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Research Report

Positive schizotypy and Motor Impulsivity correlate with response aberrations in ventral attention network during inhibitory control

Martina Vanova [a,b,c,*], Ulrich Ettinger [d], Luke Aldridge-Waddon [a,b], Ben Jennings [a,b], Ray Norbury [a,b] and Veena Kumari [a,b,**]

[a] Centre for Cognitive and Clinical Neuroscience, College of Health, Medicine and Life Sciences, Brunel University London, London, United Kingdom
[b] Division of Psychology, Department of Life Sciences, College of Health, Medicine and Life Sciences, Brunel University London, London, United Kingdom
[c] Dementia Research Centre, UCL Queen Square Institute of Neurology, Faculty of Brain Sciences, University College London, London, United Kingdom
[d] Department of Psychology, University of Bonn, Bonn, Germany

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ABSTRACT

Inhibitory control (IC) aberrations are present in various psychopathologies, including schizophrenia spectrum and personality disorders, especially in association with antisocial or violent behaviour.

We investigated behavioural and neural associations between IC and psychopathology-related traits of schizotypy [Oxford-Liverpool Inventory of Feelings and Experiences (O-LIFE)], psychopathy [Triarchic Psychopathy Measure (TriPM)], and impulsivity [Barratt Impulsiveness Scale (BIS-11)], using a novel Go/No-Go Task (GNG) featuring human avatars in 78 healthy adults (25 males, 53 females; mean age = 25.96 years, *SD* = 9.85) and whole-brain functional magnetic resonance imaging (fMRI) in a separate sample of 22 right-handed healthy individuals (7 males, 15 females; mean age = 24.13 years, *SD* = 5.40).

Behaviourally, O-LIFE Impulsive Nonconformity (impulsive, anti-social, and eccentric behaviour) significantly predicted 16 % of variance in false alarms (FAs). O-LIFE Unusual Experiences (positive schizotypy) and BIS-11 Motor Impulsivity predicted 15 % of d prime (d') (sensitivity index) for the fastest (400 ms) GNG trials. When examined using fMRI, higher BIS-11 Motor Impulsivity uniquely, and also together with Unusual Experiences, was associated with lower activity in the left lingual gyrus during successful inhibition (correct No-Go over baseline). Additionally, higher Impulsive Nonconformity was associated with

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* *Corresponding author*. Centre for Cognitive and Clinical Neuroscience, College of Health, Medicine and Life Sciences, Brunel University London, London, United Kingdom.
** *Corresponding author*. Centre for Cognitive and Clinical Neuroscience, College of Health, Medicine and Life Sciences, Brunel University London, London, United Kingdom.
E-mail addresses: m.vanova@ucl.ac.uk (M. Vanova), veena.kumari@brunel.ac.uk (V. Kumari).
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lower activity in the caudate nucleus and anterior cingulate during No-Go compared to Go stimuli reactions.

Positive schizotypy, motor, and antisocial-schizotypal impulsivity correlate with some common but mostly distinct neural activation patterns during response inhibition in areas within or associated with the ventral attention network.

1. Introduction

Inhibitory control (IC) refers to the ability to suppress or stop unwanted actions, thoughts, or feelings and, therefore, to be able to adapt to emerging changes in the environment (Anderson and Weaver, 2009; Spechler et al., 2016) and found to be negatively associated with trait impulsivity (Logan et al., 1997; Aichert et al., 2012; Leshem and Yefet, 2019). The Go/No-Go Task (GNG) is widely used to assess IC; when a participant fails to withhold a response, they produce commission errors - false alarms (FAs) reflecting poor inhibition, whereas errors of omission (missed Go trials) indicate attention lapses or poor vigilance (Wright et al., 2014). Response inhibition typically engages the frontoparietal and ventral attention networks in the right hemisphere (Zhang et al., 2017), with more widespread activations for complex and less frequent No-Go stimuli (Criaud and Boulinguez, 2013). Previous studies have shown activations mainly in the right inferior frontal gyrus (IFG), bilaterally anterior cingulate cortex (ACC), insula, supplementary motor area (SMA), precentral gyrus, and right inferior parietal lobule (Friedman and Robbins, 2022; Gavazzi et al., 2021; Isherwood et al., 2021; Wessel and Aron, 2017). The right IFG mainly inhibits physical responses and controls task sets, attentional interference, and items in memory (Aron, 2007) while the ACC evaluates whether to inhibit certain action (Gavazzi et al., 2021). Withholding the Go action (correct No-Go) activates the right IFG to the insula and middle-superior frontal gyrus, angular gyrus to middle temporal and supramarginal gyri, and SMA to cingulate, pallidum, and the putamen (Zhang et al., 2017). FAs typically accompany lower activation in the IFG, ACC, and prefrontal cortex (PFC) (Festini and Katz, 2021).

