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The neurophenomenology of early psychosis: An integrative empirical study

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ABSTRACT

Background: The integration of various domains or levels of analysis (clinical, neurobiological, genetic, etc.) has been a challenge in schizophrenia research. A promising approach is to use the core phenomenological features of the disorder as an organising principle for other levels of analysis. Minimal self-disturbance (fragility in implicit first-person perspective, presence and agency) is emerging as a strong candidate to play this role. This approach was adopted in a previously described theoretical neurophenomenological model that proposed that source monitoring deficits and aberrant salience may be neurocognitive/neurobiological processes that correlate with minimal self-disturbance on the phenomenological level, together playing an aetiological role in the onset of schizophrenia spectrum disorders. The current paper presents full cross-sectional data from the first empirical test of this model.

Methods: Fifty ultra-high risk for psychosis patients, 39 first episode psychosis patients and 34 healthy controls were assessed with a variety of clinical measures, including the Examination of Anomalous Self-Experience (EASE), and neurocognitive and neurophysiological (EEG) measures of source monitoring deficits and aberrant salience.

Results: Linear regression indicated that source monitoring (composite score across neurocognitive and neurophysiological measures), with study group as an interaction term, explained 39.8% of the variance in EASE scores ($R^2 = 0.41$, $F(3,85) = 14.78$, $p < 0.001$), whereas aberrant salience (composite score) explained only 6% of the variance in EASE scores ($R^2 = 0.06$, $F(3,85) = 1.44$, $p = 0.93$). Aberrant salience measures were more strongly related to general psychopathology measures, particularly to positive psychotic symptoms, than to EASE scores.

Discussion: A neurophenomenological model of minimal self-disturbance in schizophrenia spectrum disorders may need to be expanded from source monitoring deficits to encompass other relevant constructs such as temporal processing, intermodal/multisensory integration, and hierarchical predictive processing. The cross-sectional data reported here will be expanded with longitudinal analysis in subsequent reports. These data and other related recent research show an

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emerging picture of neuro-features of core phenomenological aspects of schizophrenia spectrum disorders beyond surface-level psychotic symptoms.

1. Introduction

In recent years there has been considerable interest in the construct of minimal self-disturbance as a phenotypic marker of the schizophrenia spectrum (Maj, 2012; Nelson, Parnas, & Sass, 2014; Nelson & Raballo, 2015; Parnas & Henriksen, 2014), particularly with regard to its utility in nosological, aetiological and prediction research. The 'minimal self', aka 'basic' or 'core' self, widely discussed in neuroscience, philosophy of mind, and phenomenology, refers to the pre-reflective and immediate consciousness of action, experience, and thought. Two nested concepts can be identified as constituting this aspect of selfhood: sense of ownership/mine-ness and sense of agency (Gallagher, 2011). While the former refers to perceiving my body, perceptions, and thoughts as my own, the latter refers to experiencing myself as the source of my actions and their consequences. These are generally *implicit* aspects of a normal sense of minimal self and facilitate interactions with others/the world (Zahavi, 2003). A fragile or unstable minimal self can manifest in a variety of anomalous subjective experiences including:

- disturbed sense of ownership of moment-to-moment experience, e.g., the sense that my thoughts or body parts are not my own;
- disturbed agency, e.g., the sense of not being the source or cause of my actions;
- unstable 'first-person' perspective, associated with states of depersonalisation, e.g., feeling as though I am watching myself from a distance or somehow alienated from my own body;
- difficulty forming a continuous and coherent identity, e.g., feeling anonymous or without a stable perspective and identity over time.

Such experiences frequently result in perplexity, disorientation, and difficulties with social functioning and understanding, also referred to as a lack of common sense (Blankenburg, 2001), and are profoundly distressing (Nelson et al., 2009). Minimal self-disturbance can intensify and crystallise over time into full-blown positive and negative psychotic symptoms (Davidsen, 2009; Møller & Husby, 2000; Nelson, Thompson, & Yung, 2012; Parnas, 1999, 2000; Sass & Parnas, 2003).

The main measure of minimal self-disturbance is the Examination of Anomalous Self-Experience (EASE) (Parnas et al., 2005a, 2005b). Empirical findings using the EASE and pre-EASE scales indicate that minimal self-disturbance:

- characterises schizophrenia spectrum disorders independent of presence of frank psychotic symptoms, i.e., is present in schizotypal disorder as well as in psychotic schizophrenia-spectrum disorders (Handest & Parnas, 2005; Nordgaard & Parnas, 2014; Parnas et al., 2005a, 2005b);
- correlates moderately with clinical features of schizophrenia (Nordgaard & Parnas, 2014);
- is more prominent in schizophrenia than in psychotic disorders outside the schizophrenia spectrum, such as bipolar disorder with psychosis (Haug, Lien, et al., 2012; Nordgaard & Parnas, 2014; Parnas, Handest, Saebye, & Jansson, 2003);
- correlates moderately with prodromal symptoms in non-psychotic adolescents (Koren, Lacoua1, Rothschild-Yakar, & Parnas, 2016; Koren et al., 2013; Raballo et al., 2016) and predicts future onset of schizophrenia spectrum disorders in non-psychotic clinical populations (Parnas et al., 2011) and in clinical high risk for psychosis patients (Nelson et al., 2012);
- increases in relation to schizophrenia symptom expression in a large genetic linkage sample (Raballo & Parnas, 2011; Raballo, Saebye, & Parnas, 2011) and in relation to severity of psychotic diagnostic staging (Raballo et al., 2018);
- is related to suicidality (Haug, Melle, et al., 2012; Skodlar & Parnas, 2010; Skodlar, Tomori, & Parnas, 2008), poor functioning (Haug et al., 2014; Raballo et al., 2016), and longer duration of untreated psychosis (Haug et al., 2015) in schizophrenia, and to failure to achieve symptomatic and functional recovery in patients with psychotic disorders (Svendsen, Merete, Møller, Nelson, Haug, & Melle, 2019).

Together, this body of research indicates that minimal self-disturbance is a trait vulnerability feature that has considerable specificity to schizophrenia spectrum disorders and is present in the prodromal phase of these disorders (Nelson, Parnas, et al., 2014; Nelson & Raballo, 2015; Parnas, 2011, 2012; Parnas, Bovet, & Zahavi, 2002; Parnas & Henriksen, 2014; Sass & Parnas, 2003). Indeed, disturbed 'self-experience' is included in the schizophrenia criteria of the beta version of the International Classification of Diseases 11th revision (ICD-11) (Organisation, 2018).

In our view, schizophrenia research has suffered from a lack of integration across 'levels' of analysis, such as phenomenological, psychological, neurocognitive, neurobiological, genetic and social levels (Martin et al., 2014; Nelson, Whitford, Lavoie, & Sass, 2014a, 2014b). We have argued that integrative models of vulnerability to schizophrenia spectrum disorders should be guided and constrained by the disorders' core phenomenological features (Parnas & Zandersen, 2018), which can function as a central organising factor akin to Minkowski (1926) concept of *le trouble générateur* (generating disorder). Minimal self-disturbance is emerging as a strong candidate for this role. It is not clear at this stage how minimal self-disturbance relates to these different levels of analysis (see Sass, Borda, Madeira, Pienkos, and Nelson (2018) for a recent attempt at theoretical integration). Although there has been considerable recent empirical neuroscientific research into anomalies of bodily (e.g., Benson & Park, 2019; Sestito, Raballo, Stanghellini,

& Gallese, 2017; Sestito et al., 2015), temporal (e.g., Giersch, Lalanne, & Isope, 2016; Giersch & Mishara, 2017; Martin, Franck, Cermolacce, Coull, & Giersch, 2018; Martin et al., 2014) or perceptual experience (e.g., Uhlhaas & Mishara, 2007) in the schizophrenia spectrum, this has tended not to extend to the broader construct of minimal self-disturbance which includes, but is not limited to, anomalous bodily, temporal or perceptual experience.

