) but also connected to other domains, including negative associations with positive symptoms (PPos) and positive associations with cognitive functioning (PAL, DS-B, OTSC, and AST). Cognitive impairments additionally connected with negative symptoms (AVLT – PNeg, AVLT – EXP, AST – PNeg, ERT – PNeg, PAL – MAP, OTSC – EXP, RT – Pneg, DS-B – EXP, DS-B – MAP) and positive symptoms (RT – PPos, SWM – PPos). The MIC-SR (a self-reported measure of cognitive difficulties) was most strongly associated with positive symptoms.

Change network – CR

Figure 2 shows the change networks, including the symptoms and cognitive variables shown to change between pre- and post-CR. In the social and occupational functioning network, an increase in SOFAS score was associated with a reduction in negative symptoms (PNeg, EXP, MAP) and an improvement in cognition (PAL and AVLT). Improvement in visual (PAL) and verbal learning (AVLT) was also independently associated with a reduction in negative symptoms (MAP and PNeg, respectively). Decreased positive symptoms were associated with improved self-reported cognitive ability and with improvement in negative symptoms (PNeg) but had no direct association with social and occupational functioning. In the GAS network, only improvement in visual learning was associated with goal attainment. All other associations were the same.

Pre- and post-CR network comparisons

The pre- (**A**) and post-CR (**B**) networks and centrality indices (**C**) are shown together in Figure 3. The post-CR network was denser than the pre-CR network, with 66% (vs 57%) of possible edges. Networks did not differ in structure (M = 0.20, p = 0.45) but differed in global strength, reflecting greater overall connectivity in the post-CR network (S = 0.91, p = 0.03). Overall strength centrality did not significantly differ between networks (C = 0.13, p = 0.051), but visual learning (PAL) (p = 0.03) and motivation and pleasure (MAP) (p = <0.001) increased in strength centrality. In terms of individual edges, significantly stronger connections were observed between digit-span backward and auditory verbal learning (AVLT); attention-switching (AST) and rapid visual processing (RVP); and visual learning (PAL) and negative symptoms (Neg).

Network stability and sensitivity analysis

Bootstrapping demonstrated acceptable stability, with edge weight stability coefficients of 0.67 and 0.75 for the pre- and post-CR networks, respectively, and 0.28 and 0.36 for the SOFAS and GAS change networks. Strength centrality stability was also acceptable for the pre-CR network (0.44) but fell below the minimum threshold of 0.25 for the post-CR network (0.21), indicating that strength

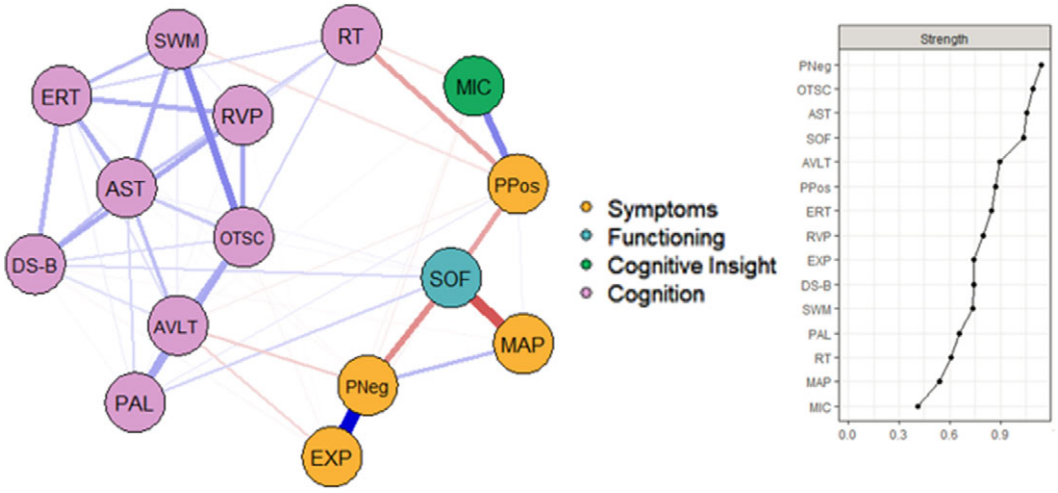

Figure 1. pre-CR network and centrality indices estimate pre-CR and their strength centrality scores (**C**). Nodes (circles) represent cognitive (purpose), clinical (yellow), cognitive insight (green), and functioning (blue) scores. Higher scores for cognitive and functioning nodes represent better performance, whilst higher scores for cognitive insight and symptoms represent worse performance. Edge weights (lines) represent associations between nodes, with denser lines indicating stronger associations. Blue edges depict positive associations, and red edges depict negative associations. AST = Attention Switching Task; AVLT = Auditory Verbal Learning Task, DS-B = Digit Span Backward, ERT = Emotion Recognition Test; EXP = CAINS Expressive Score; MAP = CAINS Motivation and Pleasure Score; MIC = Measure of Insight into Cognition – Self Report; OTSC = One-Touch Stockings of Cambridge; PAL = Paired Associates Learning; PNeg = PANSS Negative; PPos = PANSS Positive; RT = Reaction Time; RVP = Rapid Visual Processing; SOF = Social and Occupational Functioning Assessment Scale; SWM = Spatial Working Memory.

https://doi.org/10.1017/S0033291725000212 Published online by Cambridge University Press

