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Relationships between intra-individual variability and subclinical psychosis

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ABSTRACT

Extensive research indicates that elevated intra-individual variability (IIV) of reaction time is associated with subclinical psychosis, as well as clinically diagnosed psychotic disorder. However, findings regarding the details of this relationship are equivocal. In particular, it is unknown whether associations between elevated IIV and subclinical psychosis are specific to certain psychotic symptoms or to complex reaction time tasks. Data from 492 undergraduates from the University of Otago were used to address this issue. Schizotypy and psychotic-like experiences (PLE) were assessed via interview and questionnaire, and participants completed both a simple reaction time (SRT) task and a continuous performance task–identical pairs version (CPT-IP). The individual standard deviation and coefficient of variation (ICV) were used as measures of IIV. Participants reporting PLE were more likely to have elevated ICV on the CPT-IP. These associations were specific to paranoid psychotic experiences, and to the suspiciousness subscale of the Schizotypal Personality Questionnaire. There were also weak associations between SRT ICV and PLE. The inclusion of a battery of reaction time tasks assessing different aspects of cognitive control is suggested for future research, and the findings are discussed in relation to theoretical approaches to paranoia and delusions.

1. Introduction

A growing body of evidence suggests that the psychosis phenotype is not specific to psychotic disorders. Instead, the phenotype might be graduated, expressed at non-clinical and clinical levels along a continuum (Kelleher et al., 2011). When reported by persons without a clinical diagnosis, these symptoms are often referred to as psychotic-like experiences (PLE; Kelleher et al., 2011). PLE appear to characterise risk of psychotic episodes and diagnosis of psychotic disorder (Garety et al., 2001; Hanssen et al., 2005). Subclinical psychosis symptoms may also be expressed as trait-like characteristics in those unaffected by mental disorder. This set of personality traits reflects a diathesis to psychotic disorder and are collectively termed *schizotypy* (Mason, 2015; Meehl, 1962).

The notion that the psychosis phenotype can be expressed at levels below its clinical manifestation has led to a proliferation of studies exploring the aetiology and consequences of PLE and schizotypy in general population samples. Compared to research with clinical populations, these studies avoid or minimise confounds such as the effects of medication, institutionalisation, and neurocognitive decline associated with psychotic illness (Nelson et al., 2013). They also manage to circumvent issues with motivation or cognitive ability that may result from acute symptoms in medication-naïve patients experiencing their first episode of psychotic illness (e.g., Barch et al., 2001, 2003).

Clinical and subclinical expressions of psychosis appear to have a common aetiology. For example, several factors that predict risk for psychotic disorders predict PLE and schizotypy. These include childhood trauma (Kelleher et al., 2008), cannabis use (Moore et al., 2007), urbanicity (Spauwen et al., 2004), and family history of mental illness (van Os and Linscott, 2012). Schizotypal traits are highly expressed in relatives of patients with psychotic disorder (Linscott et al., 2017; Walter et al., 2016), and are predicted by genetic factors that predict schizophrenia (Morton et al., 2017).

Deficits in domains such as attention, working memory, executive functioning, and social cognition are present along the psychosis continuum (Fusar-Poli et al., 2013). One aspect of cognition that has received increasing focus in schizophrenia research is intra-individual variability (IIV). IIV reflects short-term within-person variations in task performance (MacDonald et al., 2009) and is regarded as an index of the stability of cognitive processing (Ram and Gerstorf, 2009). Excess fluctuations in performance over brief intervals are generally defined as maladaptive, in contrast to variability associated with learning or adaptability (Li et al., 2004; MacDonald et al., 2009).

Much of the research into IIV has focused on within-person variation on reaction time (RT) tasks. Increased IIV on RT tasks is associated

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with poorer cognitive, and particularly executive, functioning (MacDonald et al., 2009; Stuss et al., 2003). IIV exhibits a U-shaped function across the lifespan (Williams et al., 2005) coinciding with development of the frontal lobes in adolescence (MacDonald et al., 2006) and cognitive decline in late adulthood (Li et al., 2004). Elevated IIV is also related to a variety of neuropsychiatric conditions, including attention deficit hyperactivity disorder (Castellanos and Tannock, 2002), Parkinson's disease (Burton et al., 2006), and traumatic brain injuries (MacDonald et al., 2006; Stuss et al., 2003). Taken together, these findings suggest that IIV of RT is indicative of compromised neurological integrity (Li and Lindenberger, 1999).