The theoretical models regarding neuro-correlates (neurocognitive, neurophysiological and neurobiological correlates) of minimal self-disturbance (Borda & Sass, 2015; Mishara et al., 2015; Nelson & Sass, 2017; Nelson, Whitford, et al., 2014a, 2014b; Parnas, Bovet, & Innocenti, 1996; Sass & Borda, 2015) have not been sufficiently empirically examined to date. The four studies that have directly examined neurocognitive correlates of minimal self-disturbance have found no correlation or a weak correlation between the variables (Comparelli et al., 2016; Haug, Oie, et al., 2012; Koren et al., 2017; Nordgaard, Revsbech, & Henriksen, 2015). However, the neurocognitive variables examined in these studies were derived from traditional measures of general intelligence, psychomotor speed, working memory and executive function, which may lack specificity to the disturbances at play in minimal self-disturbance (Nelson & Sass, 2017; Nelson, Whitford, et al., 2014a, 2014b). Indeed, two recent studies are consistent with the suggestion of more specific neuro-disturbances being of relevance to minimal disturbance. Sestito et al. (2015) found that facial reactions in response to negative emotional stimuli, recorded using electromyography, specifically and strongly correlated with minimal self-disturbance in schizophrenia spectrum patients. Martin et al. (2017) findings in schizophrenia indicated a relationship between compromised extraction of temporally predictive information assessed in experimental tasks and minimal self-disturbance. Given the complexity and foundational nature of the minimal self-disturbance construct it is likely that there are multiple rather than single neuro-mechanisms associated with this constellation of anomalous subjective phenomena (Martin et al., 2014).

Nelson et al. (Nelson & Sass, 2017; Nelson, Whitford, et al., 2014a, 2014b) introduced a theoretical model proposing that the neuro-constructs of source monitoring deficits and aberrant salience may be of particular relevance to minimal self-disturbance in schizophrenia (see supplementary material video 1 for an animated diagram). Both of these constructs have been found to be prominent in schizophrenia spectrum disorders and related to psychosis risk (Gaweda et al., 2018; Gaweda, Woodward, Moritz, & Kokoszka, 2013; Waters, Woodward, Allen, Aleman, & Sommer, 2012). Source monitoring deficits refer to difficulties in making attributions about the origins of mental experiences, e.g., whether an experience was real or imagined, or whether its origin was internal (self-generated) or external (other-generated) (Crapse & Sommer, 2008; Stephan, Friston, & Frith, 2009; Whitford, Ford, Mathalon, Kubicki, & Shenton, 2012). Aberrant salience refers to the reduced ability to suppress attention to irrelevant or familiar information or environmental stimuli (in other words, *excessive* attention to information that is irrelevant or highly familiar), leading to an unusual salience of stimuli (Kapur, 2003; Kapur, Mizrahi, & Li, 2005).

There is strong face validity that the experiential disturbances that might arise from (and in turn consolidate (Sass et al., 2018)) these neuro-disturbances accord with many of the experiential alterations associated with minimal self-disturbance (Nelson & Sass, 2017; Nelson, Whitford, et al., 2014a, 2014b; Sass et al., 2018). In brief, confusion regarding the *origin* of mental experiences associated with source monitoring deficits accord with a variety of aspects of minimal self-disturbance:

- diminished 'ownership' of mental content;
- confusion of self-other boundaries;
- hyper-reflexivity, i.e., heightened awareness of aspects of one's experience that are normally tacit and implicit) (Poletti, Gebhardt, & Raballo, 2017).

Aberrant salience, due to the reduction in the constraining and directing role of *context*, also accords with various aspects of minimal self-disturbance:

- rigidity and perplexity in interaction with others/the world;
- disturbance of 'common sense' (intuitive social understanding);
- loosened 'grip' on the cognitive/perceptual world, i.e., the sharpness or stability with which meaning or perceptions emerge against a background context;
- frequent shifts in perspective that undermine the possibility of blocking out alternative perspectives (referred to as 'perspectival abridgement');
- weakened sense of the functional value (referred to as the 'affordance value') of objects;
- hyper-reflexivity (see Nelson, Whitford, et al. (2014a, 2014b) for full explication of this integrated model).

We recently reported the first empirical support for the source monitoring aspect of this model, i.e., an association between minimal self-disturbance and source monitoring deficits in early psychosis patients (Nelson et al., 2019). However, these data, presented in letter format, were only partial data from the study. The purpose of the current report is to present the full data of this first empirical test of the proposed neurophenomenological model. The focus here is on cross-sectional association between variables.

It is particularly valuable to research pathogenic models of psychotic disorders in the early stages of disorder because these stages may allow a clearer view of the mechanisms at play, before the effects of advanced illness stages cloud the clinical picture (Klosterkötter, Hellmich, Steinmeyer, & Schultze-Lutter, 2001; Nelson, Yung, Bechdolf, & McGorry, 2008; Parnas, 2000; Yung, Phillips, & McGorry, 2004), as well as point towards possible preventative treatment targets. In this study, clinical measures, including the EASE, and neurocognitive and neurophysiological measures of source monitoring deficits and aberrant salience were administered in two patient groups (a first-episode psychosis [FEP] sample and an ultra-high risk [UHR] for psychosis sample), as well as a healthy control (HC) group. We hypothesised that:

1. Minimal self-disturbance, source monitoring deficits and aberrant salience would show an increasing gradient of severity from HC to UHR to FEP individuals (HC < UHR < FEP). The expectation that minimal self-disturbance would show this differentiation between groups was based on the fact that schizophrenia spectrum cases are mostly highly represented in the FEP group.
2. Minimal self-disturbance would be predicted by source monitoring deficits and aberrant salience in FEP and UHR individuals.

2. Material and methods

2.1. Setting

Patients were recruited from Orygen Youth Health Clinical Program (OYHCP), a tertiary public mental health service for young people aged between 15 and 25 years living in north-western Melbourne, Australia. UHR participants were recruited from the Personal Assessment and Crisis Evaluation (PACE) clinic, a specialist psychosis risk clinic within OYHCP, and FEP participants were recruited from the Early Psychosis Prevention and Intervention Centre (EPPIC), a specialist clinic for first-episode psychosis.

2.2. Sample

The UHR participants consisted of the standard three UHR groups: attenuated psychotic symptoms (APS), brief limited intermittent psychotic symptoms (BLIPS), and trait vulnerability in combination with deteriorating or chronic low functioning (see Nelson et al. (2017) for full details). FEP was defined as daily positive psychotic symptoms for longer than one week, as per previous research (Yung et al., 2003). Participants were required to have stabilised from acute psychotic symptoms at time of recruitment. The healthy control group did not have a current or past psychiatric diagnosis and did not meet UHR criteria. This group was recruited via advertisements placed in local newspapers and various public locations across the OYHCP catchment area.

Exclusion criteria for all groups were presence of an intellectual disability (IQ < 70), lack of proficiency in English, or being outside the 15–25 age range.

The sample was recruited between March 2014 and January 2018. The study was approved by the local research and ethics committee, and participants provided written informed consent.

2.3. Measures

2.3.1. Demographics and treatment history

A demographic and medication information sheet was used to capture the following information: age, gender, referral source, psychotropic medication prescription and compliance, and previous psychiatric treatment.