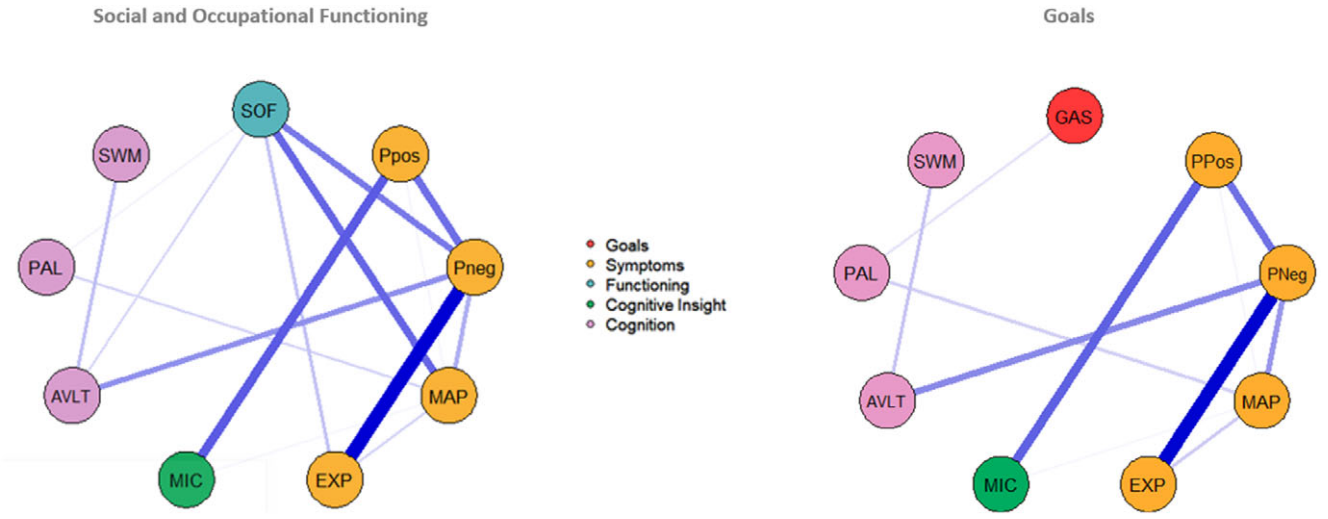

Figure 2. Network of change scores for symptoms and metacognition were reversed so that all blue edges depict improvement. Network estimates of change scores (pre- and post-CR). Nodes (circles) represent cognitive (purpose), clinical (yellow), cognitive insight (green), functioning (blue), and goals (red) scores. Edge weights (lines) represent associations between nodes, with denser lines indicating stronger associations. AST = Attention Switching Task; AVLT = Auditory Verbal Learning Task, DS-B = Digit Span Backward, ERT = Emotion Recognition Test; EXP = CAINS Expressive Score; GAS = Goal Attainment Scale; MAP = CAINS Motivation and Pleasure Score; MIC = Measure of Insight into Cognition – Self Report; OTSC = One-Touch Stockings of Cambridge; PAL = Paired Associates Learning; PNeg = PANSS Negative; PPos = PANSS Positive; RT = Reaction Time; RVP = Rapid Visual Processing; SOF = Social and Occupational Functioning Assessment Scale; SWM = Spatial Working Memory.

indices should be interpreted with caution in the post-CR network. Results of the edge weight bootstrapping are visualized in the supplementary materials.

Networks remained dense, showed comparable levels of stability, key central items remained the same, and network and strength invariance coefficients were also similar in the sensitivity analysis for the complete cases (N96). However, the difference in network strength was no longer significant (p = 0.10) (see supplementary materials).

Discussion

The baseline network shows that cognition, negative symptoms, and positive symptoms are separable constructs, with symptoms having independent relationships with cognitive domains. Negative symptoms played a central role in almost all networks and were most linked to changes in social and occupational functioning (particularly motivation and pleasure). This finding accords with evidence that negative symptoms account for a large proportion of variance in functional outcomes in people with psychosis (Evensen et al., 2012; Fervaha, Foussias, Agid, & Remington, 2014; Gee et al., 2016; Ho, Nopoulos, Flaum, Arndt, & Andreasen, 1998; Milev, Ho, Arndt, & Andreasen, 2005) and that negative symptoms interfere with the translation of cognitive improvement into functional gains following CR (Tinch-Taylor et al., 2024). The exception was the variables influencing change in goal attainment, where only improvement in a task measuring visual memory and new learning (PAL) was positively associated with the achievement of personal goals.

Negative symptoms and cognitive deficits are correlated (Addington, Addington, & Maticka-Tyndale, 1991; Dominguez, Viechtbauer, Simons, van Os, & Krabbendam, 2009; Fervaha, Zakzanis, et al., 2014; Heydebrand et al., 2004) and partially mediate the relationship between cognitive deficits and functional outcomes (González-Ortega et al., 2013; Tinch-Taylor et al., 2024; Ventura, Hellemann, Thames, Koellner, & Nuechterlein, 2009). Different hypotheses about the nature of this relationship have been proposed, including that they are the manifestation of the same underlying process, share a common etiology, or that they have separable but related etiologies (Harvey, Koren, Reichenberg, & Bowie, 2006). Previous research has also shown a relationship between negative symptoms and verbal and visual learning in relation to motivation (Fervaha, Foussias, et al., 2014) and expressive (Hartmann-Riemer et al., 2015) deficits, with the current study supporting that negative symptoms may at least partially mediate a relationship between verbal and visual learning and social and occupational functioning. It is important to note, however, that change in both verbal and visual learning had unique associations with change in social and occupational functioning even after accounting for the relationship with negative symptoms, indicating distinct relationships with functional outcomes.

