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An Item Response Theory Analysis of the Prodromal Questionnaire-Brief Child Version: Developing a Screening Form That Informs Understanding of Self-Reported Psychotic-Like Experiences in Childhood

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The Prodromal Questionnaire-Brief Child Version (PQ-BC) has been developed as a tool for identifying psychotic-like experiences (PLEs) in school-age children. The current study examined the psychometric properties of the PQ-BC, examined how well the PQ-BC estimates the latent construct of PLEs ($\hat{\theta}$), and began the process of developing a screening form informed by item response theory (IRT). Utilizing the baseline (N = 11,129) sample from the Adolescent Brain Cognitive Development study, we examined which PQ-BC items provide the most information and best discriminate individuals experiencing PLEs. Using hierarchical linear models (HLMs), we found that $\hat{\theta}$ scores were significantly associated with several previously identified predictors of psychosis spectrum symptoms (i.e., history of psychosis, internalizing symptoms, cognitive impairments, developmental milestone delays, and resting-state functional connectivity impairments) at baseline and Year 1 (n = 5,532). Using item-level information and discrimination parameters of the PQ-BC from the baseline sample, we created a 7-item screening form. HLMs generally found significant associations between screening form scores for both baseline and Year 1 with the aforementioned predictors. The analyses provide evidence for the validity of a screening form derived from the PQ-BC using IRT-derived parameters. This screening form could prove useful when the full measure is not feasible.

General Scientific Summary

The current study examined a measure of unusual thoughts and unusual perceptual experiences in school-age children, specifically looking at which items in the measure were the most informative and most likely to be endorsed by individuals with higher levels of these experiences. Using this information, the current study developed a screening form of this measure and found that this screening form showed the expected associations with predictors of these unusual experiences (e.g., family history of psychosis, impaired cognition, delays in attaining motor and speech milestones, and symptoms of depression and anxiety).

Keywords: item response theory, psychotic-like experiences, psychosis spectrum, screening form, nomological network

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Data used in the preparation of this article were obtained from the Adolescent Brain Cognitive Development (ABCD) study (https://abcdstudy.org), held in the NIMH Data Archive (NDA). This is a multisite, longitudinal study designed to recruit more than 10,000 children age 9–10 and follow them over 10 years into early adulthood. The ABCD Study is supported by the National Institutes of Health and additional federal partners under awards U01DA041022, U01DA041028, U01DA041048, U01DA041089, U01DA041106, U01DA041117, U01DA041120, U01DA041134, U01DA041148, U01DA041156, U01DA041174, U24DA041123, U24DA041147, U01DA041093, and U01DA041025. A full list of supporters is available at https://abcdstudy.org/federal-partners.html. A listing of participating sites and a complete listing of the study investigators can be found at https://abcdstudy.org/study-sites/. ABCD consortium investigators designed and implemented the study and/or provided data but did not necessarily participate in analysis or writing of this report. This article reflects the views of the authors and may not reflect the opinions or views of the NIH or ABCD consortium investigators. The ABCD data repository grows and changes over time. The ABCD data used in this report came from DOI 10.15154/1503209. This work was supported by National Institute on Drug Abuse Grant U01 DA041120 (Deanna M. Barch), and National Institute of Mental Health Grants MH014677 (Nicole R. Karcher) and 2T32MH100019-06 (Michael T. Perino). We thank the families participating in the Adolescent Brain and Cognitive Development study. The manuscript contains original work that has not been published or submitted for publication elsewhere. All procedures were approved by the institutional review board at each Adolescent Brain Cognitive Development collection site (WUSTL IRB: 201708123; https://abcdstudy.org/study-sites/). Nicole R. Karcher and Michael T. Perino contributed equally to this work.

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Since its development, the Prodromal Questionnaire has been an important tool to assist in identifying individuals at risk for the development of psychosis spectrum disorders (Loewy, Bearden, Johnson, Raine, & Cannon, 2005; Savill, D'Ambrosio, Cannon, & Loewy, 2018). Abbreviated versions of the Prodromal Questionnaire have been developed to shorten administration time while providing valid and reliable estimates of psychotic-like experiences (PLEs; Loewy, Pearson, Vinogradov, Bearden, & Cannon, 2011). PLEs are subclinical psychotic symptoms, including subthreshold unusual beliefs and perceptual distortions. PLEs in childhood can be considered as unspecific, though potentially subclinical, expression of psychosis (Rimvall et al., 2019; van Os & Reininghaus, 2016; Wüsten et al., 2018) experienced by approximately 13% to 17% of all children (Kelleher et al., 2012; Laurens et al., 2007). PLEs are thought to arise as a result of a combination of genetic, environmental, and pathophysiological factors (e.g., disruptions in connectivity), factors that can be indexed using predictors of psychosis spectrum symptoms, including family history of psychosis, cognitive functioning (and especially working memory), developmental milestone delays and motor impairments, and impairments in resting state functional connectivity (RSFC; Cannon et al., 2002; Linscott & van Os, 2013; Satterthwaite et al., 2015; van Os, Linscott, Myin-Germeys, Delespaul, & Krabbendam, 2009). The current study examined the extent to which the latent construct of PLEs (θ) in school-age children is associated with these psychosis spectrum symptom predictors.

The most widely used short form of the Prodromal Questionnaire is the Prodromal Questionnaire-Brief (Loewy et al., 2011). This questionnaire has been extensively validated in a variety of populations, including both clinical and nonclinical samples, and was designed as part of a two-step screening process in conjunction with a clinical assessment. In addition, the Prodromal Questionnaire-Brief was adapted for a childhood sample, titled the Prodromal Questionnaire-Brief Child Version (PQ-BC; Karcher et al., 2018). The PQ-BC is a 21-item scale validated for use with 9- to 10-year-old children and used to identify PLEs in this nonclinical population. However, future community-based assessment efforts will likely necessitate briefer measures for screening children with self-reported PLEs. The current study aimed to better understand θ, examine the psychometric properties of the PQ-BC, and begin the process of developing a screening form using item response theory (IRT).