2.3.2. Clinical measures

- Family History questionnaire to assess family history of psychiatric disorder.
- *Examination of Anomalous Self-Experience* (*EASE;* Parnas et al., 2005a, 2005b). The EASE was used to assess minimal self-disturbance. The EASE is a 57-item instrument designed for semi-structured, phenomenological exploration of subjective anomalies indicative of disturbance of the minimal self. The instrument categorises anomalous subjective experiences according to five domains (Cognition and stream of consciousness; Self-awareness and presence; Bodily experiences; Demarcation/transitivism; Existential reorientation). Ratings can be made dichotomously or continuously on a 5-point severity/frequency scale. A total score is derived by summing individual item scores, with higher scores corresponding to greater minimal self-disturbance.
- *Mini International Neuropsychiatric Interview (MINI;* First, Spitzer, Gibbon, & Williams, 1996): used to establish DSM-IV psychiatric diagnoses.
- *Structured Clinical Interview for DSM-IV AXIS-I Psychosis Module (SCID-I;* First, Spitzer, Gibbon, & Williams, 1997): used to determine type of psychotic diagnosis in the FEP group.
- *Structured Clinical Interview for DSM-IV AXIS-II (SCID-II;* First et al., 1997): used to determine schizophrenia spectrum personality disorders (schizotypal, schizoid and paranoid personality disorders).
- *Comprehensive Assessment of At Risk Mental States (CAARMS;* Yung et al., 2005). The CAARMS is a semi-structured interview designed to assess a wide range of symptoms associated with the prodromal phase of psychotic disorders and to determine FEP threshold.
- *Brief Psychiatric Rating Scale (BPRS;* Overall & Gorham, 1962). The BPRS is a widely used 24-item scale that rates various domains of psychopathology (positive psychotic symptoms, negative psychotic symptoms, general psychopathology).
- *Scale for Assessment of Negative Symptoms (SANS;* Andreasen, 1983). The SANS is a widely used observer-rated scale for assessing negative psychotic symptoms.

2.3.3. Neurocognitive assessments

- *Wechsler Abbreviated Scale of Intelligence (WASI)*: used to obtain an estimate of current general intellectual functioning.
- *Verbal Memory* and *Digit Sequencing tasks* from the *Brief Assessment of Cognition in Schizophrenia (BACS*; Keefe et al., 2004): used to assess verbal learning and memory and working memory, respectively.

Source monitoring deficits were assessed using the following measures, covering a range of stimulus domains and task contexts:

- *Action Memory Task* (Moritz, Ruhe, Jelinek, & Naber, 2009). This task involves presenting actions to participants either verbally (short instructions) or nonverbally (icons). Some of the items require participants to physically perform the action whereas other actions are imagined. In the recognition phase of the task, participants are asked whether an action was previously displayed (verbally or nonverbally), whether it was a new action (not presented before), and if they had performed or imagined the action. Participants also rate how confident they are in their decision. The focus of the current analysis was on discrimination between imagined and performed actions. Higher scores indicate greater source monitoring deficits. The task has previously been used with psychotic (Gaweda et al., 2013) and UHR patients (Gaweda et al., 2018).
- *Word Recognition Test* (Giráldez, Caro, López Rodrigo, Piñeiro, & González, 2000). A series of 30 words are presented on a computer screen. For each word, participants are required to type a single word on the keyboard that is conceptually related to the word displayed on the screen. In the second phase of the task, participants are re-presented with all the words (those generated by the computer and those generated by the participant) in random order, and asked to identify whether each word was generated by the computer (external origin) or generated by themselves (internal origin). Source monitoring deficits are measured by two types of errors: 1) Internal Attribution Errors (when participants inaccurately identify self-generated words to be computer generated) and 2) External Attribution Errors (when participants inaccurately identify computer-generated words to be self-generated). Higher scores indicate greater source monitoring deficits.
- *Temporal Binding Task* (Haggard, Clark, & Kalogeras, 2002; Moore & Haggard, 2008). This task requires participants to view a Libet clock hand rotating (one rotation = 2560 ms) on a computer screen. The clock face is marked with conventional intervals (5, 10, 15, etc.). The initial position of the clock hand is randomly placed. Participants are asked to press a key while the clock hand is rotating and then estimate at what time on the clock face they pressed the key. 50% of keypresses result in an audible tone. Previous research (Haggard et al., 2002) indicates that when the keypress results in a tone there is a tendency amongst healthy participants to estimate the timing of the keypress closer to the tone than actually occurred, referred to as an "intentional binding" of actions and their effects in conscious awareness. This provides an index of implicit agency, which we take to be dependent on source monitoring because control over one's actions ("agency") assumes a sense of the origin of actions. The score used for analysis was the difference between the estimated time of the keypress and actual time of the keypress for trial type 1 (keypress followed by beep) and trial type 2 (keypress not followed by a beep). Positive scores indicate that participants estimated their action (keypress) to occur later when it was followed by a sensory consequence (beep) compared to when it was not – this was taken as evidence of temporal binding. Conversely, negative scores indicate that participants estimated their action to occur earlier when it was followed by a sensory consequence compared to when it was not – this was taken as the inverse of sensory binding.

Aberrant salience was assessed using the following measures:

- *Salience Attribution Test (SAT;* Roiser et al., 2009; Roiser, Stephan, den Ouden, Friston, & Joyce, 2010). The SAT is a reward-based speed-response game, which measures responses to task-relevant and task-irrelevant cue features. The SAT provides measures of adaptive (relevant) and aberrant (irrelevant) motivational salience on the basis of visual analogue scale ratings (explicit salience) and reaction times (implicit salience). The test has been used in a number of previous studies to measure aberrant salience (Roiser, Howes, Chaddock, Joyce, & McGuire, 2012; Roiser et al., 2009; Roiser et al., 2010).
- *Babble Task* (Hoffman et al., 2007). In this task participants are presented with verbal babble (meaningless syllables) via headphones and asked to repeat any real words or phrases that they perceive. The extent to which spurious messages are extracted from meaningless noise (i.e., meaningless stimuli being endowed with significance) is thought to index aberrant salience (Hoffman et al., 2007) and has previously been found to predict onset of psychosis in a UHR sample (Hoffman et al., 2007). The task measures both number of words/phrases heard and length of phrases heard (higher scores corresponding to greater aberrant salience).

2.3.4. Neurophysiological assessments

Electroencephalography (EEG) was used to measure neurophysiological indices of source monitoring deficits and aberrant salience.

- *Auditory button-press task* (Whitford et al., 2011). Source monitoring deficits were indexed by comparing electrical brain activity evoked by self-generated auditory stimuli versus externally-generated auditory stimuli. In the 'self-generated' condition, participants were trained to press a button at will to produce an auditory tone delivered to them through a set of headphones. In the 'externally-generated' condition, tones were presented to the participant at random intervals (0.5–2.5 s) while they were sitting passively. There was also a 'motor' condition in which participants pressed a button but did not hear a sound. The brain activity evoked in the motor condition was subtracted from the brain activity evoked in the self-generated condition in an effort to remove motor-evoked potentials, as is standard practice (Horvath, 2015). The difference between the motor-corrected self- and externally-generated conditions corresponds to source monitoring (N1-suppression), with reduced difference scores indicating source monitoring deficits.
- *Auditory Oddball Paradigm (AOP).* Aberrant salience was indexed by a measure of mismatch negativity (MMN), evoked using an auditory oddball paradigm (AOP). This AOP consisted of unexpected, deviant (i.e., oddball) stimuli of both duration and pitch)

being presented amongst an otherwise continuous stream of stimuli. MMN is a change in the activity of the brain induced by the occurrence of novel stimuli, leading to a switch of attention (Naatanen et al., 2011). Reduced MMN amplitudes have consistently been observed in schizophrenia (Umbricht & Krljes, 2005), which has been interpreted as an altered level of automatic cortical activation in response to salient events (Javitt, Doneshka, Grochowski, & Ritter, 1995).

EEG data were recorded using Neuroscan software and a Neuroscan SynAmps 2 amplifier (Neuroscan, El Paso, Texas) with internal filters set to 0.5–1000 Hz. The data were processed with BrainVision Analyzer 2 software (Brain Products GmbH, Munich). Data were continuously sampled at 1000 Hz from 64 electrode sites, located in accordance with the 10–20 system. The data were referenced to the mastoid electrodes. For the auditory button-press task, the data were filtered offline at 0.1–15 Hz, were epoched from −100 to 400 ms, corrected for eye movements, baseline corrected from −100 to 0 ms, and averaged. For the AOP task, the data were filtered offline at 0.1–20 Hz, were epoched from −100 to 400 ms, corrected for eye movements, baseline corrected from −100 to 0 ms, and averaged.

2.4. Procedure

The UHR participants were assessed within two months of entry to clinical services. The FEP participants were assessed at any time during their two-year period of treatment at the clinical services, after remission from acute symptoms of FEP had been achieved.

Clinical, neurocognitive and neurophysiological assessments were conducted consecutively over two or three sessions.