The observation that changes in positive symptoms are unrelated to changes in social functioning supports a now-established body of evidence that changes in positive symptoms are a poor predictor of functional outcomes in this population (Rabinowitz et al., 2012). Interestingly, the association between CAINS MAP and PANSS Negative symptoms was weaker than expected, likely reflecting and providing support for the distinct constructs these scales measure despite their conceptual overlap (Strauss et al., 2018). Furthermore, self-reported cognitive difficulties were most strongly related to positive symptoms (rather than objective performance on cognitive measures), suggesting that insight into cognitive difficulties may be influenced by positive symptoms and that self-report measures of cognitive difficulties provide a different assessment compared to objective measures of cognitive ability.

Implications for intervention

The findings suggest that negative symptoms should be considered carefully when planning CR interventions, with a reduction in negative symptoms likely to be critical to achieving improvement in social and occupational outcomes.

https://doi.org/10.1017/S0033291725000212 Published online by Cambridge University Press

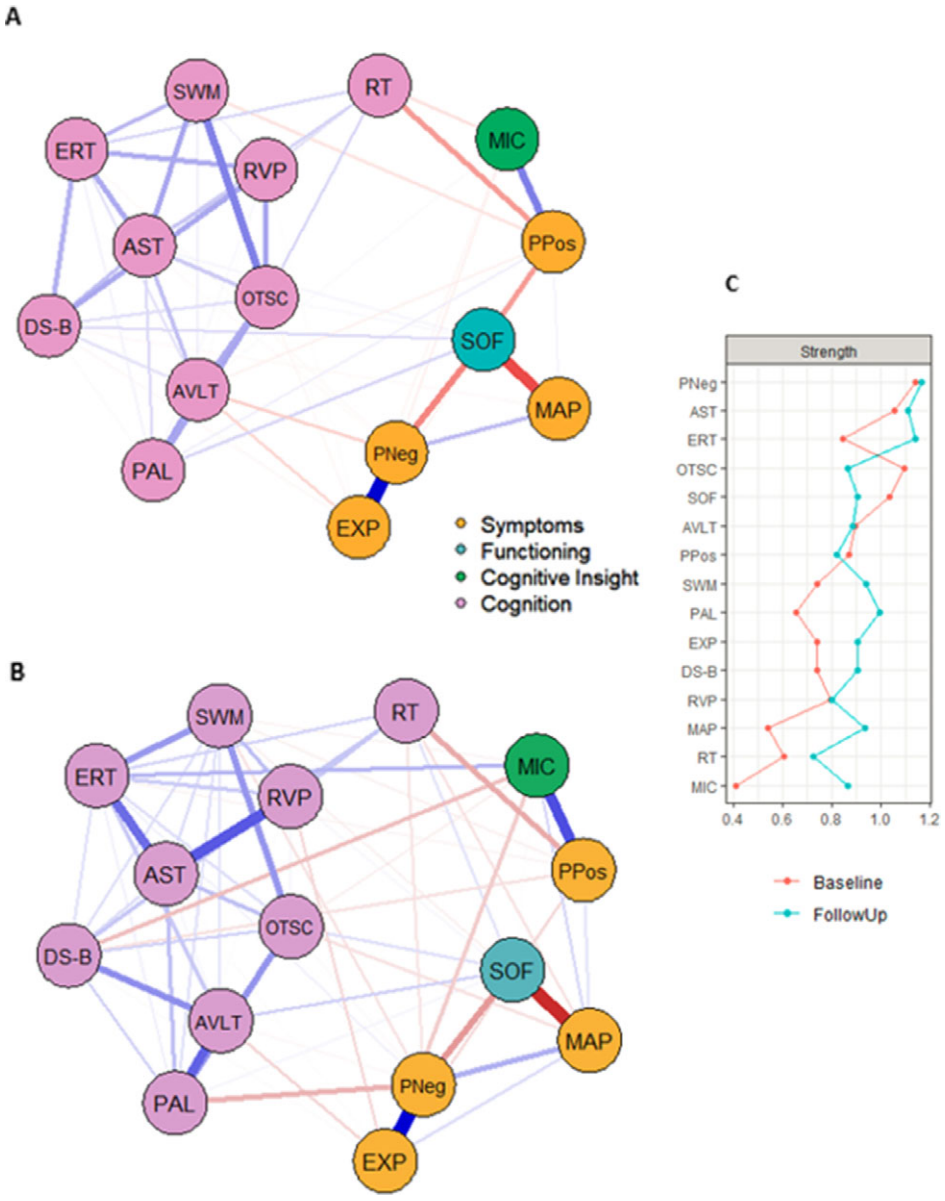

Figure 3. Network estimates pre-CR (**A**) and post-CR (**B**) and their strength centrality scores (**C**). Nodes (circles) represent cognitive (purpose), clinical (yellow), cognitive insight (green), and functioning (blue) scores. Higher scores for cognitive and functioning nodes represent better performance, whilst higher scores for cognitive insight and symptoms represent worse performance. Edge weights (lines) represent associations between nodes, with denser lines indicating stronger associations. Blue edges depict positive associations, and red edges depict negative associations. AST = Attention Switching Task; AVLT = Auditory Verbal Learning Task, DS-B = Digit Span Backward, ERT = Emotion Recognition Test; EXP = CAINS Expressive Score; MAP = CAINS Motivation and Pleasure Score; MIC = Measure of Insight into Cognition – Self Report; OTSC = One-Touch Stockings of Cambridge; PAL = Paired Associates Learning; PNeg = PANSS Negative; PPos = PANSS Positive; RT = Reaction Time; RVP = Rapid Visual Processing; SOF = Social and Occupational Functioning Assessment Scale; SWM = Spatial Working Memory.