IRT (Lawley, 1943) refers to psychometric modeling techniques (Lord, 1953; Rasch, 1960; Samejima, 1969) used to develop, improve, and scale assessments of individual differences. IRT offers researchers detailed information about the items used in psychological assessments and their relationship to the underlying trait. IRT differs from classical test theory (CTT) techniques in the assumption that individual test items reflect varying levels of an underlying trait (Hambleton, Swaminathan, & Rogers, 1991). By accounting for information about both individual response profiles and scalar properties, IRT can provide researchers with significant advantages for understanding how psychological instruments tap into the latent constructs. For example, IRT techniques can provide information about item discriminability (i.e., how well a test item delineates low trait individuals from high trait individuals), difficulty (i.e., how high on a trait one must be to respond affirmatively to a particular question), and total trait information (i.e., how responses across the whole scale should be translated to estimate an individual's true trait score). IRT methodology has been used estimate trait levels within individuals (Hays, Morales, & Reise, 2000) and identify items for the creation of short-form measures (Maples-Keller et al., 2019), just to name a few applications.

IRT applications may be particularly advantageous for trait assessment of clinically relevant phenomena (Reise & Waller, 2009); rather than treating all symptoms of clinical conditions as equally important, IRT allows for symptom presence (via responses on specific test items) to be weighted based on individual and population responses. Participants responses are scored based on individual and test characteristics, which translate to a theoretically more accurate score along the measured trait. Given that psychopathological assessments often focus on constructs situated at extreme values (Reise & Waller, 2009), the greater distribution at extrema of trait situations that IRT approaches provide is a particularly important assessment concern from a psychometric standpoint. IRT is a methodology well suited for determining how well the PQ-BC assesses across the range of latent trait (θ) of PLEs, including the range of the trait that the PQ-BC is measuring. Thus, the current study will utilize IRT in order to examine how well the PQ-BC estimates the latent trait ($\hat{\theta}$) of PLEs as well as associations between $\hat{\theta}$ and predictors of psychosis spectrum symptoms, providing valuable insight about PLEs in school-age children. In particular, it will help inform key questions such as the age at which PLEs can manifest, whether predicted associations with external variables are present even at Ages 9 and 10, and the distribution of this trait in a large population of 9- to 10-year-olds. In addition, IRT will be used to create a PQ-BC screening form for efficiently identifying PLEs in school-age children.

The current study aimed to better understand θ in school-age children, and is the first to examine psychometric properties of the PQ-BC using the entire baseline sample from the Adolescent Brain Cognitive Development (ABCD) study as well as the first to analyze the PQ-BC using IRT analyses to begin the process of developing a screening form, including examining the psychometric properties of the screening form. Our goals were to (a) examine which PQ-BC items provide the most information and discriminate individuals experiencing PLEs, (b) examine the associations between $\hat{\theta}$ and predictors of psychosis spectrum symptoms (i.e., parent-rated PLEs, internalizing symptoms, cognitive deficits, developmental milestone delays, resting-state functional connectivity) at baseline and Year 1 of the ABCD data, and (c) use the information and discrimination parameters to assess the PQ-BC and derive a screening form.

Method

Participants

A sample of 11,874 individuals was obtained from the ABCD study (Data Release 2.0.1), a large-scale study tracking 9- to 10-year-olds recruited from 21 research sites across the United States (see the online supplemental materials for study-wide exclusion criteria; Barch et al., 2018). Institutional review board approval was obtained for each site before data collection. All parents provided written informed consent and all children provided assent.

These data were accessed from the National Institutes of Mental Health Data Archive (see the acknowledgments paragraph for more information). Participants were removed from analyses in the case of missing data (baseline, $n = 744$; Year 1, $n = 237$). The

final sample size for baseline analyses was 11,129 individuals (47.9% female; 52.6% White, 20.1% Hispanic, 14.6% African American, 2.2% Asian, and 10.5% Other; Year 1: final sample size, n = 5,532; 47.7% female; 59.3% White, 18.1% Hispanic, 10.2% African American, 2.3% Asian, and 10.0% Other). Only a subset of individuals with complete imaging data were included in imaging data analyses (baseline: n = 8,859; Year 1: n = 4,283).

Measures

Prodromal Questionnaire-Brief Child Version. Participants completed the PQ-BC (Loewy et al., 2011), a 21-item self-report questionnaire with a visual response scale included as a Distress scale (see the online supplemental materials for additional questionnaire details; Hirshfeld-Becker, 2006). As previously mentioned, the PQ-BC demonstrates validity in the ABCD sample (Karcher et al., 2018). Consistent with previous research (Karcher et al., 2018), the Total and Distress scores were calculated. The Total score is the sum of endorsed questions (i.e., 0 = no, 1 = yes). The Distress score is the total number of endorsed questions weighted by level of distress (that is, 0 = no, 1 = yes [but no distress], 2–6 = yes [1+ score on Distress scale]). Consistent with previous work (Karcher et al., 2018), we also examined log-transformed Distress scores (Howell, 2007; formula = LG10[X + 1]). Sixty-one percent of the baseline sample endorsed at least one PQ-BC question (46.2% for Year 1), with 42.9% reporting distress associated with at least one PQ-BC question (28.8% for Year 1). Both the PQ-BC Total (α = .86; Year 1, α = .87) and Distress (α = .87; Year 1, α = .87) scores showed high internal reliability, which did not increase when any item was deleted. The correlation coefficients between each item and the PQ-BC Total score were 0.35 to 0.52 (Year 1 = 0.35 to 0.55), and for the Distress score, 0.38 to 0.54 (Year 1 = 0.37 to 0.60).

Symptom measures. The parent and youth versions of the validated and computerized Kiddie-Structured Assessment for Affective Disorders and Schizophrenia for *DSM–5* (Kaufman et al., 1997; Kobak, Kratochvil, Stanger, & Kaufman, 2013) were used in current analyses as measures of psychopathology (Barch et al., 2018). We examined baseline internalizing symptoms using a composite of summations of current child-rated depression and generalized anxiety disorder symptoms. A measure of parent-rated child PLEs was created from four items from the Child Behavior Checklist (CBCL; Achenbach, 2009; Ducharme et al., 2015; Sheffield, Kandala, Burgess, Harms, & Barch, 2016). These questions were "Hears sounds or voices that aren't there," "Sees things that aren't there," "Strange behavior," and "Strange ideas." Each question was scored from 0 = *not true*, 1 = *somewhat or sometimes true*, and 2 = *very true or often true*.