1.1. *Inhibitory control in schizophrenia spectrum conditions*

People with schizophrenia show impulsive behaviour (Kaladjian et al., 2011; Nolan et al., 2011) and poorer IC [more FAs, longer reaction times (RTs)] than controls (Araki et al., 2016; Bates et al., 2002; Bellgrove et al., 2006; Enticott et al., 2008; Nolan et al., 2011; Wright et al., 2014). In schizophrenia, deficient IC is also implicated in attention (Matzke et al., 2017), executive function (Ettinger et al., 2018; Antonova et al., 2004) and memory impairments (Soriano et al., 2009), aggravated by positive symptoms (Galaverna et al., 2012), and associated with aberrant activation in the IFG (Hughes et al., 2012; Zandbelt et al., 2011), striatum and the temporoparietal junction (Zandbelt et al., 2011). Similar patterns are observed in non-clinical populations with elevated schizotypal traits (Lubow and De la Casa, 2002; Peters et al., 1994). Specifically, various dimensions of schizotypy, including positive schizotypy (paranoid ideation, unusual perceptual experiences, magical thinking) (Moritz and Mass, 1997), have been associated with lower accuracy (Ettinger et al., 2015, 2018) and lower activation of the PFC, cingulate, putamen, thalamus, cerebellum, and visual cortex during different IC tasks (Aichert et al., 2012; Kim et al., 2012; Nishimura et al., 2011).

1.2. *Inhibitory control in association with psychopathy, impulsivity, and violence*

Impulsivity is a known predictor of violence (Derefinko et al., 2011; Farrington and Jolliffe, 2001) and a key component in psychopathy (Copestake et al., 2011; Snowden and Gray, 2011), specifically, Factor 2, the antisocial, deviant, aggressive aspect of psychopathy (Poythress and Hall, 2011; Snowden and Gray, 2011). The callous aggression trait (Meanness) is also strongly associated with aspects of impulsivity in the Triarchic model of psychopathy (Patrick et al., 2009). People with pronounced psychopathy traits produce more FAs than controls during IC tasks (Baliousis et al., 2019; Munro et al., 2007), possibly due to attentional problems leading to an inability to properly process contextual information (Zeier et al., 2009), and also show impaired integration of IC with other cognitive processes (Baliousis et al., 2019).

1.3. *The present study*

This correlational study consists of a behavioural experiment and a functional magnetic resonance imaging (fMRI) experiment to investigate the relationship of psychopathology-related traits of schizotypy, impulsivity, and psychopathy with IC, as assessed by a GNG featuring human avatars. We used human avatars with different attributes as Go and No-Go stimuli to enhance the ecological validity of our task and its potential utility in the context of mental health research (O'Shea et al., 2010). In the behavioural experiment, we hypothesised that higher psychopathology-related traits will be associated with more FAs and lower overall IC [d prime (d')]. In the functional magnetic resonance imaging (fMRI) experiment, we hypothesised activity during successful inhibition (No-Go stimuli) in the insula, putamen, parietal and supramarginal gyri, middle-superior frontal gyrus, and some overlap with FAs in the IFG, and ACC; and expected lower activation of these areas in association with psychopathology-related traits, tentatively predicting common as well as

distinct areas being associated with schizotypy, impulsivity, and psychopathy.