A meta-analysis of CR for people with psychosis showed small-to-moderate durable benefits on negative symptoms (Cella, Preti, et al., 2017), but the mechanisms of this effect remain poorly understood. Gold et al., (2008) proposed that memory is instrumental in activating motivational resources and that memory deficits may limit an individual's ability to retrieve and use the information to motivate and guide future goal-directed behaviors. Furthermore, neuroimaging studies have provided evidence for the intersectionality of memory deficits and negative symptoms, showing that disturbances in verbal and associative learning may result from impaired pre-frontal cortex functioning, which is also expressed in increased negative symptoms of flat affect, loss of motivation, and impairments in goal-directed behavior (Nestor et al., 2022; Oertel et al., 2019). However, evidence that working memory mediates negative symptom improvement has been mixed (Cella et al., 2017) with some suggesting a role of social cognition (Raucher-Chéné, Thibaudeau, Sauvé, Lavigne, & Lepage, 2021).

In the present study, negative symptoms significantly reduced following CR and were linked to verbal and visual learning. This hints at the possibility that targeting both verbal and visual learning may provide secondary benefits on negative symptoms, with recalibration of reward sensitivity being a potential driver of change (Cella et al., 2014). The direction of this relationship requires further clarification, but the independent relationship between these variables and social functioning provides promise that verbal

https://doi.org/10.1017/S0033291725000212 Published online by Cambridge University Press

and visual learning may be considered important intervention targets to both directly and indirectly enhance social and occupational functioning.

In addition to verbal learning, measures of executive functioning and attention switching showed the highest strength centrality in the pre-CR network and may be important remediation targets (also more in line with CR treatment targets). Interestingly, change in neither positive nor negative symptoms were related to goal attainment, indicating the need for a better understanding of the barriers to achieving personalized goals in this clinical group and how improvement in visual memory and new learning may facilitate their improvement.

Comparatively greater overall connectivity post-CR requires careful interpretation. Previous studies of symptoms in mental illness have found that increased connectivity is associated with more acute illness (Pe et al., 2015; van Borkulo et al., 2015; van Rooijen et al., 2018), whilst others have shown evidence that increased symptom connectivity parallels decreases in symptom severity (Bos et al., 2018; Fokkema, Smits, Kelderman, & Cuijpers, 2013; Quilty et al., 2013). Of note, these studies focused on symptoms of illness and did not include possible strengths, such as more homogenous cognitive abilities, which, in the context of positive change in social and occupational functioning, may be interpreted as positively affecting outcomes.

Limitations

This study is the first to examine change in the network structure of symptoms following a psychological intervention in early psychosis; it was not possible to make comparisons to a TAU network due to the sample size. As a result, changes in network structure and relationships cannot be attributed directly to the intervention, even though this is the most parsimonious explanation. Data were missing for 69 participants, which accounted for 6.6% overall, with 1.6% at baseline and 11.7% at follow-up. While we employed imputation to address this issue, imputation techniques rely on assumptions about the data and may not fully account for the complexity of the missingness. A sensitivity analysis using only complete cases showed comparable results to the imputed dataset, providing reassurance regarding the robustness of our findings. The reduced sample size in this analysis resulted in slightly diminished statistical power, and it is possible that some nuanced associations may have been missed. Finally, we chose to include two negative symptom measures in the analysis (i.e., the PANSS Negative subscale and the CAINS subscales). These measures assess distinct aspects of negative symptoms (as evidenced by a weak relationship between PANSS negative and CAINS MAP), but there is conceptual overlap between them (see supplementary materials for more detail). This overlap could introduce a degree of redundancy and may complicate the interpretation of findings, particularly when examining associations with other variables.

Conclusions and future directions

Our results point to the centrality of negative symptoms for influencing social and occupational outcomes but also suggest that CR may be able to reduce these symptoms via improvement in cognitive domains. Visual and verbal learning appear to be related to changes in social and occupational functioning. Overall, the findings indicate that CR may achieve its effect on functioning outcomes through combinatory effects on cognitive domains but also by changing symptoms linked to reduced motivation, pleasure experience, and social contact. Future research should examine which therapeutic mechanisms contribute to negative symptom reduction and functioning change in CR.

One emerging approach is the extension of network analyses to time-series data, which may provide insights into the temporal relationships between negative symptoms, cognition, and functioning. Such insights will provide valuable information on the etiology of functioning impairments and inform the further development of a successful targeted cognitive remediation intervention.

Supplementary material. The supplementary material for this article can be found at http://doi.org/10.1017/S0033291725000212.

Acknowledgments. Prof. Wykes, with Dr Clare Reeder, developed the cognitive remediation software, CIRCuiTS™, used in this study. Eileen Joyce and Til Wykes are grateful to Cambridge Cognition for the use of CANTAB Connect.

Funding. (1) The ECLIPSE trial, of which this study uses data, was funded by the National Institute for Health Research (NIHR) Programme grant for Applied Research (NIHR-PGfAR RP-PG-0612-20002). (2) T.W., M.C., and A.P. were partly funded by the National Institute for Health Research (NIHR) Maudsley Biomedical Research Centre at South London and Maudsley NHS Foundation Trust and King's College London and their NIHR Senior Investigator Awards. E.J. was partly funded by the NIHR University College London Hospitals Biomedical Research Centre. NIHR Applied Research Collaborations (ARC) supported M.B. (West Midlands), J.P. (East of England), and D.F. (Kent, Surrey, and Sussex). The UK Clinical Research Collaboration-registered King's Clinical Trials Unit at King's Health Partners, which is part funded by the NIHR Biomedical Research Centre for Mental Health at South London and Maudsley NHS Foundation Trust and King's College London and the NIHR Evaluation, Trials and Studies Coordinating Centre supported our randomization.