History of psychosis in first-degree relatives was assessed at baseline using the parent-rated Family History Assessment Module Screener (Rice et al., 1995), with each scored as either "present" or "absent." A financial adversity index was computed as the sum of binary responses to seven parent-rated questions of financial adversity from a demographic questionnaire (e.g., "Were evicted from your home for not paying the rent or mortgage?"; see the online supplemental materials for all questions).

Neuropsychological test battery. At baseline, participants completed all tests within the National Institutes of Health Toolbox Cognitive Battery (NIHTB-CB; Weintraub et al., 2013). The NIHTB-CB consists of seven tasks, grouped into two composite scores. The fluid composite consists of Flanker Inhibitory Control and Attention, List Sorting Working Memory, Dimensional Change Card Sort, Pattern Comparison Processing Speed, and Picture Sequence Memory. The crystallized composite consists of Picture Vocabulary and Oral Reading Recognition test (see Weintraub et al., 2013, for descriptions of individual NIHTB-CB tests). Consistent with previous research using the ABCD sample to examine associations with PQ-BC scores, the current study examined associations with the fluid and crystallized composite scores as well as the List Sorting Working Memory task (Karcher et al., 2018). The current study utilized uncorrected NIHTB-CB scores, but all analyses include age and sex as covariates.

Developmental milestones. The parent assessment battery included questions regarding motor and speech development rated at baseline (Achenbach, 2009; Kessler et al., 2009). The motor delays composite was coded as the summation of delays in attaining motor milestones (scored as 0 = *no delay* or 1 = *delay*; individual milestones: rolling over [delay = 6 months or later], sitting [delay = after 9 months], and walking [delay = after 18 months]), parent-rated concern regarding motor development (0 = *earlier*, 1 = *average*, 2 = *later*), and parent-rated current child clumsiness (0 = *not true*, 1 = *somewhat or sometimes true*, and 2 = *very true or often true*). The speech delays composite was coded as the summation of a delay in speaking the first word (scored as 0 = *no delay* or 1 = *delay*; delay = after 12 months) and parent-rated concern regarding speech development (0 = *earlier*, 1 = *average*, 2 = *later*).

Consistent with previous research using the ABCD sample to examine associations with PQ-BC scores, the current study examined associations with the motor and speech delays composite scores as well as the parent-rated current child clumsiness (Karcher et al., 2018).

Resting state functional connectivity. Consistent with previous research using the ABCD sample to examine associations with PQ-BC scores (Karcher, O'Brien, Kandala, & Barch, 2019), we examined cingulo-opercular (CON) within-network connectivity, cingulo-parietal (CPAR) within-network connectivity, default mode (DMN) within-network connectivity, CON to cerebellar connectivity, and CPAR to cerebellar connectivity. In terms of collecting RSFC data, all children were run on a 3T scanner (either Siemens or General Electric; note that we followed recent guidance from ABCD about excluding the data from the Philips scanners) with a 32-channel head coil and completed T1-weighted and T2-weighted structural scans (1 mm isotropic). Participants also completed four 5-min resting-state BOLD scans, with their eyes open and fixated on a crosshair. Resting state images were acquired in the axial plane using an EPI sequence. Other resting-state image parameters varied by 3T scanner and have been previously detailed[1] (Casey et al., 2018). The data analysis pipeline has also been detailed previously (Karcher et al., 2019). Briefly, the aforementioned RSFC metrics were created using pair-wise correlations for regions of interest (ROIs) within functionally defined parcellations (i.e., Gordon networks; Gordon et al., 2016) and subcortical

[1] Please see https://abcdstudy.org/images/Protocol_Imaging_Sequences.pdf for a summary of resting-state image parameters.

ROIs (i.e., cerebellum; Fischl et al., 2002). The Fisher *z*-transform of the correlation values were examined.

IRT Methodology

IRT models assume that the latent trait being measured is unidimensional (Hambleton et al., 1991) or has a dominant first factor (Drasgow & Hulin, 1990), which the PQ-BC had satisfied with its previously established single factor structure (PQ-BC; Karcher et al., 2018). This is consistent with evidence from large (that is, between 449 [Fonseca-Pedrero, Gooding, Ortuño-Sierra, & Paino, 2016] and 15,000 [Fonseca-Pedrero, Inchausti, Pérez-Albéniz, & Ortuño-Sierra, 2018]) community samples of adolescents and adults for a one-factor structure for the PQ-B (Cicero, Krieg, & Martin, 2019; Fonseca-Pedrero et al., 2016, 2018). Confirmatory factor analyses results based on the larger baseline sample (N = 11,129) again demonstrated a single-factor solution (for Total scores: comparative fit index [CFI] = 0.929, root mean square error of approximation [RMSEA] = 0.026; for binned Distress scores [see Statistical Analyses section for binning procedure]: CFI = 0.923, RMSEA = 0.023; see the online supplemental materials for additional details about factor analyses [Brown, 2014; Muthén & Muthén, 2010; Rosseel, 2012]).

After passing this requirement, we assessed item performance by applying a two-parameter logistic (2PL) graded response model using the ltm R package (Rizopoulos, 2006); 2PL models create item characteristic curves for each test item, which are logistic functions that represent how responses on said item relates to its underlying trait (i.e., the amount of information the item provides), denoted as $\hat{\theta}$ (Edelen & Reeve, 2007), as well as item response functions (IRFs), which can be used to assess estimation and parameter information. The two parameters assessed in such models—difficulty (or location/threshold) parameters, denoted by *b*, and discrimination (or slope of the IRF at *b*) parameter, denoted by *a*, can be utilized to assess how well (or poorly) an item performs at measuring the underlying trait of interest, as well as individual strengths or weakness of particular items. Discrimination parameters are often used to identify items that more successfully discriminate between those who do (or do not) possess the underlying trait, with high *a* items indicating stronger relationships with the underlying trait compared with lower *a* items. Threshold parameters reflect the point at which the probability of endorsing the trait is chance; therefore, higher *b* parameters serve as markers of difficulty, for which larger values suggest respondents must possess higher trait thresholds for endorsement.