2. Methods

2.1. Participants

Seventy-eight healthy adults (25 males, 53 females; mean age = 25.96, *SD* = 9.85) participated in the behavioural investigation, and another 22 right-handed adults (7 males, 15 females; mean age = 24.13, *SD* = 5.40) participated in the fMRI investigation. All participants reported no history of mental illness or instrumental violence. They were studying for, or already had, an undergraduate degree and were recruited via Brunel University London network. All participants were requested to refrain from using alcohol or drugs (except usual caffeine consumption) on the day of their scheduled study participation. This research was approved by the Research Ethics Committee of Brunel University London. All participants provided written informed consent prior to their participation and were compensated for their time.

2.2. Materials

2.2.1. Self-report measures

All participants were assessed on: a) schizotypy – Oxford-Liverpool Inventory of Feelings and Experiences (O-LIFE) (Mason and Claridge, 2006), b) psychopathy – Triarchic Psychopathy Measure (TriPM) (Patrick et al., 2009), c) impulsivity - Barratt Impulsiveness Scale (BIS-11) (Patton et al., 1995) and Impulsive Behavior Scale-Short (S-UPPS-P) (Whiteside et al., 2005), as previously reported (Vanova et al., 2022).

2.3. Behavioural experiment

2.3.1. Inhibitory control - Go/No-Go Task

We used a modified version of the classic GNG (Gomez et al., 2007) featuring 3D human avatars. There were altogether 150 trials (20 % of No-Go trials) of three different stimulus durations: 1000 ms, 700 ms, and 400 ms (50 trials each) presented in three consecutive blocks. The stimuli consisted of four different "Go" and two "No-Go" images of male and female avatars in grey clothing. The Go avatars were sideways-facing and the No-Go avatars were forward-facing (Fig. 1). Each trial consisted of a 200 ms blank screen, the 1000/700/400 ms stimulus and another 100 ms blank screen. Participants were presented with the following instructions: *"You will be presented with a series of images. All side-facing characters are Go images. Press the "Go button" as fast as possible when these appear. All front-facing characters are No-Go images. DO NOT press any button when these appear. Press "ENTER" to continue."* Participants were given a modified keyboard with a marked "Go-button". If a response was made before the maximal length of the trial duration was reached the experiment immediately proceeded with another trial. All three blocks were presented continuously without previous warning to the participant. The pre-experimental practice session consisted of 16 trials providing participants with feedback on their accuracy after each response. No feedback was displayed during the main trials. Response accuracy and RTs were recorded throughout. The total duration of the main experiment was 3 minutes.

The number of FAs and RTs for Go trials was examined. The FAs were calculated as a percentage of No-Go trials that were responded to. The overall performance was calculated as a d' value using the formula: d' = (Z-score for correct Go) minus (Z-score for FAs) for each Stimulus-Duration independently.

2.3.2. Statistical analyses

All analyses were performed using IBM SPSS Statistics, V26.0 (IBM Corp., 2019), with $p < .05$. Performance accuracy (number of FAs, d' scores) and RTs for correct Go stimuli were analysed using a 3 (Stimulus-Duration) × 2 (Sex) Analysis of Variance (ANOVA) with Stimulus-Duration (1000 ms, 700 ms, and 400 ms trials) as a within-subject factor, and Sex (males, females) as the between-subject factor. The Greenhouse-Geisser correction was applied where Mauchly's Test indicated a significant sphericity violation. Pearson's correlation coefficients (r) were used to examine associations between traits and GNG performance across the whole sample. Bonferroni correction for multiple correlations was applied per psychopathology measure group to control for type-I Family-Wise Error (FWE) (Curtin and Schulz, 1998), forming four (O-LIFE, TriPM, BIS-11, S-UPPS-P) sets of correlations. GNG accuracy and RTs variables significantly associated with two or more traits (surviving Bonferroni correction) were analysed further using linear regression 'Stepwise' method. This method determines the final model based on a process of selecting/eliminating predictors one at a time depending on the outcome of the *t*-tests for the slope parameters, (i.e., partial *F*-tests) and the amount of shared and unique variance explained by these predictors using the commonality analysis.