2.5. Statistical analysis

One-way analysis of variance (ANOVA) were conducted to compare the three groups on baseline demographic, clinical, neurocognitive, and neurophysiological measures. Composite scores across the neuro-measures of aberrant salience and source monitoring deficits were used for inferential analyses with the EASE. These composite scores were derived by summing unit-weighted z scores of constituent tests of aberrant salience and source monitoring deficits, respectively. The z scores were formed using the HC sample mean and the pooled standard deviation (i.e., root mean square error) within the three groups. This is a common approach in neurocognitive studies (Ackerman & Cianciolo, 2000; Keefe et al., 2006; Maidhof, Kastner, & Makkonen, 2014) in order to provide more stable scores when multiple measures of a single construct have been used. Moreover, they reduce the risk of type I error inflation. Unit-weighted z scores result in positive and negative values based on the relationship of the score to the mean value. Linear regression was used with the EASE regressed on the source monitoring and aberrant salience domains, with study group introduced as an interaction term. As a post-hoc test, if a main or interaction effect emerged in these regressions, then bivariate correlations were performed between the EASE and the neuro-measures within each study group. The post-hoc, exploratory correlational analyses are presented both uncorrected and corrected for multiple comparisons (see supplementary material for results correcting for multiple comparisons). An alpha level of 0.05 was used for all statistical tests, with the Benjamini & Hochberg False Discovery Rate (B-H FDR) used to correct for multiple comparisons (Benjamini, Drai, Elmer, Kafkafi, & Golani, 2001; Benjamini & Hochberg, 1995). B-H FDR

Table 1
Sample demographics and clinical characteristics.

	UHR (n = 50)	FEP (n = 39)	HC (n = 34)	P values post hoc comparisons
Mean age (SD)	18.78 (4.93)	19.87 (3.25)	21.09 (1.85)	0.025* FEP = UHR < HC
Gender – male n (%)	22 (44%)	18 (46%)	10 (29%)	0.261
Ethnicity – Caucasian n (%)	44 (88%)	30 (77%)	26 (76%)	0.342
Currently employed/studying	36 (72%)	22 (56%)	31 (91%)	0.013* FEP < UHR < HC
SOFAS mean (SD)	53.12 (8.51)	52.27 (11.56)	79.06 (6.96)	0.000*** FEP = UHR < HC
BPRS total mean (SD)	49.43 (8.13)	51.81 (13.50)	25.59 (2.46)	0.000*** HC < FEP = UHR
CAARMS positive symptom mean (SD)	23.86 (6.43)	32.26 (5.50)	3.03 (3.79)	0.000*** HC < UHR < FEP
SANS total mean (SD)	19.42 (14.32)	22.41 (16.51)	1.94 (5.37)	0.000*** HC < FEP = UHR
EASE total mean (SD)	63.30 (34.65)	78.74 (29.82)	5.32 (4.95)	0.000*** HC < UHR < FEP

SOFAS = Social and Occupational Functioning Scale; BPRS = Brief Psychiatric Rating Scale; CAARMS = Comprehensive Assessment of At Risk Mental States; SANS = Scale for the Assessment of Negative Symptoms; EASE = Examination of Anomalous Self-Experience; UHR = Ultra High Risk for Psychosis; FEP = First Episode Psychosis; HC = Healthy Controls.
**p < .01.
* p < .05.
*** p < .001.

was chosen as, unlike the Bonferroni procedure, it does not assume that all tests are independent. Continuous EASE scores were used for analysis. Only the total EASE score (not the domain scores) was used in analysis given the number of comparisons and the fact that the EASE displays a mono-factorial structure (Nordgaard & Parnas, 2014; Raballo & Parnas, 2012). Two exploratory analyses of the relationship between the clinical and neuro-variables were conducted (a correlation and principal components analysis). The two clinical groups (UHR and FEP participants) were combined for these exploratory analyses for two important reasons. First, to provide sufficient statistical power for these analyses, and second, to minimize the potential risk of range-restriction.

3. Results

3.1. Demographic and clinical characteristics

The samples consisted of 50 UHR, 39 FEP, and 34 HC participants. Demographic characteristics and clinical scale scores are presented in Table 1. The HC group was older (by a mean of 2 years) than the clinical groups. The UHR sample consisted of the following sub-groups: APS = 37 (74%), APS + Trait Vulnerability = 10 (20%), APS + BLIPS = 2 (4%), and Trait Vulnerability = 1 (2%). SCID diagnoses are presented in Table 2. At the time of assessment, 11 (22%) of the UHR group were taking antidepressant medication and 15 (39%) of the FEP group were compliant with antipsychotic medication. None of the HC group were taking psychotropic medication at the time of assessment.

Minimal self-disturbance and positive symptom scores showed a HC < UHR < FEP sequence of magnitude, with a marked difference between the HC and clinical groups. General psychopathology and negative symptoms were significantly higher in the clinical groups than the HC group, with no difference between the clinical groups. Psychosocial functioning was significantly better in the HC group than the two clinical groups, with no difference between the clinical groups.

3.2. Neurocognitive measures

Neurocognitive test scores are presented in Table 3. No group differences were apparent on measures of general intelligence and memory performance. Group differences were apparent on measures of source monitoring. Specifically, on the Action Recognition task the clinical groups incorrectly recognised previously imagined actions as having been performed compared to the HC group. On the temporal binding task, the HC group showed a temporal binding effect (positive scores), which was inversed for both of the clinical groups (negative scores).

With regard to the aberrant salience measures, the only group difference was on one measure from the Salience Attribution Test, indicating reduced implicit adaptive salience in the UHR group compared to the HC group.

3.3. Neurophysiological measures

Fig. 1 shows the EEG mismatch negativity (MMN) waveforms at Fz for the three groups, i.e., the difference between the waveforms induced by the deviant and standard stimuli (deviant minus standard). All groups showed a significant MMN amplitude generation for both types of deviant stimuli (duration and pitch), with no differences between the groups (see Table 4). The same pattern of results were obtained with other fronto-central electrodes.

Fig. 2 shows the EEG waveforms for the auditory button-press task at Cz for the three groups. The FEP group showed less N1-

Table 2
Current SCID diagnoses.

	HC (n = 34)	UHR (n = 50)	FEP (n = 39)
SCID I			
Psychotic disorders, n (%)	0	0	39 (100%)
Schizophrenia			8 (20.5%)
Schizophreniform disorder			9 (23.1%)
Mood disorder with psychotic features			9 (23.1%)
Psychotic disorder NOS			13 (33.3%)
Mood disorders, n (%)	0	32 (64%)	5 (13%)
Anxiety disorders, n (%)	0	36 (72%)	22 (56%)
Substance use disorders, n (%)	0	8 (16%)	10 (26%)
Other, n (%)			3 (8%)
No SCID I diagnosis, n (%)	0	5 (10%)	0
SCID II			
Schizotypal personality disorder, n (%)	0	3 (6%)	7 (17.9%)
Schizoid personality disorder, n (%)		2 (4%)	1 (2.6%
Paranoid personality disorder, n (%)		2 (4%)	1 (2.6%)

Only SCID II schizophrenia spectrum diagnoses were assessed. Psychotic disorder NOS = Psychotic disorder not otherwise specified; UHR = Ultra High Risk for Psychosis; FEP = First Episode Psychosis; HC = Healthy Controls.
The sum of the presence of disorders exceeds the sample size due to comorbidity.

Table 3
Neurocognitive scale scores (group means).