Although 2PL models were originally suited for binary response choices (Reise & Waller, 2009), graded response modeling represents a generalization of this approach translatable to polytomous scale data (Samejima, 1969). In our data, the raw response data was translated into an ordinal scale using the procedure addressed in the prior scale validation (Karcher et al., 2018). To increase the efficiency of item parameter estimation (Cho, Drasgow, & Cao, 2015; Stark, Chernyshenko, & Drasgow, 2006), we binned the seven response categories into three categories—0 = *symptom not present* ("no" to trait), 1 = *symptom present without (or mild) distress* ("yes" to trait but reported either no distress or distress = 2 or 3), and 2 = *symptom present with distress* ("yes" to trait and distress = 4, 5, or 6)—a strategy highlighted as useful when incorporating items with low endorsement rates (Chernyshenko, Stark, Drasgow, & Roberts, 2007).

Statistical Analyses

Following IRT analyses, the remainder of the analyses used hierarchical linear models (HLMs). To account for nonindependence of observations because of familial relatedness, family members were treated as clustered observations, as were the 21 ABCD research sites. All HLM analyses were conducted in the R lme4 package (Bates, Mächler, Bolker, & Walker, 2015; multcomp package for multiple comparison analyses [Hothorn, Bretz, & Westfall, 2008]) with family unit and research site modeled as random intercepts, and age, sex, financial adversity, family history of psychosis, and ethnicity included as covariates. First, we examined the longitudinal stability from baseline to Year 1 for all PQ-BC scores, including $\hat{\theta}$ scores and differences between significant correlations were examined using Meng's *z*-test procedures (Meng, Rosenthal, & Rubin, 1992). HLMs analyzed the associations between $\hat{\theta}$ scores for both baseline and Year 1, and the following predictors previously identified as significantly associated with PLEs in a subset of the ABCD baseline sample (Karcher et al., 2018): (a) parent-rated PLEs, (b) history of psychosis, (c) internalizing symptom composite, (d) neuropsychological test performance (crystallized or fluid intelligence NIHTB-CB composites, then the working memory subset), (e) motor and speech developmental milestone delays (composites, then the individual clumsiness items), and (f) RSFC metrics (CON within-network connectivity, CPAR within-network connectivity, DMN within-network connectivity, CON to cerebellar connectivity, and CPAR to cerebellar connectivity). These estimates were then compared with the Total, Distress, and log-transformed PQ-BC scores for baseline and Year 1, respectively (and differences between significant correlations were examined using Meng's *z*-test procedures; Meng et al., 1992). Then, based on item information and discrimination parameters from baseline ABCD data, we created a screening form with similar psychometric properties as the full PQ-BC. HLMs analyzed the associations between screening form Total, Distress, and log-transformed Distress scores for both baseline and Year 1 with the aforementioned predictors (i.e., Items 1–5) to identify whether the screening form performed in the expected manner at both baseline and Year 1.

Results

IRT Parameters and Information

Item discrimination quantifies how well an item can discriminate individuals at varying levels of θ, with higher discrimination parameter values indicating that the item excels at discriminating low- from high-trait individuals. IRT item discrimination (*a*) ranged from 1.365 to 2.210 (M = 1.819). The discrimination parameters for the PQ-BC are quite high, on average, which indicates that every item is highly discriminatory and that the measured construct (PLEs) is conceptually narrow (Reise, 2009). The means of the two difficulty parameter estimates (*b*) were 1.64 (range = 1.14–2.3) and 2.75 (range = 1.93–3.85), respectively. These estimates reflect the location of the inflection points of the item response functions. Both the *b*1 and *b*2 threshold estimates

are large, positive, and range restricted, which indicates that only people with high trait levels of PLEs are typically endorsing PQ-BC items (i.e., endorsing the item statement with significant distress). Finally, we calculated information provided by each test item, which utilizes both *a* and *b* parameters to estimate how much information a test item contributes to $\hat{\theta}$ (see Figure 1 for the overall test information function for the PQ-BC scores and screening form; see Supplemental Figures 1 and 2 of the online supplemental materials for the individual IRFs; see Table 1 for item parameter estimates and information).

Associations of $\hat{\theta}$ and CTT Indices to Predictors of Psychosis Spectrum Symptoms

The Total and Distress factor scores significantly correlated with $\hat{\theta}$ scores (Total = .915, Distress = .884; *p*s <.001). Next, we examined the longitudinal stability of $\hat{\theta}$ scores from baseline to Year 1. The longitudinal stability of $\hat{\theta}$ scores was $\beta = 0.43$ (95% CI [0.41, 0.45], $p < .001$), which was comparable with other PQ-BC scores (Total scores: $\beta = 0.43$, 95% CI [0.41, 0.46], $p < .001$; Distress: $\beta = 0.40$, 95% CI [0.38, 0.42], $p < .001$; log-transformed Distress: $\beta = 0.43$, 95% CI [0.41, 0.46], $p < .001$). Next, to better understand θ, we also examined the associations between $\hat{\theta}$ scores and psychosis spectrum symptom predictors (i.e., parent-rated PLEs, family history of psychosis, internalizing symptoms, cognitive functioning, developmental milestone delays, RSFC metrics). Baseline $\hat{\theta}$ scores were significantly associated with almost all predictors, with the exception of several of the RSFC metrics (see Table 2). Notably, none of the PQ-BC scores were significantly associated with CON-cerebellar or CPAR-cerebellar connectivity. Furthermore, only baseline log-transformed Distress scores were significantly associated with impaired CPAR connectivity. In terms of discriminant validity, as expected, the CBCL somatization index was not significantly associated with PQ-BC scores, $\beta = -.016$, $p = .21$. As can be seen in Table 2, Year 1 $\hat{\theta}$ scores were also associated with almost all predictors, with the exception of the RSFC metrics. Notably, most Year 1 PQ-BC scores were not significantly associated with RSFC metrics, with the exception of Total, Distress, and $\hat{\theta}$ scores being significantly associated with impaired CON connectivity and Total scores being significantly associated with impaired CPAR connectivity. This provides evidence that $\hat{\theta}$ showed the expected associations with predictors of psychosis spectrum symptoms.