2.4. fMRI experiment

2.4.1. fMRI paradigm and procedure

Participants were presented with 120 stimuli (96 Go and 24 No-Go images) in three blocks. Each trial lasted 700 ms, consisting of the 500 ms stimulus and two 100 ms blank screens at the beginning and at the end of the trial. Each trial was proceeded by a random 1000–5000 ms jitter (3000 ms average). A 15-s blank screen was presented between the blocks. The overall experiment duration was 474 s. In total, 240 volumes were obtained.

Participants were instructed to press the button when they saw a Go stimulus and to withdraw a response when a No-Go stimulus appeared. A four-button MRI-compatible response box (Lumitouch, PhotonControl Inc., Baxter, Canada) was used to record responses.

2.4.2. fMRI data acquisition and analyses

The functional images were acquired in one run using the pulse sequence: TR = 2000 ms, TE = 30.6 ms, 50 interleaved slices, voxel size = 2x2x3 mm, flip angle = 78°, field of view = 192 mm, base resolution = 96, 96x96 matrix. Time correction was based on the middle slice and realignment reference volume was the first volume. High-resolution T1-weighted images were acquired with the following settings:

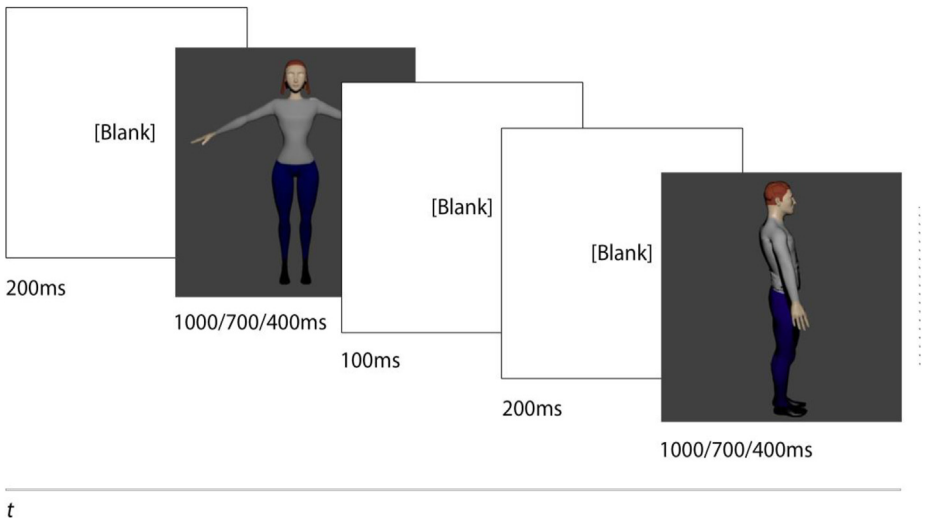

Fig. 1 – Go/No-Go Task (GNG) trials. The front-facing character represents a No-Go stimulus, side-facing character Go stimulus.

TR = 2300 ms, TE = 2.9 ms, 192 images of 1x1x1 mm voxel size, flip angle = 9°, field of view = 256 mm, base resolution = 256, matrix 256x256.

The data were pre-processed and analysed using the SPM12 toolbox (Friston et al., 2007) for MATLAB (MATLAB, 2020), and MRIcroGL (Rorden and Brett, 2000) for graphic visualisation. Firstly, the anterior commissure was set as an origin for the structural and all functional images. Then, functional images were realigned and co-registered with the corresponding structural images. The resulting images were normalised to the Montreal Neurological Institute coordinate system (MNI) space with 2 × 2 × 2 mm voxel resolution for functional images, and forward deformations field. The transformation parameters were obtained from the segmentation of structural images. Lastly, the normalised images were then smoothed with full width at a half-maximum (FWHM) Gaussian smoothing kernel of 10 mm.