References

Addington, J., Addington, D., & Maticka-Tyndale, E. (1991). Cognitive functioning and positive and negative symptoms in schizophrenia. *Schizophrenia Research*, **5**(2), 123–134. https://doi.org/10.1016/0920-9964(91)90039-t

Betz, L. T., Penzel, N., Kambeitz-Ilankovic, L., Rosen, M., Chisholm, K., Stainton, A., … Kambeitz, J. (2020). General psychopathology links burden of recent life events and psychotic symptoms in a network approach. *Npj Schizophrenia*, **6**(1), 1–8. https://doi.org/10.1038/s41537-020-00129-w

Borsboom, D. (2017). A network theory of mental disorders. *World Psychiatry: Official Journal of the World Psychiatric Association (WPA)*, **16**(1), 5–13. https://doi.org/10.1002/wps.20375

Borsboom, D., & Cramer, A. O. J. (2013). Network analysis: An integrative approach to the structure of psychopathology. *Annual Review of Clinical Psychology*, **9**, 91–121. https://doi.org/10.1146/annurev-clinpsy-050212-185608

Bos, F. M., Fried, E. I., Hollon, S. D., Bringmann, L. F., Dimidjian, S., DeRubeis, R. J., & Bockting, C. L. H. (2018). Cross-sectional networks of depressive symptoms before and after antidepressant medication treatment. *Social Psychiatry and Psychiatric Epidemiology*, **53**(6), 617–627. https://doi.org/10.1007/s00127-018-1506-1

Boschloo, L., Bekhuis, E., Weitz, E. S., Reijnders, M., DeRubeis, R. J., Dimidjian, S., … Cuijpers, P. (2019). The symptom-specific efficacy of antidepressant medication vs. cognitive behavioral therapy in the treatment of depression: Results from an individual patient data meta-analysis. *World Psychiatry*, **18**(2), 183–191. https://doi.org/10.1002/wps.20630

Bowie, C. R., Bell, M. D., Fiszdon, J. M., Johannesen, J. K., Lindenmayer, J.-P., McGurk, S. R., … Wykes, T. (2020). Cognitive remediation for schizophrenia: An expert working group white paper on core techniques. *Schizophrenia Research*, **215**, 49–53. https://doi.org/10.1016/j.schres.2019.10.047

Bringmann, L. F., Albers, C., Bockting, C., Borsboom, D., Ceulemans, E., Cramer, A., … Wichers, M. (2022). Psychopathological networks: Theory,

methods and practice. *Behaviour Research and Therapy*, **149**, 104011. https://doi.org/10.1016/j.brat.2021.104011

Buuren, S. van, & Groothuis-Oudshoorn, K. (2011). Mice: Multivariate imputation by chained equations in R. *Journal of Statistical Software*, **45**, 1–67. https://doi.org/10.18637/jss.v045.i03

Cella, M., Stahl, D., Morris, S., Keefe, R. S. E., Bell, M. D., & Wykes, T. (2017). Effects of cognitive remediation on negative symptoms dimensions: Exploring the role of working memory. *Psychological Medicine*, **47**(15), 2593–2601. https://doi.org/10.1017/S0033291717000757

Cella, M, Bishara, A. J., Medin, E., Swan, S., Reeder, C., & Wykes, T. (2014). Identifying cognitive remediation change through computational modelling—Effects on reinforcement learning in schizophrenia. *Schizophrenia Bulletin*, **40**(6), 1422–1432. https://doi.org/10.1093/schbul/sbt152

Cella, M, Preti, A., Edwards, C., Dow, T., & Wykes, T. (2017). Cognitive remediation for negative symptoms of schizophrenia: A network meta-analysis. *Clinical Psychology Review*, **52**, 43–51. https://doi.org/10.1016/j.cpr.2016.11.009

Cervin, M., Storch, E. A., Piacentini, J., Birmaher, B., Compton, S. N., Albano, A. M., … Kendall, P. C. (2020). Symptom-specific effects of cognitive-behavioral therapy, sertraline, and their combination in a large randomized controlled trial of pediatric anxiety disorders. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, **61**(4), 492–502. https://doi.org/10.1111/jcpp.13124

Chang, W. C., Wong, C. S. M., Or, P. C. F., Chu, A. O. K., Hui, C. L. M., Chan, S. K. W., … Chen, E. Y. H. (2019). Inter-relationships among psychopathology, premorbid adjustment, cognition and psychosocial functioning in first-episode psychosis: A network analysis approach. *Psychological Medicine*, 1–9. https://doi.org/10.1017/S0033291719002113

Contreras, A., Nieto, I., Valiente, C., Espinosa, R., & Vazquez, C. (2019). The study of psychopathology from the network analysis perspective: A systematic review. *Psychotherapy and Psychosomatics*, **88**(2), 71–83. https://doi.org/10.1159/000497425

Cowman, M., Holleran, L., Lonergan, E., O'Connor, K., Birchwood, M., & Donohoe, G. (2021). Cognitive predictors of social and occupational functioning in early psychosis: a systematic review and meta-analysis of cross-sectional and longitudinal data. *Schizophrenia Bulletin*, **47**(5), 1243–1253. https://doi.org/10.1093/schbul/sbab033

Cramer, A. O. J., Waldorp, L. J., van der Maas, H. L. J., & Borsboom, D. (2010). Comorbidity: A network perspective. *The Behavioral and Brain Sciences*, **33**(2–3), 137–150; discussion 150–193. https://doi.org/10.1017/S0140525X09991567