Screening Form

Importantly, the IRT analyses enabled the examination of whether the total number of PQ-BC items could be shortened based on IRT-derived parameters. For the purpose of scale reduction, we prioritized both item-level information and discrimination parameters from baseline ABCD data. Based on this information, we created a screening form comprised of items that ranked in the top 10 for both discrimination and information (see Table 1). This screening form consists of the following questions: 5, 10, 14, 16, 19, 20, and 21 (see Table 1 for question content). This screening form showed fair internal consistency (screening form Total: $\alpha = .72$, Year 1: $\alpha = .71$; screening form Distress: $\alpha = .72$, Year 1: $\alpha = .74$), which did not increase when any item was deleted. In comparison, for the overall PQ-BC Total: $\alpha = .86$, (Year 1: $\alpha = .87$), and for Distress: $\alpha = .87$ (Year 1: $\alpha = .87$). The correlation coefficients between each item and the screening form Total score were 0.33 to 0.48 (Year 1: 0.32–0.52), and for the screening form Distress score, 0.35 to 0.49 (Year 1: 0.37–0.52). The longitudinal stability of the screening form for the Total score was $\beta = 0.35$ (95% CI [0.32, 0.37], $p < .001$), for the Distress score was $\beta = 0.32$ (95% CI [0.29, 0.34], $p < .001$), and for the log-transformed Distress score was $\beta = 0.34$ (95% CI [0.32, 0.36], $p < .001$).

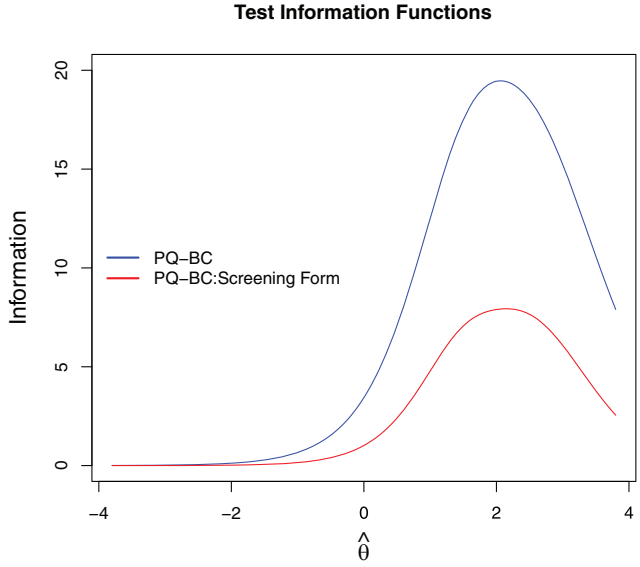

Figure 1. Test information functions for both PQ-BC scores and PQ-BC Screening Form scores. PQ-BC = Prodromal Questionnaire-Brief Child Version; $\hat{\theta}$ = estimates of theta (i.e., estimates of the latent construct of PLEs). See the online article for the color version of this figure.

Table 1
Item Response Theory Parameters for the Baseline ABCD Sample

Item #	PQ-BC question	*a*	*b*1	*b*2	Information provided	Discrimination ranking	Information ranking
1	"Did places that you know well, such as your bedroom, or other rooms in your home, your classroom or school yard, suddenly seem weird, strange or confusing to you; like not the real world?"	1.828	2.228	2.983	2.62	8	13
2	"Did you hear strange sounds that you never noticed before like banging, clicking, hissing, clapping, or ringing in your ears?"	1.660	1.235	2.376	2.6	18	14
3	"Did things you looked at seem different than they usually do; like did they seem shinier or darker, larger or smaller or changed in some other way?"	1.663	1.770	3.276	2.82	16	11
4	"Did you feel like you had special, unusual powers like you could make things happen by magic, or that you could magically know what was inside another person's mind, or magically know what was going to happen in the future when other people could not?"	1.742	1.731	3.583	3.14	14	8
5	"Did you feel that someone else, who is not you, has taken control over the private, personal, thoughts or ideas inside your head?"	**2.103**	**2.139**	**2.668**	**2.85**	**4**	**10**
6	"Did you suddenly find it hard to figure out how to say something quickly and easily so that other people would understand what you meant?"	1.538	1.351	3.119	2.66	20	12
7	"Did you ever feel very certain that you have very special abilities or magical talents that other people do not have?"	1.743	1.704	3.849	3.25	13	5
8	"Did you suddenly feel that you could not trust other people because they seemed to be watching you or talking about you in an unfriendly way?"	1.643	1.136	2.051	2.41	19	19
9	"Did your skin or just beneath your skin suddenly start feeling strange, like bugs crawling?"	1.661	1.540	2.376	2.38	17	20
10	"Did you lose concentration because you noticed sounds in the distance that you usually don't hear?"	**2.079**	**1.395**	**2.283**	**3.23**	**5**	**6**
11	"Although you could not see anything or anyone, did you suddenly start to feel that an invisible energy, creature, or some person was around you?"	1.738	1.224	1.931	2.42	15	18
12	"Did you start to worry at times that your mind was trying to trick you or was not working right?"	1.786	1.781	2.449	2.46	11	17
13	"Did you feel that the world is not real, you are not real, or that you are dead?"	1.795	2.119	2.889	2.57	10	15
14	"Did you feel confused because something you experienced didn't seem real or it seemed imaginary to you?"	**1.945**	**1.589**	**2.764**	**3.21**	**6**	**7**
15	"Did you honestly believe in things that other people would say are unusual or weird?"	1.365	1.953	3.293	2.11	21	21
16	"Did you feel that parts of your body had suddenly changed or worked differently than before; like your legs had suddenly turned to something else or your nose could suddenly smell things you'd never actually smelled before?"	**2.121**	**1.914**	**3.047**	**3.55**	**3**	**1**
17	"Did you feel that sometimes your thoughts were so strong you could almost hear them, as if another person, NOT you, spoke them?"	1.757	1.652	3.032	2.95	12	9
18	"Did you feel that other people might want something bad to happen to you or that you could not trust other people?"	1.798	1.470	2.186	2.53	9	16
19	"Did you suddenly start to see unusual things that you never saw before like flashes, flames, blinding light, or shapes floating in front of you?"	**2.140**	**1.498**	**2.327**	**3.29**	**2**	**3**
20	"Did you suddenly start to be able to see things that other people could not see or they did not seem to see?"	**2.210**	**1.637**	**2.529**	**3.5**	**1**	**2**
21	"Did you suddenly start to notice that people sometimes had a hard time understanding what you were saying, even though they used to understand you well?"	**1.887**	**1.384**	**2.780**	**3.24**	**7**	**4**

Note. ABCD = adolescent brain cognitive development; *a* = discrimination parameter (i.e., how well an item can discriminate individuals at varying levels of the psychotic-like experiences); *b*1 and *b*2 = two difficulty parameter estimates (i.e., how high on trait psychotic-like experiences one must be to respond affirmatively); PQ-BC = Prodromal Questionnaire-Brief Child Version. Bolded questions indicate inclusion in the screening form.