Kraepelin (1971) pointed out irregular motor performance as a key feature of schizophrenia his historic description of the disorder. Research into this relationship has persisted with studies of IIV. Elevated IIV of RT is reported to be stable and enduring in patients with schizophrenia (Roalf et al., 2013; Vinogradov et al., 1998). Elevated IIV differentiates non-affected relatives of schizophrenia patients from controls (Birkett et al., 2007) and predicts the occurrence of PLE in the general population (Wallace and Linscott, 2017).

The relationship between IIV and schizophrenia has been primarily assessed using complex RT paradigms, such as the continuous performance task (CPT; Kaiser et al., 2008), stop-signal task (Logan and Cowan, 1984; Shin et al., 2013), and go/no-go task (Rentrop et al., 2010). These tasks tap sustained attention and response inhibition, and are more cognitively demanding than simple reaction time tasks (SRT), which primarily assess vigilance (Jensen, 2006). Variants of the CPT assess working memory in the case of the identical pairs version (CPT-IP; Cornblatt et al., 1988), and sensory processing in the case of the degraded stimulus version (Munro et al., 1987).

Elevated IIV on complex RT tasks is associated with expressions of psychosis along the psychosis continuum. For instance, performance on a stop-signal RT task, but not SRT, predicted PLE in an adolescent population sample (Wallace and Linscott, 2017). Variability on complex RT tasks also consistently differentiates patients and their relatives from controls (Birkett et al., 2007; Shin et al., 2013). However, some of the specifics of this relationship are less clear. Kane et al. (2016) found that a latent factor from non-conflict trials on a range of RT tasks correlated with positive, paranoid, and disorganised schizotypy. This association suggests that the relationship between IIV and schizotypy is not entirely due to processes such as response inhibition.

Findings regarding the relationship between IIV and specific psychotic symptoms are also equivocal. Some studies have linked elevated IIV with positive and disorganised symptoms (Vinogradov et al., 1998), whereas others have reported associations with negative symptomatology (O'Gráda et al., 2008) or no associations between IIV and symptom grouping (Pellizzer and Stephane, 2007). These divergent findings may reflect that such studies often use different RT paradigms or symptom classifications. Alternatively, they may also reflect the idea that elevated IIV represents a deficit that is orthogonal to changes in symptoms. In any case, further exploration of the relationship of IIV, assessed across diverse tasks, to different schizotypal symptoms is warranted, particularly in general population samples where these relationships are as yet unstudied.

In the present study, we explore whether PLE and schizotypy are associated with elevated IIV, and whether any relationship is dependent on the complexity of the RT task or symptom grouping. To do so, we assessed schizotypy, PLE, and variability on the CPT-IP and SRT in an undergraduate sample. We hypothesised that persons who report PLE or elevated schizotypy will have greater IIV on the more complex CPT-IP, but not the SRT, compared to persons who do not report PLE. We aim to explore whether there is any relationship between IIV and type of PLE or schizotypy subscale, though refrain from specific hypotheses regarding the exact nature of this association due to the equivocal nature of this literature.

2. Methods

2.1. Sample

Undergraduates (n = 500, 17–55 years, 74.8% female) enrolled in introductory psychology classes at the University of Otago volunteered as participants. Given the relationship between IIV and age, participants 30 years and older were excluded, leaving a total sample of 492 participants. The majority (77.4%) identified as New Zealand European. Data from one person who was diagnosed with psychosis were excluded from analysis.

At the conclusion of the study, participants learnt about the research purpose and design, and could earn course credit on the basis of assessment of this learning. The study was reviewed and approved by the University of Otago Human Ethics Committee (Health) and undertaken in accordance with the Code of Ethics of the New Zealand Psychological Society.