We conducted a two-level analysis of the pre-processed images. At the first level, we performed a random-effect analysis of participant-specific contrast activations (i.e., three stimulus types compared to the implicit baseline-resting condition – Correct Go, Correct No-Go, and FA, each over Baseline; and one another – combinations of the three stimuli-types. Full list in Supplementary Table 3 - Notes). At the second level, we identified task-related neural activations using one-sample t-tests across the sample (height threshold $p < .001$; FWE corrected for multiple comparisons at the cluster level $p < .05$). Afterwards, we examined the relationships of psychopathology-related traits, that were identified as significant predictors of GNG performance in the behavioural component, with neural activity across the whole brain for each contrast using a regression model within SPM12 (Friston et al., 2007) with questionnaire scores entered as a covariate (height threshold $p < .01$ uncorrected; FWE corrected at peak level $p < .05$). Due to a limited power for the FAs contrasts (small number of observed FAs), we applied small volume corrections for any *a priori* hypothesised areas.

3. Results - behavioural experiment

3.1. Sample characteristics

Full sample characteristics including descriptive statistics for psychopathology-related traits are presented in Supplementary Table 1. Table 1 presents descriptive statistics for all GNG experimental variables.

3.2. Sample size calculation

A priori sample size correlation power analysis was executed using G*Power 3.1 (Faul et al., 2007) to determine the sample size which would be required to detect significant correlations. This showed that for a one-tailed test, with an expected power of 80 % at $\alpha = .05$, a total of 64 participants would be necessary to detect a moderate effect size of Pearson's $r = .30$ (Cohen, 1992).

Table 1 – Descriptive statistics for GNG performance for the behavioural investigation sample (N = 78).

Variable	*Mean(SD)*	*Min*	*Max*
Correct Go 1000 ms [%]	99.5 (1.4)	90.0	100.0
Correct Go 700 ms [%]	99.0 (2.0)	91.9	100.0
Correct Go 400 ms [%]	89.3 (9.7)	45.0	100.0
FAs 1000 ms [%]	9.0 (10.5)	0	40.0
FAs 700 ms [%]	16.3 (13.0)	0	60.0
FAs 400 ms [%]	25.6 (16.1)	0	60.0
d' 1000 ms	1.017 (.716)	−1.010	1.680
d' 700 ms	.447 (.945)	−2.350	1.680
d' 400 ms	−1.473 (1.759)	−7.070	1.680
RTs Correct Go 1000 ms [ms]	384.939 (67.649)	269.533	582.145
RTs Correct Go 700 ms [ms]	354.619 (52.071)	240.660	503.628
RTs Correct Go 400 ms [ms]	314.573 (31.667)	248.708	387.149
RTs FAs 1000 ms [ms]	176.979 (201.954)	0	997.200
RTs FAs 700 ms [ms]	230.855 (127.860)	0	601.800
RTs FAs 400 ms [ms]	234.460 (86.601)	0	392.400

Note. Reaction times (RTs); False alarms (FAs); d prime (d').

3.3. GNG performance

3.3.1. Accuracy

There was a main effect of Stimulus-Duration for FAs [$F(1.82, 138.09) = 45.538$, $p < .001$, $\eta_p^2 = .375$]. Participants produced significantly fewer FAs at 1000 ms than 700 ms [$t(77) = 5.084$, $p < .001$] and 400 ms trials [$t(77) = 9.129$, $p < .001$], and fewer FAs at 700 ms than 400 ms trials [$t(77) = 5.127$, $p < .001$]. The main effect of Sex [$F(1, 76) = .034$, $p = .854$] and Sex*Stimulus-Duration interaction [$F(1.82, 138.09) = .741$, $p = .467$] was non-significant. Similarly, for d', Stimulus-Duration had a significant main effect [$F(1.37, 104.40) = 90.025$, $p < .001$, $\eta_p^2 = .542$], with participants showing better performance for 1000 ms than 700 ms [$t(77) = 5.497$, $p < .001$] and 400 ms trials [$t(77) = 8.960$, $p < .001$], and for 700 ms than for 400 ms trials [$t(77) = 12.550$, $p < .001$]. The main effect of Sex [$F(1, 76) = .125$, $p = .725$] and Sex*Stimulus-Duration interaction [$F(2, 76) = .027$, $p = .974$] was non-significant.