Table 2
Associations of PQ-BC Models for Baseline and Year 1 ABCD Samples

Variable	Total			Distress			Log-transformed distress			$\hat{\theta}$		
	β	*t*	*p*	β	*t*	*p*	β	*t*	*p*	β	*t*	*p*
Baseline (N = 11,129)												
Parent-rated PLEs	0.089	9.55	<.001	0.095	10.11	<.001	0.082	8.86	<.001	0.086	9.28	<.001
Family history of psychosis	0.035	3.71	<.001	0.036	3.86	<.001	0.035	3.70	<.001	0.032	3.44	.001
Internalizing symptoms	0.323	37.79	<.001[a]	0.369	43.51	<.001[b]	0.283	32.65	<.001	0.286	33.28	<.001
Cognitive functioning												
Fluid	−0.058	−5.42	<.001	−0.066	−6.20	<.001	−0.075	−7.14	<.001[c]	−0.069	−6.57	<.001[d]
Crystalized	−0.077	−6.942	<.001	−0.085	−7.58	<.001	−0.098	−8.90	<.001[c]	−0.091	−8.32	<.001[d]
Working memory	−0.055	−5.10	<.001	−0.064	−5.88	<.001	−0.064	−6.04	<.001[c]	−0.060	−5.65	<.001
Developmental milestone delays												
Motor	0.036	3.89	<.001	0.035	3.71	<.001	0.040	4.35	<.001	0.039	4.19	<.001
Speech	0.044	4.63	<.001	0.046	4.80	<.001	0.054	5.74	<.001[c]	0.048	5.17	<.001
Clumsiness	0.031	3.43	.001	0.041	4.44	<.001	0.037	4.04	<.001	0.034	3.70	<.001
RSFC[e]												
CON	−0.025	−2.32	.02	−0.030	−2.75	.006	−0.026	−2.43	.02	−0.027	−2.60	.009
CPAR	−0.005	−0.49	.63	−0.009	−0.87	.39	−0.025	−2.39	.02[c]	−0.017	−1.669	.095[d]
DMN	−0.028	−2.68	.007	−0.030	−2.77	.006	−0.029	−2.71	.007	−0.029	−2.81	.005
CON-cerebellar	0.015	1.42	.16	0.016	1.56	.12	0.014	1.33	.18	0.015	1.45	.15
CPAR-cerebellar	−0.015	−1.52	.13	−0.012	−1.13	.26	−0.015	−1.51	.13	−0.016	−1.61	.11
Year 1 (n = 5,532)												
Parent-rated PLEs	0.037	3.854	<.001	0.033	3.367	<.001	0.085	6.252	<.001	0.088	6.49	<.001[d,f]
Family history of psychosis	0.063	4.673	<.001	0.069	5.082	<.001	0.059	4.432	<.001	0.060	4.47	<.001
Internalizing symptoms	0.241	19.061	<.001[a]	0.234	18.257	<.001[b]	0.218	17.282	<.001	0.215	17.10	<.001
Cognitive functioning												
Fluid	−0.052	−3.463	.001	−0.062	−4.108	<.001	−0.055	−3.685	<.001	−0.052	−3.51	<.001
Crystalized	−0.060	−3.831	<.001	−0.060	−3.816	<.001	−0.092	−5.953	<.001	−0.089	−5.74	<.001[d,f]
Working memory	−0.059	−3.883	<.001	−0.052	−3.385	.001	−0.063	−4.246	<.001	−0.060	−4.03	<.001
Developmental milestone delays												
Motor	0.043	3.240	.001	0.043	3.148	.002	0.053	4.015	<.001	0.048	3.65	<.001
Speech	0.045	3.355	.001	0.042	3.072	.002	0.047	3.517	<.001	0.048	3.59	<.001
Clumsiness	0.051	3.895	<.001	0.051	3.875	<.001	0.051	3.925	<.001	0.049	3.80	<.001
RSFC[e]												
CON	−0.025	−2.13	.03	−0.026	−2.14	.03	−0.026	−1.63	.10	−0.037	−2.30	.02
CPAR	−0.028	−2.44	.01	−0.019	−1.62	.11	−0.013	−0.85	.40	−0.012	−0.80	.42
DMN	−0.012	−1.05	.29	0.006	0.48	.63	−0.013	−0.84	.40	−0.014	−0.92	.36
CON-cerebellar	0.008	0.68	.50	0.004	0.34	.73	0.000	0.02	.98	0.000	0.01	.99
CPAR-cerebellar	−0.012	−1.10	.27	−0.002	−0.22	.83	−0.003	−0.21	.84	0.001	0.07	.94

Note. PQ-BC = Prodromal Questionnaire Brief-Child Version; ABCD = adolescent brain cognitive development; $\hat{\theta}$ = estimates of the latent construct of PLEs, or scores that estimate how responses across the whole scale should be translated to rescore individual's placement along the trait continuum; PLEs = psychotic-like experiences; RSFC = resting-state functional connectivity; CON = cingulo-opercular within-network connectivity; CPAR = cingulo-parietal within-network connectivity; DMN = default mode within-network connectivity.
[a] Associations with Total scores were significantly stronger than $\hat{\theta}$ ($p < .05$). [b] Associations with Distress scores were significantly stronger than $\hat{\theta}$ ($p < .05$). [c] Associations with log-transformed Distress scores were significantly stronger than $\hat{\theta}$ scores ($p < .05$). [d] Associations with $\hat{\theta}$ scores were significantly stronger than Total scores ($p < .05$). [e] For RSFC, baseline n = 8,859; Year 1 n = 4,283. [f] Associations with $\hat{\theta}$ scores were significantly stronger than Distress scores ($p < .05$).