2.2. Outcome measures

2.2.1. Psychotic-like experiences

PLE were measured using the Psychosis Screening Questionnaire (PSQ; Bebbington and Nayani, 1995), which was administered as an interview. The PSQ was designed as a brief screening instrument for PLE to be used primarily with non-clinical populations (Bebbington and Nayani, 1995). In this study, a senior postgraduate clinical psychology student administered the PSQ under guidance of a registered clinical psychologist. The PSQ has five sections that screen for common psychotic-like symptoms over the past 12 months: hypomania, thought insertion, paranoia, strange experiences, and hallucinations. Each section starts with a screening question that, if endorsed, is followed by one or two probe questions (Bebbington and Nayani, 1995). As we were specifically interested in positive PLE, data from the hypomania items were not considered. The primary outcome measure from the PSQ was the positive endorsement of one or more psychotic symptoms (screen plus probe questions) from the remaining four domains. Secondary analyses included the type of PLE as an outcome measure.

2.2.2. Schizotypal personality

Schizotypy was measured with the Likert version of the Schizotypal Personality Questionnaire (SPQ; Raine, 1991). The SPQ is a 74-item self-report questionnaire. The SPQ is based on diagnostic criteria for schizotypal personality disorder (American Psychiatric Association, 1987; Mason, 2015), and is ubiquitous in schizotypy research (Mason, 2015). The original structure of the SPQ comprises nine subscales that assess ideas of reference, odd beliefs, unusual perceptual experiences, suspiciousness, lack of close friendships, constricted affect, social anxiety, eccentric behaviour, and odd speech (Raine, 1991; Rossi and Daneluzzo, 2002). In the Likert version, items were rated on a five-point ordinal scale (*strongly agree* to *strongly disagree*). The primary outcome measures were the total scores on each of the nine subscales.

2.3. Predictor variables

IIV of RT was derived from performance on the SRT and CPT-IP (Cornblatt et al., 1988). Both tasks were administered on Mac computers and were conducted alongside other neuropsychological measures as part of a broader study on schizotypy. Written instructions for both tasks were presented on the computer screen prior to the tasks.

2.3.1. Simple reaction time

For the SRT, participants were instructed to attend to a fixation point (a white cross) in the centre of the screen, and to respond as quickly as possible when it was replaced by the stimulus (a filled green box) by pressing the “B” button on the keyboard. The fixation point was

presented for a pseudo-random period of 250, 350, 450, 650, or 750 ms before being replaced by the stimulus. The stimulus disappeared either when a response was made, or after 700 ms if there was no response. Participants were provided with auditory feedback if their response was early (within 100 ms of stimulus onset), or late (after 700 ms of stimulus onset). Following three practice trials, four experimental blocks were conducted, each comprising 36 trials. Outcome data from this study were derived from successful responses to stimuli, defined as a response occurring 100–700 ms from stimulus onset.

2.3.2. Continuous performance test-identical pairs version

During the CPT-IP task, white four-digit numbers were presented in the centre of a black computer screen at a rate of one per second (50 ms stimulus duration). Participants were instructed to respond when they saw the same number presented consecutively, by pressing the spacebar on a keyboard. In total, there were 160 trials, which included 32 target trials, 32 catch trials, and 96 filler trials. For catch trials, one of the four digits differed, and for filler trials the numbers were pseudo-random with no distinct likeness to previous trials. No feedback was provided to participants for correct or incorrect trials, and responses within 100 ms of stimulus onset were excluded.

The IIV measures used were the individual standard deviation (ISD) and individual coefficient of variation (ICV), which were calculated from raw data for correct responses on both tasks. ISD is the standard deviation of RT on trials. ICV is the ratio of the ISD to the participant's mean RT on the task ($ICV = RT_{SD}/RT_{M}$). As longer RTs may result in increased ISD for an individual, ICV was used as an alternate measure to control to some degree for mean RT (Stuss et al., 2003).

2.4. Covariates

A series of potential confounders were identified as being associated with IIV, psychotic disorder, or both, and were included in the analyses. Information on these confounders was derived from questionnaires presented prior to administration of RT tasks. They included age, sex, ethnicity, birthweight, cumulative cannabis use (number of times cannabis has been used in lifetime), proximal cannabis use (use within 24 h of study participation), prior diagnosis of mental disorder, and socio-economic status (based on parental annual income).

Disingenuous or inattentive responding was assessed using 12-item validity scale, with items dispersed across the SPQ and several other self-report questionnaires in the study protocol. For these 12 items, participants were asked to provide designated responses (e.g., *Respond to this question by selecting number 3*).