Dickinson, D., & Coursey, R. D. (2002). Independence and overlap among neurocognitive correlates of community functioning in schizophrenia. *Schizophrenia Research*, **56**(1–2), 161–170. https://doi.org/10.1016/s0920-9964(01)00229-8

Dominguez, M. de G., Viechtbauer, W., Simons, C. J. P., van Os, J., & Krabbendam, L. (2009). Are psychotic psychopathology and neurocognition orthogonal? A systematic review of their associations. *Psychological Bulletin*, **135**(1), 157–171. https://doi.org/10.1037/a0014415

Epskamp, S., Borsboom, D., & Fried, E. I. (2018). Estimating psychological networks and their accuracy: A tutorial paper. *Behavior Research Methods*, **50**(1), 195–212. https://doi.org/10.3758/s13428-017-0862-1

Epskamp, S., Cramer, A. O. J., Waldorp, L. J., Schmittmann, V. D., & Borsboom, D. (2012). qgraph: network visualizations of relationships in psychometric data. *Journal of Statistical Software*, **48**, 1–18. https://doi.org/10.18637/jss.v048.i04

Epskamp, S., & Fried, E. I. (2018). A tutorial on regularized partial correlation networks. *Psychological Methods*, **23**(4), 617–634. https://doi.org/10.1037/met0000167

Esfahlani, F. Z., Sayama, H., Visser, K. F., & Strauss, G. P. (2017). Sensitivity of the Positive and Negative Syndrome Scale (PANSS) in detecting treatment effects via network analysis. *Innovations in Clinical Neuroscience*, **14**(11–12), 59–67.

Evensen, J., Røssberg, J. I., Barder, H., Haahr, U., Hegelstad, W. ten V., Joa, I., … McGlashan, T. (2012). Apathy in first episode psychosis patients: A ten year longitudinal follow-up study. *Schizophrenia Research*, **136**(1–3), 19–24. https://doi.org/10.1016/j.schres.2011.12.019

Fervaha, G., Foussias, G., Agid, O., & Remington, G. (2014). Impact of primary negative symptoms on functional outcomes in schizophrenia. *European Psychiatry: The Journal of the Association of European Psychiatrists*, **29**(7), 449–455. https://doi.org/10.1016/j.eurpsy.2014.01.007

Fervaha, G., Zakzanis, K. K., Foussias, G., Graff-Guerrero, A., Agid, O., & Remington, G. (2014). Motivational deficits and cognitive test performance in schizophrenia. *JAMA Psychiatry*, **71**(9), 1058–1065. https://doi.org/10.1001/jamapsychiatry.2014.1105

Fett, A.-K. J., Viechtbauer, W., Dominguez, M.-G., Penn, D. L., van Os, J., & Krabbendam, L. (2011). The relationship between neurocognition and social cognition with functional outcomes in schizophrenia: A meta-analysis. *Neuroscience and Biobehavioral Reviews*, **35**(3), 573–588. https://doi.org/10.1016/j.neubiorev.2010.07.001

Fokkema, M., Smits, N., Kelderman, H., & Cuijpers, P. (2013). Response shifts in mental health interventions: An illustration of longitudinal measurement invariance. *Psychological Assessment*, **25**(2), 520–531. https://doi.org/10.1037/a0031669

Fruchterman, T. M. J., & Reingold, E. M. (1991). Graph drawing by force-directed placement. *Software: Practice and Experience*, **21**(11), 1129–1164. https://doi.org/10.1002/spe.4380211102

Galderisi, S., Rucci, P., Kirkpatrick, B., Mucci, A., Gibertoni, D., Rocca, P., … Maj, M. (2018). Interplay among psychopathologic variables, personal resources, context-related factors, and real-life functioning in individuals with schizophrenia: A network analysis. *JAMA Psychiatry*, **75**(4), 396–404. https://doi.org/10.1001/jamapsychiatry.2017.4607

Gee, B., Hodgekins, J., Fowler, D., Marshall, M., Everard, L., Lester, H., … Birchwood, M. (2016). The course of negative symptom in first episode psychosis and the relationship with social recovery. *Schizophrenia Research*, **174**(1), 165–171. https://doi.org/10.1016/j.schres.2016.04.017

Gold, J. M., Waltz, J. A., Prentice, K. J., Morris, S. E., & Heerey, E. A. (2008). Reward processing in schizophrenia: A deficit in the representation of value. *Schizophrenia Bulletin*, **34**(5), 835–847. https://doi.org/10.1093/schbul/sbn068

González-Ortega, I., de los Mozos, V., Echeburúa, E., Mezo, M., Besga, A., Ruiz de Azúa, S., … González-Pinto, A. (2013). Working memory as a predictor of negative symptoms and functional outcome in first episode psychosis. *Psychiatry Research*, **206**(1), 8–16. Scopus. https://doi.org/10.1016/j.psychres.2012.08.025

Griffiths, S. L., Leighton, S. P., Mallikarjun, P. K., Blake, G., Everard, L., Jones, P. B., … Upthegrove, R. (2021). Structure and stability of symptoms in first episode psychosis: A longitudinal network approach. *Translational Psychiatry*, **11**(1), 1–8. https://doi.org/10.1038/s41398-021-01687-y

Hajdúk, M., Penn, D. L., Harvey, P. D., & Pinkham, A. E. (2021). Social cognition, neurocognition, symptomatology, functional competences and outcomes in people with schizophrenia – A network analysis perspective. *Journal of Psychiatric Research*, **144**, 8–13. https://doi.org/10.1016/j.jpsychires.2021.09.041