We also examined associations between the screening form to predictors of psychosis spectrum symptoms (i.e., parent-rated PLEs, family history of psychosis, internalizing symptoms, cognitive functioning, developmental milestone delays, RSFC metrics). As can be seen in Table 3, the screening form was significantly correlated with most predictors for both baseline and Year 1, with the exception of some of the RSFC metrics for both baseline and Year 1. Specifically, none of the Year 1 PQ-BC screening form scores were associated with DMN within-network connectivity. Furthermore, baseline and Year 1 PQ-BC screening form scores were not significantly associated with either CON-cerebellar or CPAR-cerebellar connectivity. These findings are generally consistent with what was found for the full scale, as can be seen in Table 2.

Discussion

Our goals were to (a) examine item properties of the PQ-BC by utilizing IRT, (b) examine associations of $\hat{\theta}$ with previously identified predictors of psychosis spectrum symptoms, and (c) use the information and discrimination parameters to assess the PQ-BC and derive a screening form. For the first aim, similar to many other clinical measures that have been assessed using IRT, analyses of the PQ-BC suggest that each item provides a large amount of information and is highly discriminatory at high trait levels but provides less reliable estimates at lower trait levels. Given that the measure was designed to measure a clinical phenomenon, this is not surprising; however, it does suggest that the PQ-BC is less sensitive at assessing low trait presentation. As for the second aim, as predicted, $\hat{\theta}$ showed significant

Table 3
Associations of Screening Form Total and Distress Scores for Baseline and Year 1

Variable	Screening form total			Screening form distress			Screening form log-transformed distress		
	β	*t*	*p*	β	*t*	*p*	β	*t*	*p*
Baseline									
Parent-rated PLEs	0.080	8.52	<.001	0.085	8.92	<.001	0.076	8.02	<.001
Family history of psychosis	0.036	3.81	<.001	0.035	3.63	<.001	0.039	4.15	<.001
Internalizing symptoms	0.298	33.95	<.001	0.336	38.53	<.001	0.297	33.91	<.001
Cognitive functioning									
Fluid	−0.048	−4.44	<.001	−0.054	−4.95	<.001	−0.057	−5.26	<.001
Crystalized	−0.084	−7.55	<.001	−0.081	−7.13	<.001	−0.090	−8.03	<.001
Working memory	−0.045	−4.17	<.001	−0.053	−4.81	<.001	−0.051	−4.74	<.001
Developmental milestone delays									
Motor	0.037	3.88	<.001	0.030	3.13	.002	0.036	3.82	<.001
Speech	0.039	4.16	<.001	0.040	4.22	<.001	0.048	5.07	<.001
Clumsiness	0.034	3.71	<.001	0.038	4.11	<.001	0.037	4.00	<.001
RSFC									
CON	−0.032	−2.92	.004	−0.035	−3.19	.001	−0.036	−3.36	<.001
CPAR	−0.001	−0.07	.95	−0.006	−0.59	.56	−0.051	−1.65	.10
DMN	−0.031	−2.87	.004	−0.036	−3.35	<.001	−0.040	−3.74	<.001
CON-cerebellar	0.012	1.16	.25	0.017	1.59	.11	0.012	1.11	.27
CPAR-cerebellar	−0.019	−1.88	.06	−0.014	−1.34	.18	−0.014	−1.39	.16
Year 1									
Parent-rated PLEs	0.073	5.26	<.001	0.070	5.03	<.001	0.071	5.14	<.001
Family history of psychosis	0.052	3.91	<.001	0.052	3.70	<.001	0.047	3.43	.001
Internalizing symptoms	0.223	17.33	<.001	0.200	15.57	<.001	0.202	15.96	<.001
Cognitive functioning									
Fluid	−0.046	−3.08	.002	−0.052	−3.33	.001	−0.044	−2.88	.004
Crystalized	−0.066	−4.20	<.001	−0.064	−3.95	<.001	−0.087	−5.39	<.001
Working memory	−0.050	−3.26	.001	−0.036	−2.19	.03	−0.054	−3.34	.001
Developmental milestone delays									
Motor	0.035	2.60	.009	0.034	2.47	.01	0.045	3.34	.001
Speech	0.046	3.38	.001	0.037	2.69	.007	0.039	2.87	.004
Clumsiness	0.041	3.08	.002	0.049	3.62	<.001	0.052	3.87	<.001
RSFC									
CON	−0.053	−3.22	.001	−0.049	−2.96	.003	−0.054	−3.29	.001
CPAR	−0.022	−1.46	.14	−0.017	−1.12	.26	−0.028	−1.83	.07
DMN	−0.022	−1.36	.17	−0.017	−1.04	.30	−0.023	−1.47	.14
CON-cerebellar	−0.009	−0.59	.56	−0.007	−0.42	.67	−0.007	−0.42	.67
CPAR-cerebellar	0.012	0.77	.44	0.008	0.49	.62	0.005	0.31	.76

Note. PLEs = psychotic-like experiences; RSFC = resting-state functional connectivity; CON = cingulo-opercular within-network connectivity; CPAR = cingulo-parietal within-network connectivity; DMN = default mode within-network connectivity.

associations in the expected direction with previously established predictors of psychosis spectrum symptoms. Finally, the seven-item screening form, derived from information and discrimination parameters, performed adequately within the ABCD data set and may be beneficial for more general use when administration of the full measure is prohibitive.

Endorsement of any of the PQ-BC items was relatively rare; with that stated, IRT results suggest that endorsement of particular items may be more important for assessing syndrome severity than others. Importantly, our results replicate other recent work (Phalen et al., 2018), which found Item 20 to be particularly useful when assessing for PLEs. Examining the discrimination parameters provides convergent evidence, as the values reported for each item are quite high (Reise & Waller, 2009), suggesting that PQ-BC items were highly discriminatory at each *b* inflection point, though discrimination suffers at low levels of trait assessment. Other IRT examinations of clinical syndromes have reported similar parameter estimates (Aggen, Neale, & Kendler, 2005), suggesting that this is not an issue specific to the PQ-BC but to clinical instrumentation broadly. Whereas the PQ-BC provides information at a restricted range of the trait (e.g., high levels of information at high levels of θ), past scholarship using IRT in PLE assessment identified several items that provided less overall information but perhaps greater coverage across $\hat{\theta}$ (Laurens, Hobbs, Sunderland, Green, & Mould, 2012). Although this restricted range is desirable for our screening form measure to serve as a quick screening tool, inclusion of other items may provide useful for more comprehensive assessment of PLEs at lower trait levels. Because the items in the PQ-BC are range-restricted to the highest levels of θ, the PQ-BC's association with other variables will be less reliable at lower θ levels. Overall, the IRT results are generally consistent with what would be expected for subclinical PLEs and support evidence of the feasibility and utility of IRT analyses for PLEs measures (Fonseca-Pedrero, Paino, Ortuño-Sierra, Lemos-Giráldez, & Muñiz, 2014; Levey et al., 2018; van Bebber et al., 2017).