2.5. Data cleaning and analysis

Participants were excluded from analyses if there were two or more errors on items detecting inattentive responding, or if they were multivariate outliers. Multivariate outliers were detected using Cook's distance and leverage (Tabachnick et al., 2007). Sociodemographic and other differences between participants who did or did not endorse probe questions on the PSQ were assessed using chi-squared tests and Mann Whitney *u*-tests. RT data underwent a *z*-score transformation to ensure a common metric among measures of IIV.

Binary logistic regression models were used to estimate the relationship between endorsement of any PLEs and IIV of RT. This was performed separately for ICV and ISD, given the collinearity between these variables. Binary logistic regression models were then used to estimate the relationship between IIV and PLE type, with comparisons made between endorsement of specific PLEs and non-endorsement of any PLE. Discriminant function analysis was also performed to determine the unique contributions of IIV outcomes to predicting group membership. The relationship between IIV outcomes and each subscale of the SPQ were analysed by Spearman rank order correlations, given the marked positive skew of SPQ outcome data. Given the lack of association between covariates and PLE outcome, these analyses were conducted unadjusted. Significance for all analyses was set to $p < .05$. Statistical analyses were conducted using IBM Statistical Package for the Social Sciences version 23 and Stata version 14.1 (StataCorp, 2015).

Table 1
Characteristics of subgroups defined by psychotic symptom questionnaire outcome.

Characteristic (reference)	PSQ outcome Absent N/M	%/SD	One or more PLEs N/M	%/SD	Cross-tabulation[a] χ^2
Sex (female)	74.7	290	76.9	40	0.11
Low income (< $50,000)	12.9	50	23.1	12	3.93*
Cannabis use (yes)	40.2	156	30.8	16	1.71
NZ European	80.2	311	78.8	41	0.49
Maori	8.2	32	3.8	2	1.24
Other	34.8	135	28.8	15	0.72
	M	SD	M	SD	Z
Age	19.92	1.48	19.81	1.60	0.46
Birthweight	3.45	0.51	3.42	0.54	0.27

Note. PSQ, Psychotic Symptoms Questionnaire; PLEs, Psychotic-Like Experiences; OR, Odds Ratio; CI, Confidence interval.
[a] χ^2 for categorical variables, Mann-Whitney *u*-test *z*-score for continuous variables.
* $p < .05$.

3. Results

3.1. Descriptive statistics

Participants were excluded if their responses were classed as disingenuous or inattentive ($n = 38$), or they were multivariate outliers ($n = 14$). Analyses were based on 440 participants. Of these, 52 (11.8%) endorsed experiencing PLE within the past year. The greatest number of those reported strange experiences ($n = 48$), with hallucinations ($n = 6$), paranoia ($n = 5$), and thought insertion ($n = 4$) reported less frequently.

Demographic information for the sample is provided in Table 1. Participants were predominantly female, identified as NZ European, and ranged in age from 17 to 29 years. Compared to those who did not report PLE, those who endorsed psychotic experiences on the PSQ were more likely to have a lower household income. There were no other statistically significant relationships between PSQ outcome and demographic variables.

Table 2
Association between Psychotic-Like Experiences and Reaction Time Variability.

Measurement of RT	PSQ outcome Absent M	SD	One or more PLEs M	SD	OR[a]	95% CI
SRT						
ISD	−0.02	1.02	0.09	0.94	1.09	[0.87, 1.36]
ICV	−0.03	1.02	0.15	0.99	1.16	[0.94, 1.43]
CPT-IP						
ISD	−0.07	0.98	0.08	1.04	1.14	[0.91, 1.42]
ICV	−0.09	0.93	0.16	1.07	1.28*	[1.03, 1.60]

Note. RT, Reaction time; SRT, Simple Reaction Time; CPT-IP, Continuous Performance Task–Identical Pair Version; ISD, Individual standard deviation; ICV, Individual coefficient of variation; PSQ, Psychosis Screening Questionnaire; OR, Odds Ratio; CI, Confidence Interval.
[a] Binomial Logistic Regression.
* $p < .05$.

Table 3
Standardised coefficients of predictor variables of the discriminant function.

Predictor	Standardised coefficient
ISD for SRT	0.278
ICV for SRT	0.442
ISD for CPT-IP	0.368
ICV for CPT-IP	0.661

Note. SRT, Simple Reaction Time; CPT-IP, Continuous Performance Task–Identical Pair Version; ISD, Individual standard deviation; ICV, Individual coefficient of variation.