	HC (n = 34)	UHR (n = 50)	FEP (n = 39)	P values post hoc comparisons
WASI (FSIQ)	107.46 (SD = 9.14)	111.94 (SD = 33.52)	111.52 (SD = 15.91)	0.73
BACS				
Verbal Recall Task (raw scores)	12.24 (SD = 1.67)	10.79 (SD = 1.93)	11.78 (SD = 2.71)	0.09
Digit Sequence Task (raw scores)	19.88 (SD = 3.57)	25.64 (SD = 26.89)	19.00 (SD = 4.20)	0.28
Source Monitoring Deficits				
Action Memory Task				
Performed actions recognised as imagined (number)	1.41 (SD = 0.99)	3.01 (SD = 1.99)	2.59 (SD = 1.90)	0.25
Imagined actions recognised as performed (number)	2.35 (SD = 2.00)	3.15 (SD = 2.26)	3.00 (SD = 2.19)	0.000*** UHR > HC FEP > HC
Incorrect recognition of performed and imagined actions (number)	3.76 (SD = 2.35)	6.17 (SD = 3.66)	5.59 (SD = 3.36)	0.005** UHR > HC FEP > HC
Word Recognition Task				
Internal attribution errors (number)	3.38 (SD = 3.25)	3.62 (SD = 2.74)	4.94 (SD = 3.53)	0.09
External attribution errors (number)	3.79 (SD = 2.77)	4.40 (SD = 3.46)	4.72 (SD = 3.35)	0.49
Total errors (number)	7.09 (SD = 5.40)	8.02 (SD = 5.41)	9.62 (SD = 6.24)	0.18
Temporal Binding Task (ms)	16.42 (SD = 45.99	−7.88 (SD = 50.22)	−15.31 (SD = 50.72)	0.028* FEP > HC UHR > HC
Aberrant Salience				
Salience Attribution Test				
Adaptive salience (implicit measure; ms)	16.57 (SD = 18.34)	1.95 (SD = 19.50)	9.41 (SD = 23.83)	0.009** UHR < HC
Adaptive salience (explicit measure; mm)	11.05 (SD = 9.13)	13.61 (SD = 10.77)	16.43 (SD = 18.82)	0.901
Aberrant salience (implicit measure; ms)	41.67 (SD = 31.73)	39.94 (SD = 32.49)	43.39 (SD = 33.09)	0.269
Aberrant salience (explicit measure; mm)	8.79 (SD = 10.00)	6.17 (SD = 6.58)	10.48 (SD = 10.73)	0.113
Babble Task				
Number of words heard	12.85 (SD = 8.98)	9.40 (SD = 5.14)	9.32 (SD = 8.21)	0.08
Longest phrase length	2.32 (SD = 1.47)	1.98 (SD = 1.18)	1.93 (SD = 1.78)	0.48

WASI = Wechsler Abbreviated Scale of Intelligence; BACS = Brief Assessment of Cognition in Schizophrenia; UHR = Ultra High Risk for Psychosis; FEP = First Episode Psychosis; HC = Healthy Controls; ms = milliseconds; mm = millimeters.
* p < .05.
** p < .01.
*** p < .001. Only significant differences are displayed in the post-hoc comparisons.

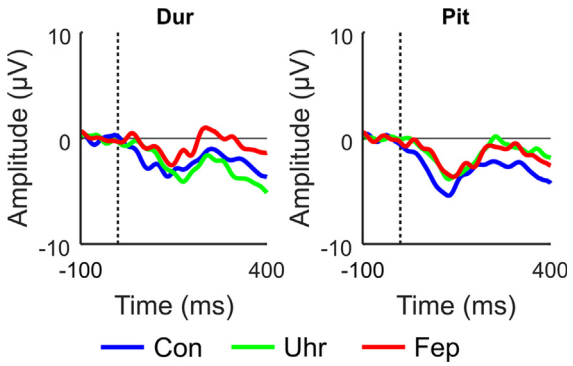

Fig. 1. EEG mismatch negativity waveforms at Fz for the three groups for duration and pitch deviant stimuli.

suppression (the difference between the passive 'listen' response and the active 'press for beep' response) than both the UHR and the HC groups (see Table 4).

3.4. Relationship between clinical scales, neurocognitive and neurophysiological measures

Given that the intercorrelations between the neuro-measures (both neurophysiological and neurocognitive) in each domain (source monitoring deficits and aberrant salience) were reasonably high ($r > 0.48$), the composite scores for each domain were

Table 4
Neurophysiological measures (group means).

	HC (n = 34)	UHR (n = 50)	FEP (n = 39)	P values post hoc comparisons
Auditory Oddball Task (MMN magnitude)				
Pitch	−4.43 (SD = 6.68)	−2.79 (SD = 3.23)	−2.66 (SD = 4.23)	ANOVA, p = .30
Duration	−2.93 (SD = 7.13)	−2.20 (SD = 2.24)	−1.12 (SD = 3.69)	ANOVA, p = .38
Auditory Button Press Task				
N1-suppression	2.32 (SD = 2.79), n = 39	3.73 (SD = 3.72), n = 30	0.20 (SD = 3.58), n = 19	ANOVA, p = .002 HC vs FEP, p = .024 HC vs UHR, p = .083 FEP vs UHR, p < .001

MMN = mismatch negativity; UHR = Ultra High Risk for Psychosis; FEP = First Episode Psychosis; HC = Healthy Controls.
*p < .05; **p < .01; ***p < .001.

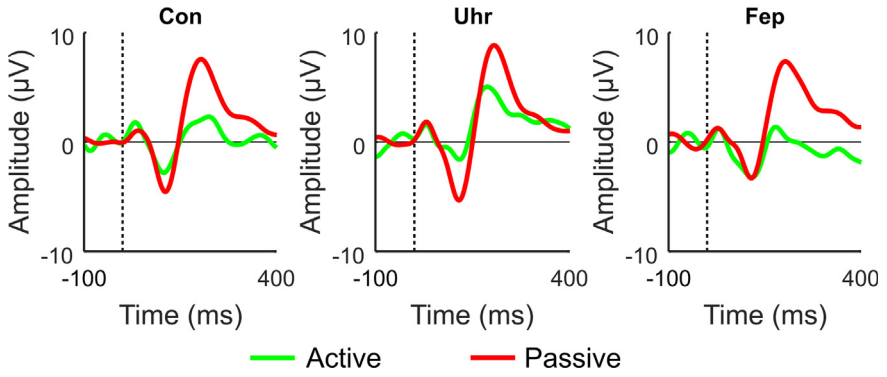

Fig. 2. EEG waveforms for the auditory button-press task at Cz for the three groups.

Table 5
Correlations between self-disturbance scores (EASE) and neuro-measures of general neurocognition and source monitoring deficits.

	EASE scores		
General neurocognitive measures	HC	UHR	FEP
WASI	0.03	−0.002	0.223
BACS			
Verbal Recall Task	−0.22	0.313	0.043
Digit Sequence Task	−0.08	0.155	−0.190
Source monitoring deficit measures			
Action Recognition Task			
Performed actions recognised as imagined	**0.33***	**0.348***	0.118
Imagined actions recognised as performed	0.13	**0.345***	**0.378***
Incorrect recognition of performed and imagined actions	**0.35***	**0.403****	0.290
Word Recognition Task			
Internal attribution errors	**0.51****	**0.447****	**0.355***
External attribution errors	0.18	**0.418****	**0.450****
Total attribution errors	**0.38***	**0.494****	**0.437***
Temporal Binding Task	−0.06	**−0.301***	**−0.352***
Auditory Button Press Task			
N-1 Suppression	−0.15	0.315	**−0.489***
Source Monitoring Deficits Composite Score	0.14	**0.401***	**0.690****

N-1 = N-1 suppression; UHR = Ultra High Risk for Psychosis; FEP = First Episode Psychosis; HC = Healthy Controls.
***p < .001.
* p < .05.
** p < .01.

entered in the regression analyses, rather than entering each measure separately. The results of the regression indicated that source monitoring (composite score), with study group as an interaction term, explained 39.8% of the variance in EASE scores ($R^2 = 0.41$, $F(3,85) = 14.78$, $p < .001$). Source monitoring significantly predicted EASE scores ($\beta = 0.80$, $p < .001$) and there was a significant source monitoring by study group interaction effect ($\beta = 0.29$, $p < .05$).