Hartmann-Riemer, M. N., Hager, O. M., Kirschner, M., Bischof, M., Kluge, A., Seifritz, E., & Kaiser, S. (2015). The association of neurocognitive impairment with diminished expression and apathy in schizophrenia. *Schizophrenia Research*, **169**(1), 427–432. https://doi.org/10.1016/j.schres.2015.10.032

Harvey, P. D., Koren, D., Reichenberg, A., & Bowie, C. R. (2006). Negative symptoms and cognitive deficits: What is the nature of their relationship? *Schizophrenia Bulletin*, **32**(2), 250–258. https://doi.org/10.1093/schbul/sbj011

Hasson-Ohayon, I., Goldzweig, G., Lavi-Rotenberg, A., Luther, L., & Lysaker, P. H. (2018). The centrality of cognitive symptoms and metacognition within the interacting network of symptoms, neurocognition, social cognition and metacognition in schizophrenia. *Schizophrenia Research*, **202**, 260–266. https://doi.org/10.1016/j.schres.2018.07.007

Henry, T. R., Robinaugh, D. J., & Fried, E. I. (2021). On the control of psychological networks. *Psychometrika*. https://doi.org/10.1007/s11336-021-09796-9

Herniman, S. E., Phillips, L. J., Wood, S. J., Cotton, S. M., Liemburg, E. J., & Allott, K. A. (2021). Interrelationships between depressive symptoms and positive and negative symptoms of recent onset schizophrenia spectrum disorders: A network analytical approach. *Journal of Psychiatric Research*, **140**, 373–380. https://doi.org/10.1016/j.jpsychires.2021.05.038

https://doi.org/10.1017/S0033291725000212 Published online by Cambridge University Press

Heydebrand, G., Weiser, M., Rabinowitz, J., Hoff, A. L., DeLisi, L. E., & Csernansky, J. G. (2004). Correlates of cognitive deficits in first episode schizophrenia. *Schizophrenia Research*, **68**(1), 1–9. https://doi.org/10.1016/S0920-9964(03)00097-5

Ho, B. C., Nopoulos, P., Flaum, M., Arndt, S., & Andreasen, N. C. (1998). Two-year outcome in first-episode schizophrenia: Predictive value of symptoms for quality of life. *The American Journal of Psychiatry*, **155**(9), 1196–1201. https://doi.org/10.1176/ajp.155.9.1196

Izquierdo, A., Cabello, M., Leal, I., Mellor-Marsá, B., Ayora, M., Bravo-Ortiz, M.-F., … AGES-CM Group. (2021). The interplay between functioning problems and symptoms in first episode of psychosis: An approach from network analysis. *Journal of Psychiatric Research*, **136**, 265–273. https://doi.org/10.1016/j.jpsychires.2021.02.024

Joyce, E. M., Hutton, S. B., Mutsatsa, S. H., & Barnes, T. R. E. (2005). Cognitive heterogeneity in first-episode schizophrenia. *The British Journal of Psychiatry*, **187**(6), 516–522. https://doi.org/10.1192/bjp.187.6.516

Lindgren, M., Holm, M., Kieseppä, T., & Suvisaari, J. (2020). Neurocognition and social cognition predicting 1-year outcomes in first-episode psychosis. *Frontiers in Psychiatry*, **11**. Scopus. https://doi.org/10.3389/fpsyt.2020.603933

Milev, P., Ho, B.-C., Arndt, S., & Andreasen, N. C. (2005). Predictive values of neurocognition and negative symptoms on functional outcome in schizophrenia: A longitudinal first-episode study with 7-year follow-up. *American Journal of Psychiatry*, **162**(3), 495–506. https://doi.org/10.1176/appi.ajp.162.3.495

Nestor, P. G., Levitt, J. J., Ohtani, T., Newell, D. T., Shenton, M. E., & Niznikiewicz, M. (2022). Loosening of associations in chronic schizophrenia: Intersectionality of verbal learning, negative symptoms, and brain structure. *Schizophrenia Bulletin Open*, **3**(1), sgac004. https://doi.org/10.1093/schizbullopen/sgac004

Oertel, V., Kraft, D., Alves, G., Knöchel, C., Ghinea, D., Storchak, H., … Stäblein, M. (2019). Associative memory impairments are associated with functional alterations within the memory network in schizophrenia patients and their unaffected first-degree relatives: An fMRI study. *Frontiers in Psychiatry*, **10**. Retrieved from https://doi.org/10.3389/fpsyt.2019.00033

Pe, M. L., Kircanski, K., Thompson, R. J., Bringmann, L. F., Tuerlinckx, F., Mestdagh, M., … Gotlib, I. H. (2015). Emotion-network density in major depressive disorder. *Clinical Psychological Science*, **3**(2), 292–300. https://doi.org/10.1177/2167702614540645

Piao, Y. H., Yun, J.-Y., Nguyen, T. B., Kim, W.-S., Sui, J., Kang, N.-I., … Chung, Y. C. (2021). *Longitudinal symptom network structure in first-episode psychosis: A possible marker for remission*. Psychological Medicine, 1–9. https://doi.org/10.1017/S0033291720005280

Quilty, L. C., Robinson, J. J., Rolland, J.-P., Fruyt, F. D., Rouillon, F., & Bagby, R. M. (2013). The structure of the Montgomery-Åsberg depression rating scale over the course of treatment for depression. *International Journal of Methods in Psychiatric Research*, **22**(3), 175–184. https://doi.org/10.1002/mpr.1388