3.2. Predicting psychotic experiences from IIV

Associations between IIV and endorsement of PLE are shown in Table 2. Participants with elevated ICV during the CPT-IP were more likely to report PLE. No associations were found between PLE endorsement and any other index of RT variability.

We examined the unique contributions of IIV on predicting group membership using a discriminant function analysis. IIV scores for each RT task were included simultaneously in the analysis to determine which of these variables could best predict a participant's PLE grouping. The combined information successfully predicted group membership (Wilks $\Lambda = 0.97$, χ^2_4 $[N = 440] = 12.54$, $P = .01$) and correctly classified 58.1% of all cases. Table 3 presents the standardized weights of each predictor. These results indicate that ICV scores on the SRT ($\beta = 0.66$) and the CPT-IP ($\beta = 0.42$) were the best predictors for identifying whether a subject reported absent or more than one PLE.

Table 4 shows associations of RT measures with type of PLE reported. There was a significant effect of PSQ outcome for the paranoia group only. Elevated ICV on the SRT and CPT-IP were associated with the reporting of paranoia. Elevated ISD on the CPT-IP was also related to reporting of paranoia but did not meet the significance threshold. No other significant associations between SRT or CPT-IP outcomes and type of PLE were found. Correlations between IIV and the SPQ subscales are reported in Table 5. Higher scores on the suspiciousness subscale were associated with greater ISD and ICV during the CPT-IP, and greater ICV during the SRT. Increased ICV during the CPT-IP was also associated with elevated scores on the odd and eccentric beliefs subscale. There were no other significant relationships between SRT or CPT-IP outcomes and any of the other SPQ subscales.

4. Discussion

4.1. Principal findings

We set out to investigate whether elevated IIV was related to PLE and schizotypy, whether this relationship was specific to complex RT tasks, and whether there were any specific associations to type of psychotic experience. The results indicate that elevated ICV during the CPT-IP was more consistently associated with endorsement of PLE than any other measure of IIV. Associations between PLE and CPT-IP ICV also appeared to be specific to paranoid experiences only. Similarly, there was an association between the suspiciousness subscale of the SPQ and all included measures of IIV.

Table 5
Correlations between schizotypy subscales and reaction time variability.

RT variability	SPQ subscale[a]								
	IOR	ESA	OBMT	UPE	OEB	NCF	OS	CA	S
SRT									
ISD	0.05	0.04	0.06	0.08	0.04	0.05	0.03	0.07	0.10*
ICV	0.06	0.03	0.05	0.09	0.04	0.04	0.03	0.06	0.11*
CPT-IP									
ISD	0.03	0.05	−0.01	0.02	0.08	0.05	0.07	0.00	0.09°
ICV	0.04	0.06	0.04	0.03	0.10*	0.05	0.07	−0.01	0.10*

Note. RT, Reaction time; SRT, Simple RT Task; CPT-IP, Continuous Performance Task–Identical Pair Version; ISD, Individual standard deviation; ICV, Individual coefficient of variation; SPQ, Schizotypal Personality Questionnaire; IOR, Ideas of Reference; ESA, Excessive Social Anxiety; OBMT, Odd Beliefs or Magical Thinking; UPE, Unusual Perceptual Experiences; OEB, Odd or Eccentric Beliefs; NCF, No Close Friends; OS, Odd Speech; CA, Constricted Affect; S, Suspiciousness.
[a] Bivariate correlation. Unadjusted analysis.
* $p < .05$.

4.2. Study limitations

A number of limitations need to be acknowledged. Data were obtained from a sample consisting of predominantly female undergraduate students, which deviates from a more representative population sample (Newman et al., 1998). Prior studies have indicated that younger, more educated persons perform better on RT tasks than older participants with lower levels of education (Anstey et al., 2005). In this study, a number of participants made zero errors during the CPT-IP on hit ($n = 32$) and catch trials ($n = 25$). Differences in performance between groups may have been masked by a ceiling effect, which occurred despite the use of the more difficult identical pairs version of the CPT (Cornblatt et al., 1988), and upper limits for response times. This issue could be addressed by increasing the number of trials—a modification that would also allow for the calculation of ex-Gaussian estimates of IIV (Luce, 1986).