In order to determine the specificity of the relationship between source monitoring deficits and EASE scores, a series of regressions with the other clinical scales as dependent variables was performed. Although source monitoring (composite score), with study group as an interaction term, was found to significantly predict variance in scores on each of these clinical measures, the variance explained was not as substantial as for the EASE scale: 25% for BPRS total ($R^2 = 0.25$, $F(3,85) = 9.01$, $p < .01$), 19% for BPRS positive symptoms ($R^2 = 0.19$, $F(3,85) = 6.69$, $p < .01$), 26% for CAARMS positive symptoms ($R^2 = 0.26$, $F(3,85) = 9.45$, $p < .01$), 14% for SANS total ($R^2 = 0.14$, $F(3,85) = 4.71$, $p < .01$).

Post-hoc Pearson correlations between EASE scores and source monitoring measures by study group are reported in Table 5. The pattern of correlations indicates moderate significant correlations between the EASE and source monitoring (individual measures and composite score) in both clinical groups, although most of these lose statistical significance when adjusting for multiple comparisons (see supplementary material). The neurophysiological measure of source monitoring, the auditory button press task, showed a moderate negative correlation with the EASE (i.e., higher EASE scores, less N1-suppression) in the FEP group, but not in the UHR group.

A regression of aberrant salience (composite score), with study group as an interaction term, explained only 6% of the variance in EASE scores ($R^2 = 0.06$, $F(3,85) = 1.44$, $p = .93$). Given the lack of relationship between aberrant salience, or interaction by group, on EASE scores, we conducted an exploratory analysis of the correlation between aberrant salience measures and other clinical scales (see Table 6). Aberrant salience measures, particularly the Babble task, showed moderate relationships with general psychopathology (BPRS total), particularly positive symptoms (BPRS positive symptoms, CAARMS positive symptoms), although most of these correlations were no longer statistically significant after adjusting for multiple comparisons (see supplementary material).

Two further exploratory analyses of the relationship between the clinical and neuro-variables were conducted in the pooled clinical groups (UHR and FEP combined). Fig. 3 shows the relationship between EASE scores and source monitoring and aberrant salience (composite scores), indicating a positive association with the former (green line) but not for the latter (blue line). A principal

Table 6
Correlations between clinical scales and aberrant salience neuro-measures in the UHR and FEP samples.

Neuro-Measures	Clinical scales			
	BPRS	BPRS Positive Symptoms	CAARMS Positive Symptoms	SANS
WASI	−0.202 UHR	−0.035 UHR	−0.116 UHR	−0.097 UHR
	−0.006 FEP	−0.269 FEP	−0.046 FEP	**0.455* FEP**
BACS				
Verbal Recall Task	−0.306 UHR	−0.157 UHR	0.346 UHR	0.051 UHR
	0.064 FEP	−0.038 FEP	0.199 FEP	0.327 FEP
Digit Sequence Task	0.126 UHR	−0.011 UHR	−0.299 UHR	0.286 UHR
	0.173 FEP	0.093 FEP	0.104 FEP	0.359 FEP
Salience Attribution Task				
Adaptive salience (implicit measure)	−0.051 UHR	−0.043 UHR	−0.040 UHR	−0.144 UHR
	0.033 FEP	0.131 FEP	−0.293 FEP	−0.163 FEP
Adaptive salience (explicit measure)	−0.052 UHR	0.082 UHR	0.027 UHR	−0.076 UHR
	−0.194 FEP	−0.095 FEP	−0.491 FEP	−0.331 FEP
Aberrant salience (implicit measure)	0.221 UHR	0.029 UHR	0.109 UHR	0.156 UHR
	0.151 FEP	0.179 FEP	0.116 FEP	0.053 FEP
Aberrant salience (explicit measure)	−0.142 UHR	−0.182 UHR	−0.097 UHR	**−0.305* UHR**
	−0.157 FEP	−0.128 FEP	−0.057 FEPO	−0.114 FEP
Babble Task				
Number of words heard	0.065 UHR	**0.331* UHR**	**0.439** UHR**	0.001 UHR
	0.436* FEP	**0.531** FEP**	−0.039 FEP	0.201 FEP
Longest phrase length	−0.050 UHR	0.139 UHR	**0.320** UHR**	−0.168 UHR
	0.209 FEP	0.217 FEP	−0.030 FEP	0.020 FEP
Auditory Oddball Task (MMN amplitude)				
Pitch	0.198 UHR	−0.063 UHR	0.096 UHR	−0.033 UHR
	0.269 FEP	0.138 FEP	0.037 FEP	0.165 FEP
Duration	0.246 UHR	−0.002 UHR	0.079 UHR	0.125 UHR
	0.089 FEP	−0.147 FEP	0.088 FEP	−0.166 FEP
Aberrant Salience Composite Score	0.172 UHR	−0.036 UHR	0.270 UHR	0.015 UHR
	0.269 FEP	0.283 FEP	0.302 FEP	0.321 FEP

MMN = mismatch negativity; UHR = Ultra High Risk for Psychosis; FEP = First Episode Psychosis; HC = Healthy Controls; SOFAS = Social and Occupational Functioning Scale; BPRS = Brief Psychiatric Rating Scale; CAARMS = Comprehensive Assessment of At Risk Mental States; SANS = Scale for the Assessment of Negative Symptoms; EASE = Examination of Anomalous Self-Experience; *p < .05; **p < .01; ***p < .001.

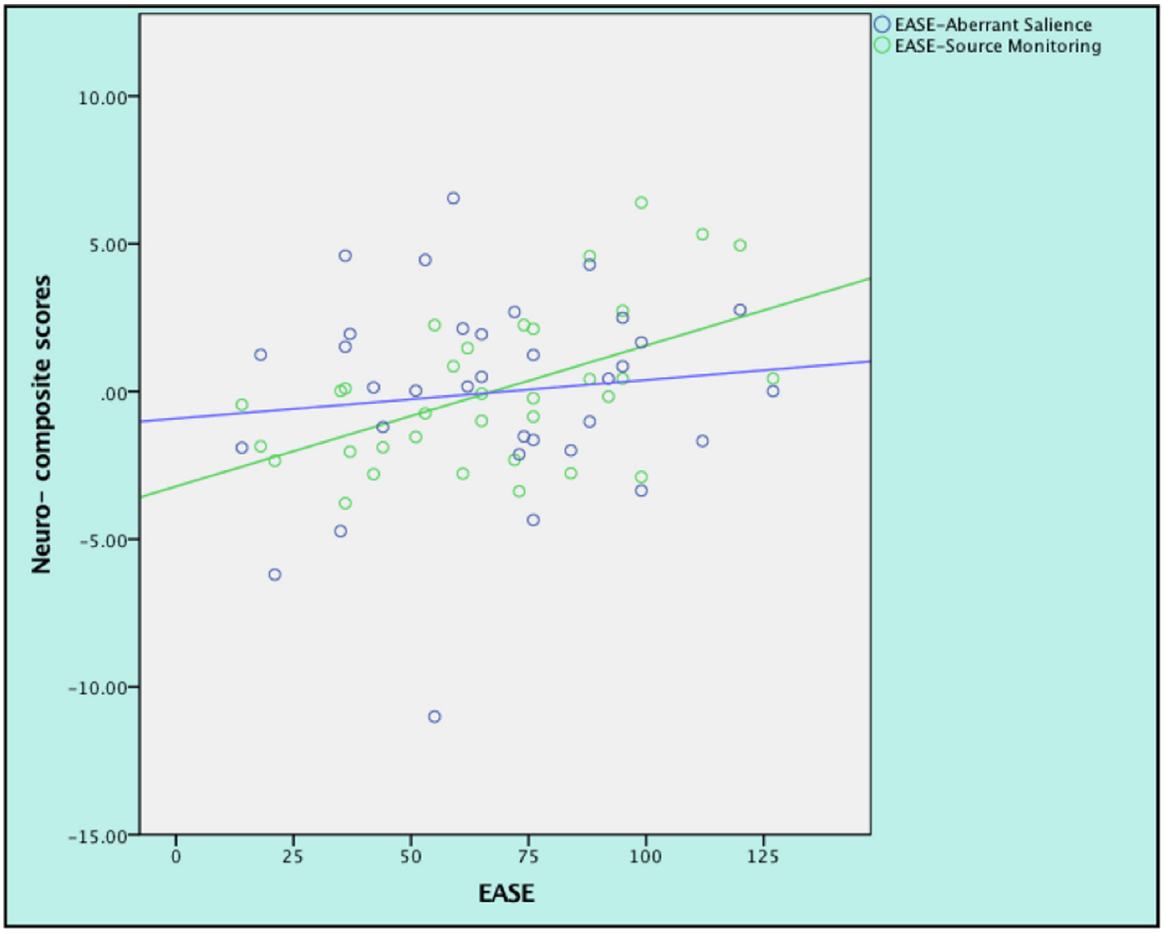

Fig. 3. Scatterplot of the relationship in the pooled clinical groups (UHR and FEP combined) between EASE scores and source monitoring and aberrant salience.

components analysis (PCA, Fig. 4) showed a closer relationship between the EASE and source monitoring deficits than with aberrant salience (represented by the closer spatial proximity between these variables in the PCA plot), while aberrant salience showed a closer relationship with other clinical scales.