Rabinowitz, J., Levine, S. Z., Garibaldi, G., Bugarski-Kirola, D., Berardo, C. G., & Kapur, S. (2012). Negative symptoms have greater impact on functioning than positive symptoms in schizophrenia: Analysis of CATIE data. *Schizophrenia Research*, **137**(1), 147–150. https://doi.org/10.1016/j.schres.2012.01.015

Raucher-Chéné, D., Thibaudeau, E., Sauvé, G., Lavigne, K. M., & Lepage, M. (2021). Understanding others as a mediator between verbal memory and negative symptoms in schizophrenia-spectrum disorder. *Journal of Psychiatric Research*, **143**, 429–435. https://doi.org/10.1016/j.jpsychires.2021.10.007

Reeder, C., Huddy, V., Cella, M., Taylor, R., Greenwood, K., Landau, S., & Wykes, T. (2017). A new generation computerised metacognitive cognitive remediation programme for schizophrenia (CIRCuiTS): A randomised controlled trial. *Psychological Medicine*, **47**(15), 2720–2730. https://doi.org/10.1017/S0033291717001234

Salagre, E., Grande, I., Solé, B., Mezquida, G., Cuesta, M. J., Díaz-Caneja, C. M., … PEPs Group. (2020). Exploring risk and resilient profiles for functional impairment and baseline predictors in a 2-year follow-up first-episode psychosis cohort using latent class growth analysis. *Journal of Clinical Medicine*, **10**(1), E73. https://doi.org/10.3390/jcm10010073

Strauss, G. P., Nuñez, A., Ahmed, A. O., Barchard, K. A., Granholm, E., Kirkpatrick, B., … Allen, D. N. (2018). The latent structure of negative symptoms in schizophrenia. *JAMA Psychiatry*, **75**(12), 1271–1279. https://doi.org/10.1001/jamapsychiatry.2018.2475

Tandon, R., Nasrallah, H. A., & Keshavan, M. S. (2009). Schizophrenia, 'just the facts' 4. Clinical features and conceptualization. *Schizophrenia Research*, **110**(1–3), 1–23. https://doi.org/10.1016/j.schres.2009.03.005

Tibshirani, R. (1996). Regression shrinkage and selection via the lasso. *Journal of the Royal Statistical Society: Series B (Methodological)*, **58**(1), 267–288. https://doi.org/10.1111/j.2517-6161.1996.tb02080.x

Tinch-Taylor, R., Pickles, A., Stringer, D., Csipke, E., Cella, M., McCrone, P., … Wykes, T. (2024). Understanding the mechanisms of cognitive remediation on recovery in people with early psychosis: A mediation and moderation analysis. *Schizophrenia Bulletin*, sbae021. https://doi.org/10.1093/schbul/sbae021

van Borkulo, C., Boschloo, L., Borsboom, D., Penninx, B. W. J. H., Waldorp, L. J., & Schoevers, R. A. (2015). Association of symptom network structure with the course of depression. *JAMA Psychiatry*, **72**(12), 1219–1226. https://doi.org/10.1001/jamapsychiatry.2015.2079

van Borkulo, C. D., van Bork, R., Boschloo, L., Kossakowski, J. J., Tio, P., Schoevers, R. A., … Waldorp, L. J. (2022). Comparing network structures on three aspects: A permutation test. *Psychological Methods*. https://doi.org/10.1037/met0000476

van Rooijen, G., Isvoranu, A.-M., Kruijt, O. H., van Borkulo, C. D., Meijer, C. J., Wigman, J. T. W., … GROUP investigators. (2018). A state-independent network of depressive, negative and positive symptoms in male patients with schizophrenia spectrum disorders. *Schizophrenia Research*, **193**, 232–239. https://doi.org/10.1016/j.schres.2017.07.035

Ventura, J., Hellemann, G. S., Thames, A. D., Koellner, V., & Nuechterlein, K. H. (2009). Symptoms as mediators of the relationship between neurocognition and functional outcome in schizophrenia: A meta-analysis. *Schizophrenia Research*, **113**(2), 189–199. https://doi.org/10.1016/j.schres.2009.03.035

Vita, A., Barlati, S., Ceraso, A., Nibbio, G., Ariu, C., Deste, G., & Wykes, T. (2021). Effectiveness, core elements, and moderators of response of cognitive remediation for schizophrenia: A systematic review and meta-analysis of randomized clinical trials. *JAMA Psychiatry*, **78**(8), 848–858. https://doi.org/10.1001/jamapsychiatry.2021.0620

Wykes, T., Huddy, V., Cellard, C., McGurk, S. R., & Czobor, P. (2011). A meta-analysis of cognitive remediation for schizophrenia: Methodology and effect sizes. *The American Journal of Psychiatry*, **168**(5), 472–485. https://doi.org/10.1176/appi.ajp.2010.10060855

Wykes, T., Joyce, E., Velikonja, T., Watson, A., Aarons, G., Birchwood, M., … Greenwood, K. (2018). The CIRCuiTS study (Implementation of cognitive remediation in early intervention services): Protocol for a randomised controlled trial. *Trials*, **19**(1), 1–12.

Wykes, T., Stringer, D., Boadu, J., Tinch-Taylor, R., Csipke, E., Cella, M., … Joyce, E. M. (2023). Cognitive remediation works but how should we provide it? An adaptive randomized controlled trial of delivery methods using a patient nominated recovery outcome in first-episode participants. *Schizophrenia Bulletin*, **49**(3), 614–625. https://doi.org/10.1093/schbul/sbac214

https://doi.org/10.1017/S0033291725000212 Published online by Cambridge University Press