A small number of participants reported PLE. This may have meant that relationships between IIV and specific types of PLE were occluded by relatively broad confidence intervals, particularly for those reporting hallucinations or thought disorder. A clearer understanding of the relationship of IIV to PLE in the general population may require much larger samples and more comprehensive neurocognitive data. This might usefully include a battery of either RT paradigms or

Table 4
Association between type of psychotic-like experience and reaction time variability.

RT variability	PSQ outcome[a]								
	None	Thought insertion		Paranoia		Strange experiences		Hallucinations	
	M (SD)	M (SD)	OR [95%CI]	M (SD)	OR [95%CI]	M (SD)	OR [95%CI]	M (SD)	OR [95%CI]
SRT									
ISD	−0.02 (1.02)	−0.49 (0.39)	0.56 [0.18–1.76]	0.14 (0.88)	1.13 [0.88–1.44]	0.10 (0.97)	1.15 [0.85–1.55]	0.37 (1.08)	1.38 [0.67–2.83]
ICV	−0.14 (1.02)	−0.20 (0.24)	0.80 [0.28–2.31]	0.24 (0.96)	1.25° [0.98–1.58]	0.11 (1.02)	1.14 [0.85–1.52]	0.45 (1.21)	1.44 [0.74–2.81]
CPT-IP									
ISD	−0.07 (0.98)	0.14 (0.52)	1.35 [0.53–3.45]	0.17 (1.07)	1.24° [0.97–1.59]	−0.14 (0.94)	0.90 [0.65–1.25]	0.13 (0.52)	1.15 [0.50–2.65]
ICV	−0.09 (0.93)	0.32 (0.26)	1.55 [0.61–3.91]	0.28 (1.08)	1.43** [1.11–1.83]	0.08 (0.96)	0.99 [0.72–1.38]	0.16 (0.72)	1.28 [0.55–2.98]

Note. RT, Reaction time; SRT, Simple Reaction Time; CPT-IP, Continuous Performance Task–Identical Pair Version; ISD, Individual standard deviation; ICV, Individual coefficient of variation; PSQ, Psychosis Screening Questionnaire.
[a] Binomial logistic regression. Comparisons are made between absent PLE and PLE grouping.
* $p < .05$, ** $p < .01$.

neurocognitive tasks, to determine whether the relationship between IIV and PLE is due to broad deficits in executive functioning or specific issues in domains such as response inhibition. Further, an assessment of current mental health status, including anxious or depressive symptomatology, may assist in testing the robustness of the association between IIV and suspiciousness or paranoia.

4.3. Compatibility with previous studies

Several studies have found elevated RT variability in persons diagnosed with schizophrenia (Rentrop et al., 2010; Vinogradov et al., 1998), as well as in those at clinical risk of psychotic disorder (Shin et al., 2013) and first-degree relatives of schizophrenia patients (Hilti et al., 2010). However, to our knowledge only two studies have assessed the relationship between IIV and specific dimensions of schizotypy using a general population sample.

Schmidt-Hansen and Honey (2009) found that elevated IIV in an *n*-back task predicted positive schizotypy more strongly than either negative or disorganized schizotypy in an undergraduate population. More recently, Kane et al. (2016) conducted a confirmatory factor analysis using non-conflict trials from five RT tasks. This ICV factor correlated moderately with positive, paranoid, and disorganized schizotypy. Our findings extend these findings by demonstrating not only an association between ICV and suspicious schizotypy, but also to paranoid PLE.

4.4. Possible mechanisms

We found evidence of an association between ICV on the CPT-IP and presence of PLE. This is in line with our previous findings that IIV on a stop-signal paradigm at age 15 predicted PLE at age 18 in a UK birth cohort (Wallace and Linscott, 2017), as well as previous studies of IIV along the psychosis continuum (Birkett et al., 2007; Shin et al., 2013). As before, this relationship may reflect some neural overlap between deficits in performance variability and the psychosis continuum.

Relationships between performance on cognitive tasks and schizophrenia symptoms are commonly thought to support the notion that structural or functional neurological alterations can cause psychotic disorder and its associated deficits (Lesh et al., 2011). Paradigms such as the CPT-IP, stop signal reaction time (Logan and Cowan, 1984), and go/no-go tasks (Cornblatt et al., 1988; Heinrichs and Zakzanis, 1998), are thought to tap aspects of executive processes. The CPT-IP is used to measure sustained attention and response inhibition (Conners et al., 2003), whereas the stop-signal RT and go/no-go tasks are purer tests of response inhibition (Weintraub, 2000). It is suggested that performance variability on these tasks reflects the stability of these executive processes, which are mediated by the prefrontal cortex (Rubia et al., 2001; Weintraub, 2000).