4. Discussion

Our first hypothesis was that minimal self-disturbance, source monitoring deficits and aberrant salience would show an increasing gradient of severity from HC participants to UHR patients to FEP patients (FEP < UHR < HC). There was partial support for this hypothesis. While minimal self-disturbance showed this pattern of severity, the neurocognitive and neurophysiological findings were less clear. One neurocognitive test of source monitoring deficits (the temporal binding task) showed the expected sequence, while on another task (the Action Memory Task) the clinical groups showed more pronounced disturbances than controls, with no difference between the clinical groups. The neurophysiological test of source monitoring deficits showed prominent disturbance (lack of suppression to self-generated stimuli) in the FEP group, which was not apparent in the UHR or HC groups. The second hypothesis was that minimal self-disturbance would be predicted by source monitoring deficits and aberrant salience in FEP and UHR patients. Again, partial support was found: while a clear relationship was apparent between minimal self-disturbance and source monitoring deficits, no relationship was apparent with aberrant salience, which showed some relationship with general psychopathology, particularly with positive psychotic symptoms. The group differences (hypothesis one) and the relationship between phenomenological and neuro-measures (hypothesis two) were unlikely to be due to differences in general intellectual ability or memory difficulties, which did not differ between the three groups. Consistent with previous research, there was no relationship between minimal self-disturbance and traditional general neurocognitive measures (WASI and BACS).

The findings raise a number of issues relating to the relative role of various neuro-constructs in relation to minimal self-disturbance versus positive psychotic symptoms, stage of disorder, and the schizophrenia spectrum versus other psychoses.

Firstly, the findings suggest that source monitoring deficits, as measured by both neurocognitive and neurophysiological paradigms, have more relevance to minimal self-disturbance than aberrant salience does. Aberrant salience is possibly more related to

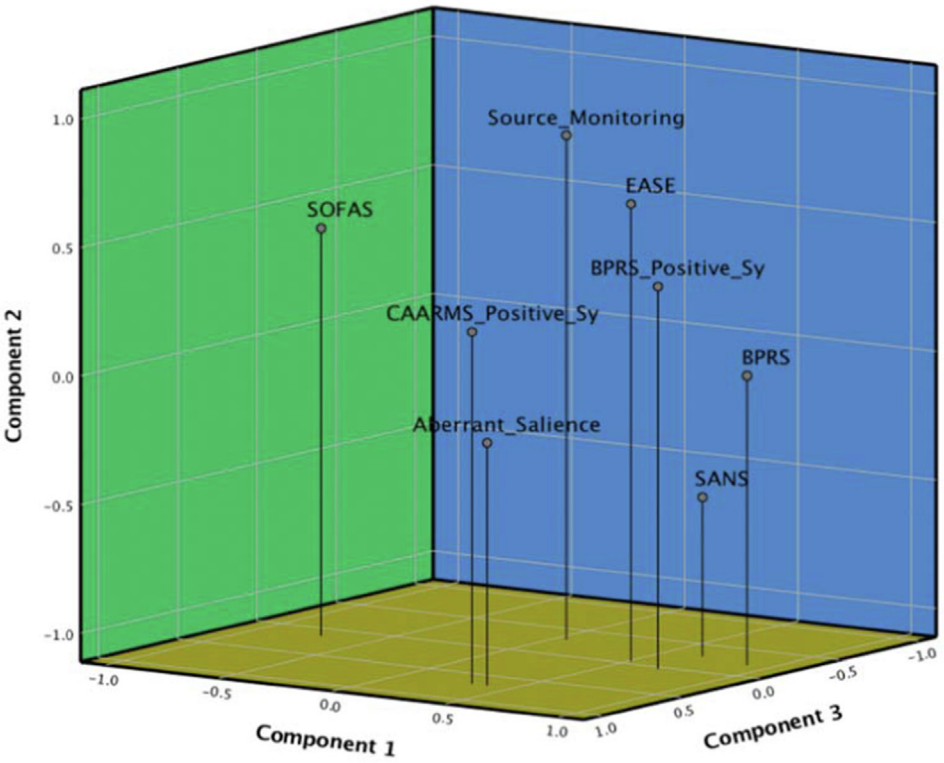

Fig. 4. Plot in rotated space from a principal components analysis of the clinical scales and composite neuro-scores.

severity of positive psychotic symptoms (i.e., a state-based feature of illness) than to the minimal self-disturbance construct (which seems to be more trait-based). This accords with another recent analysis in a UHR cohort (Leitan, Phillips, & Nelson, 2019). This proposal is consistent with the notion that aberrant salience is underpinned by a dysregulated dopaminergic system, leading to a "final common pathway" into positive psychotic symptoms (Howes & Kapur, 2009; Howes & Nour, 2016; Kapur, 2003). However, somewhat at odds with this interpretation is the fact that in the current dataset there was no observable difference between healthy controls and patients on various aberrant salience measures, including MMN. This is a surprising aspect of the findings given that aberrant salience (Galdos et al., 2011; Reininghaus et al., 2016; Roiser et al., 2012; Roiser et al., 2009) is a reasonably robust phenomenon observed in early psychosis. However, MMN, particularly pitch MMN, has not always been shown to be reduced in early psychosis (Haigh, Coffman, & Salisbury, 2017; Lavoie, Goldstone, Nelson, Polari, & McGorry, 2019; McGorry et al., 2014). It is possible that the clinically stable status of the FEP patients and the fact that approximately 40% were taking dopamine antagonising antipsychotic medications contributed to not observing aberrant salience, which may be more prominent during a period of active psychotic symptoms. Similarly, in the UHR group the positive psychotic symptoms may not yet be of sufficient intensity/frequency for this group to manifest aberrant salience and their overall risk of these symptoms intensifying to the point of a frank psychotic episode is reasonably modest (10–15% based on recent data (Nelson et al., 2018).) The lack of aberrant salience and MMN deficit may also be attributable to the modest sample size of UHR and FEP patients (lack of power). The fact that MMN was smallest in the FEP group (see Fig. 1) but not sufficiently different to be statistically significant (i.e., the direction of group differences was as expected) is consistent with this interpretation.

It should also be considered, regardless of the lack of group differences on the aberrant salience measures, that aberrant salience may be more relevant to what has been referred to as anomalous *world* experience (experience of space, time, other people, language, atmosphere, and existential orientation) rather than to self-experience, although these are clearly overlapping constructs (Sass, Pienkos, & Fuchs, 2017). This possibility could be explored in future work with use of the recently introduced EAWE (Examination of Anomalous World Experience; (Sass, Pienkos, Skodlar, et al., 2017)) instrument.