Overall, $\hat{\theta}$ scores demonstrated expected associations with several key factors linked with PLEs, including cognitive impairments, developmental milestone delays, parent-rated PLEs, family history of psychosis, anxiety/depression, and some

RSFC impairments. These important findings indicate that θ showed analogous associations to those found in previous studies of psychosis spectrum symptoms and is therefore informative about the correlates of experiences across the psychosis spectrum (Cannon et al., 2002; Kelleher et al., 2013; Mollon & Reichenberg, 2018). Furthermore, examining θ is informative regarding the construct validity of the PQ-BC and is more broadly informative of the nomological network of psychosis spectrum symptoms, including PLEs. IRT methodology includes stronger assumptions about assigning error variance at the item level than CTT methods, which proponents have argued makes $\hat{\theta}$ more accurately reflective of true trait scores (Reise & Henson, 2003). In our analyses, the $\hat{\theta}$ scores showed stronger associations with certain predictors of PLEs, such as fluid and crystallized intelligence impairments, which may suggest that some of these outcomes are more associated with PLEs trait presentation than previously reported. Our results also suggest that prior examinations with CTT-derived scores may have slightly inflated the associations of PLEs with several predictors (i.e., internalizing symptoms, working memory, speech developmental delays); with that stated, our results show that these associations are still significant, suggesting that these continue to be important associations to consider during assessment.

The current study used IRT-derived parameters to aid in the creation of a screening form. This screening form consists of seven items along multiple domains (for example, ideas of reference, auditory perceptual abnormalities, unusual beliefs [i.e., delusional confusion], other perceptual abnormalities [e.g., olfactory perceptual experiences], visual perceptual abnormalities, and disorganized speech). For both baseline and Year 1, the screening form showed expected associations with the most risk factors (although note that the screening form scores failed to show significant associations with several of the RSFC variables). The seven-item screening form had fair internal consistency, which was expected (Nunnally & Bernstein, 1967; Ziegler, Kemper, & Kruyen, 2014). Thus, one likely does not need to include all 21 items of the PQ-BC to assess elevations in PLEs, as each item provides information at similar θ ranges. Our proposed screening form is adequately reliable and provides wide, clinically relevant symptom coverage (more so than Phalen et al., 2018), and is comparable with the PQ-BC in terms of associations with known correlates of PLEs. The current study constructed a screening form starting from the full scale rather than directly replicating previous efforts (Phalen et al., 2018), due in part to several factors, including that (a) the previous study used the PQ-B rather than the PQ-BC; (b) along these lines, the previous study used an adult population; and (c) the current study decided to err on the side of retaining items that provided the most information and discrimination while incorporating a spectrum of PLEs experiences, including both delusional ideation and perceptual abnormalities.

This is the first time that the longitudinal stability and psychometric properties of the PQ-BC have been examined over time, information critical to understanding the nature of school-age PLEs. Importantly, all PQ-BC metrics (Total, Distress, log-transformed, and $\hat{\theta}$) showed evidence of longitudinal stability, including moderate positive correlations between baseline and Year 1. This provides preliminary support for this measure assessing a stable trait (Fagerberg, Söderman, Petter Gustavsson, Agartz, & Jönsson, 2018). Furthermore, the psychometric properties of the PQ-BC replicated in Year 1 (e.g., good internal consistency), providing additional evidence that the PQ-BC is validly assessing school-age PLEs. However, there were some differences between baseline and Year 1 in terms of associations between PQ-BC scores and risk factors. Interestingly, some of the associations between PQ-BC and RSFC variables were not significant at Year 1. This may indicate that during this important developmental period, maturational changes in connectivity are occurring, and therefore it will be important to examine associations between RSFC variables assessed later in development and Year 1 PQ-BC scores. However, it could also indicate that some of the RSFC findings (e.g., CPAR connectivity) do not represent stable risk correlates of school-age PLEs.

Several questions still remain regarding the developmental nature of PLEs and how well the PQ-BC assesses these symptoms longitudinally. The screening form was developed using information and discrimination values from the baseline sample; future inquiries will need to examine developmental effects using the full sample at Year 1. Examining measurement invariance at varying time points will be useful in revising which items are most appropriate for a screening-form measure. Additionally, although the ABCD sample is population-based and demographically diverse sample, these results are conducted on a non-help-seeking population. Although IRT analyses are theoretically not sample dependent (Reise & Henson, 2003), future research may seek to develop PQ-BC clinical cutoffs for specific clinical settings. In addition, a number of screening forms could have been developed based on the information and discrimination properties of the items (e.g., top five items based on information or discrimination). The current study decided to use items that were in the top 10 most informative *and* most discriminative items in order to take into account the importance of retaining items that were both (a) most informative of the PLE trait, and (b) most discriminating of those actually experiencing PLEs versus those who are not experiencing PLEs. Furthermore, the screening form was developed for early identification efforts and therefore aims to capture greater severity of PLEs (i.e., higher PQ-BC scorers) as opposed to the lower end of PLE coverage, which is less likely to be clinically relevant; thus, although the PLE trait in the general population is often expressed as mild elevations in PQ-BC scores, it is expected that a screening measure should only identify those individuals at higher levels of the trait and therefore most likely to develop sustained PLEs of clinical relevance (Dominguez, Wichers, Lieb, Wittchen, & van Os, 2011; Kalman, Bresnahan, Schulze, & Susser, 2019). A future goal of developing a screening form is for use in large-scale screening efforts to identify children at risk for increased PLEs through schools, pediatrician offices, or other community settings. Overall, the current analyses provide initial evidence that a seven-item screening form of the PQ-BC validly assesses school-age PLEs.

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