CPT-IP performance appears to more consistently differentiate between patients and controls than SRT performance. This finding has led to the suggestion that increased IIV in schizophrenia is primarily related to inefficient prefrontal neural processing (Winterer et al., 2004). This is supported by reports of pronounced dysfunction of the prefrontal cortex in schizophrenia (Callicott et al., 2003; Shenton et al., 2001) alongside findings that greater levels of executive control result in lower levels of IIV (Bellgrove et al., 2004; Stuss et al., 2003). Our findings are consistent with these observations.

Associations were more robust for CPT-IP ICV than ISD. Although novel, the specificity of associations to ICV is not unexpected. ISD increases as a function of the mean and is thus confounded by it. As a result, ISD may not be able to discern a performance that is rushed and variable from one that is effortlessly fast (Golay et al., 2013). In contrast, theoretical and empirical studies indicate that ICV can more sensitively distinguish between a rushed performance and one that is efficiently organised (Segalowitz and Frenkiel-Fishman, 2005; Segalowitz and Segalowitz, 1993). As a result, ICV is suggested to be a more sensitive index of the stability of component cognitive processes than ISD (Hulstijn et al., 2009; Segalowitz and Segalowitz, 1993).

Notably, there appear to be attenuated associations between SRT and suspicious schizotypy. SRT ICV was somewhat predictive of PLE status within a discriminant functional analysis. This mirrors some finding in the ADHD literature showing increases in IIV over a wide range of RT task types, including SRT (Borella et al., 2011; Kuntsi and Klein, 2011). A latent-variable approach in future research on IIV along the psychosis continuum may help in determining the nature and robustness of this relationship.

4.5. Associations with paranoia and suspiciousness

The observed association between elevated ICV and suspicious schizotypy appears robust. Many theoretical approaches to paranoia, suspiciousness, and delusions have been proposed, with varying degrees of support (Garety and Freeman, 1999, 2013). One emerging literature has focused on the tendency for persons with delusions to have a bias toward jumping to conclusions, noting that measures of this bias correlate with positive symptoms (Garety et al., 1991). Future research may usefully include assessment of probabilistic reasoning, such as the bead task, to assess whether this explains the association found here (Fear and Healy, 1997; Moritz and Woodward, 2005).

Bentall et al. (1994) proposed an integrative model to explain paranoid and suspicious delusions, the core of which involves abnormalities in attribution and self-representation. Integral to this model is the notion that selective attention to threat-related stimuli maintains paranoid ideas (Bentall et al., 1994; Ullmann and Krasner, 1975). Although much of the evidence for this theory is based on self-report data, findings from studies employing RT and cognitive tasks have also been incorporated (Bentall et al., 2001). For instance, in one test of this account, paranoid patients selectively attended to threat-related stimuli relative to neutral stimuli during an emotional Stroop task (Fear et al., 1996). The CPT-IP stimuli were neutral, which may have led to a more variable performance for persons endorsing paranoia and suspiciousness, relative to other participants. Assessing IIV on tasks with a threat component would be necessary for a more complete accounting.

Associations between paranoid PLE and ICV may also reflect a propensity for mind wandering, a phenomenon termed *task-unrelated thought* (Smallwood and Schooler, 2006). Persons with high schizotypy are likely to have their stream of thought disrupted by affective dysregulation and current personal concerns (McVay and Kane, 2010; Smallwood and Schooler, 2006). These disruptions, alongside relatively low thresholds for motivational or perceptual salience (Kapur, 2003), may lead to an abundance of material that contends for consciousness during RT tasks. Research indicates that the association between ICV and positive schizotypy is explained in part by task-unrelated thought (Kane et al., 2016). This suggests a partial accounting of the results reported here, which may become clearer with the inclusion of mind wandering measures. At the very least, the current findings suggest that the inclusion of a battery of RT and neurocognitive tasks would benefit any future research into the association between IIV and sub-clinical expressions of psychosis.

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Declaration of Competing Interest

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.psychres.2019.112592.

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