The proposed neurophenomenological model received partial empirical support, but the findings suggest that it needs to be refined. While source monitoring deficits indeed seem to play a role in minimal self-disturbance, there are likely to be other relevant neuro-variables which were not tested directly in the current study. As mentioned above, it is unlikely, given the complexity and foundational nature of the construct, that there is only a single neuro-variable of relevance to minimal self-disturbance. The theoretical model may need to incorporate and test some of these other constructs, which include disturbed temporal processing, multisensory integration, and hierarchical predictive processing (see supplementary material video 2 for a possible revised neurophenomenological model of minimal self-disturbance). Disturbed temporal processing refers to fragility in the ability to continuously extract temporally predictive information, for which there is already some empirical support for a relationship with minimal self-

disturbance (Martin et al., 2018; Martin et al., 2017; Martin et al., 2014). Multisensory integration (the nervous system's integration of information from the different sense modalities) may be of relevance, as lack of perceptual integration, perhaps especially between exteroceptive and interoceptive forms of perception (e.g., visual and kinaesthetic/proprioceptive) may undermine the ability to apprehend the world in a holistic, vital, contextually grounded fashion, or to fully identify with the unity of one's body (Ferri et al., 2014) or thinking (Borda & Sass, 2015; Nelson & Sass, 2017; Parnas et al., 1996; Poletti et al., 2017; Postmes et al., 2014; Sestito et al., 2015).

An approach which has gained substantial recent attention in neuroscience is the hierarchical predictive processing (HPP) approach to neural mechanisms underlying perception, cognition and action (Bubic, von Cramon, & Schubotz, 2010; Clark, 2015; Rao & Ballard, 1999). This approach may also be of relevance to minimal self-disturbance, as we (Nelson & Hartmann, 2017; Sass et al., 2018) and others (Clowes, 2018; Hohwy, 2007; Seth, Suzuki, & Critchley, 2011) have previously suggested, and has already been applied to overt psychotic symptoms (Clark, 2015; Fletcher & Frith, 2009; Seth et al., 2011). In brief, HPP models describe counter flowing top-down prediction/expectation signals and bottom-up prediction error signals. Successful perception, cognition and action are associated with successful suppression ("explaining away") of prediction error, which, as Seth et al. (2011) has suggested with regard to interoceptive processes, may play a role in the subjective sense of presence, which is a key feature of the minimal self. Indeed, HPP may offer a conceptual approach for finding common ground between source monitoring deficits, disturbed temporal processing, and multisensory integration disturbance, as all rely on a predictive processing component. Source monitoring draws on predictive processes because the tacit sense of the origin of stimuli is modulated by corollary discharge mechanisms, allowing one to predict (and hence dampen the subjective response to) internally-generated stimuli (Ford & Mathalon, 2019). However, it is important to note here that the current findings indicate the relevance to minimal self-disturbance of not only a failure to discriminate between *internal* and *external* sources ('reality monitoring'), but also failure to discriminate *between* internal sources (imagining versus performing actions, i.e. 'self-monitoring'). This is consistent with the fact that efference copies and corollary discharge mechanisms are at play in both types of source monitoring (Jack et al., 2019; Whitford, Jack, et al., 2017; Whitford, Oestreich, et al., 2017). With regard to temporal processing, compromised ability to extract predictive information from the 'flow of events' in time inherently relies on predictive processes (updating Bayesian 'priors' in response to the occurrence of events over time to predict the probability of subsequent events). Finally, multisensory integration relies on information gathered from one modality being used to predict the nature of information being received from another modality (Pearl et al., 2009)) and the 'binding together' of stimuli from the various modalities (Parnas et al., 1996). In the current dataset, *adaptive* salience measured an individual's implicit sense of the probability of subsequent stimuli by the speed of response to high probability reinforcement trials relative to low probability reinforcement trials, a form of implicit predictive processing. Interestingly, in an exploratory analysis, this variable correlated significantly with minimal self-disturbance (supplementary Table 3), consistent with the suggestion of a possible role of HPP in minimal self-disturbance.

With regard to stage of disorder, in contrast to the UHR group the FEP group showed more pronounced minimal self-disturbance, greater source monitoring disturbances, and a stronger correlation between minimal self-disturbance and source monitoring deficits. This provides support for the proposed neurophenomenological model of minimal self-disturbance in that the constituent variables are more strongly related as they each become more severe and that the associated mechanisms may be partially responsible for driving the onset of more severe stages of disorder. The latter possibility will need to be tested with longitudinal follow up of relevant samples.

The stronger findings in the FEP group are also relevant to the issue of the schizophrenia spectrum versus other psychotic disorders. Minimal self-disturbance has been found to be particularly pronounced in schizophrenia spectrum disorders (Parnas & Henriksen, 2014). The current samples were mixed diagnostic groups of those at high clinical risk for psychosis and those having experienced a first episode of psychosis. Approximately 50% of the FEP sample and 14% of the UHR sample had schizophrenia spectrum diagnoses (schizophrenia spectrum personality disorders in the latter group). It may therefore be that the variables tested in this neurophenomenological model do not necessarily relate so much to stage as to type of primary disorder, with schizophrenia spectrum cases by definition being more highly represented in the FEP group.

4.1. Limitations

Some caveats are required. The sample sizes for each group were modest, there was no clinical control group, and the post-hoc correlations were on the whole of modest magnitude and most lost statistical significance when adjusted for multiple comparisons. Given that the minimal self-disturbance construct has shown specificity to schizophrenia spectrum disorders (Parnas & Henriksen, 2014) and that our samples were mixed diagnostic groups it is possible that the relationship between the variables in question may be more apparent in samples with primary schizophrenia spectrum diagnoses, irrespective of intensity/frequency of positive psychotic symptoms (see Nelson (2013) for further discussion of this issue.) Also, while minimal self-disturbance was assessed with a semi-structured interview (EASE) that explores past experiences in which somatosensory and affective arousal usually play a significant causal role (Nelson & Sass, 2009; Parnas, Handest, Jansson, & Saebye, 2005; Saks, 2007), neuro-functioning was assessed with structured, low-stress tasks that focus on the present (Koren et al., 2017). It is possible that aberrant salience has relevance to minimal self-disturbance under *stressful* conditions (not assessed in this study), while the relationship between minimal self-disturbance and source monitoring deficits is less sensitive to stress (Gupta, Ranganathan, & D'Souza, 2016).

Future studies will report on outcome in these clinical samples in order to investigate the predictive value of these phenomenological and neuro-variables, in combination and also as single variables, particularly with regard to onset of psychotic disorder. Existing research already indicates the role of minimal self-disturbance in predicting poor outcome, including transition to psychotic disorder (Nelson et al., 2012), but the predictive value of source monitoring deficits and aberrant salience are less clear. Experimental

manipulation of variables, including augmented and virtual reality paradigms, offer a powerful means of further exploring the relationship between the variables (Lenggenhager, Tadi, Metzinger, & Blanke, 2007), in both 'standard' and stress-inducing situations. Direct test of the additional neuro-variables incorporated into the revised model in relation to minimal self-disturbance, such as the experimental tasks used by Powers et al (Powers, Mathys, & Corlett, 2017), should be included in future work.

4.2. Conclusions

The current study presents the first empirical test of a neurophenomenological model organised around the construct of minimal self-disturbance. Partial support for the model was found. While there was a relationship between minimal self-disturbance and source monitoring deficits, no relationship was found with aberrant salience, which showed more relevance to general psychopathology, particularly positive psychotic symptoms (and is therefore possibly more a state-based feature of illness). The predictive value of these variables for longitudinal evolution of disorder will be reported in subsequent papers. A neurophenomenological model of minimal self-disturbance in schizophrenia spectrum disorders may need to be expanded from source monitoring deficits to include constructs such as disturbed temporal processing, multisensory integration, and hierarchical predictive processing. These are overlapping constructs and it is yet to be determined if a particular one or several of these constructs has causal or explanatory primacy with regard to minimal self-disturbance. Nevertheless, the data presented here and in other related recent research shows an emerging picture of neuro-features of core phenomenological aspects of schizophrenia spectrum disorders beyond surface-level frank psychotic symptoms. Further pursuing these lines of enquiry offers the possibility of integrating domains of research around central features of the schizophrenia spectrum and 'mutual enlightenment' (i.e., complementary insights; (Gallagher, 1997)) across these different research domains.

Ethics statement

The study was approved by the Melbourne Health Human Research and Ethics Committee (HREC). Study participants provided full written and informed consent.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.concog.2019.102845.

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