3.3.2. RTs

There was a significant main effect of Stimulus-Duration on RTs for correct Go-trials [$F(1.42, 107.70) = 71.722$, $p < .001$, $\eta_p^2 = .486$]. Participants were significantly slower when identifying 1000 ms than 700 ms Go trials [$t(77) = 7.865$, $p < .001$] and 400 ms Go-trials [$t(77) = 1.457$, $p < .001$], and slower for 700 ms than 400 ms Go-trials [$t(77) = 8.043$, $p < .001$]. Sex had no significant effect [$F(1, 76) = .667$, $p = .417$] and Sex*Stimulus-Duration interaction [$F(1.42, 107.70) = 1.117$, $p = .314$] was also non-significant.

Similarly, Stimulus-Duration had a significant main effect on RTs for FAs [$F(1.64, 124.27) = 4.422$, $p = .020$, $\eta_p^2 = .055$]. Participants showed significantly shorter RTs for 1000 ms than 400 ms FAs [$t(77) = 2.412$, $p = .018$], but no other significant differences in RTs were found. Sex had no significant effect [$F(1, 76) = .180$, $p = .672$] and Sex*Stimulus-Duration interaction [$F(1.64, 124.27) = .924$, $p = .383$] was also non-significant.

3.3.3. GNG performance: speed-accuracy correlations

Longer RTs for correct Go trials significantly correlated with a lower number of FAs (all $p < .05$) for each stimulus duration (Table 2).

Table 2 – Speed-accuracy correlations (N = 78).

RTs/Accuracy	FAs 1000 ms	FAs 700 ms	FAs 400 ms
	r (*p*)	*r* (*p*)	*r* (*p*)
RT Correct Go 1000 ms	−.263* (.020)		
RT Correct Go 700 ms		−.381*** (<.001)	
RT Correct Go 400 ms			−.472*** (<.001)

Note. Reaction times (RTs); False alarms (FAs).
* $p < .05$; ** $p < .01$; *** $p < .001$ (2-tailed).

3.4. Relationships between psychopathology-related traits and inhibitory control

3.4.1. Correlations between IC variables and psychopathology-related traits

These are summarised in Table 3. Due to significant differences in accuracy and RTs for different stimulus durations, the 400 ms trial variables were considered the most effective measure as they put the highest demand on IC.

3.4.2. Overall model of inhibitory control and psychopathology-related traits

Regression analyses to examine how the different psychopathology traits related to the IC showed that O-LIFE Impulsive Nonconformity significantly predicted nearly 16 % of the variance [$F(1, 76) = 14.363$, $p < .001$, $R^2 = .159$] in FAs for 400 ms trials. Only O-LIFE Unusual Experiences and BIS-11 Motor Impulsivity were accepted by the model as significant predictors, together accounting for 15 % of the d' 400 ms variance [$F(2, 75) = 6.695$, $p = .002$, $R^2 = .151$] with Unusual Experiences uniquely accounting for nearly 6 % of the variance and Motor Impulsivity uniquely accounting for 4.6 % of the explained variance (Table 4).

3.5. Post-hoc power calculation

For a one-tailed test, with 78 participants and the strongest encountered effect (Pearson's correlation $r = .399$, $p < .001$), we obtained 73 % power.

4. Results - fMRI experiment

4.1. Sample characteristics

Full sample characteristics are presented in Supplementary Table 2. One participant was excluded from the fMRI analysis due to an incomplete GNG procedure in the scanner.

4.2. GNG performance

4.2.1. Accuracy and RTs

Table 5 presents descriptive statistics for all GNG task variables and relevant psychopathology-related traits scores. No significant differences were found between men and women (all $p > .05$) in any performance variables. The RTs for Correct Go trials significantly negatively correlated with FAs ($r = -.516$, $p = .014$) indicating a significant speed-accuracy trade-off.

4.2.2. Relationship between psychopathology-related traits and inhibitory control

The O-LIFE Unusual Experiences, Impulsive Nonconformity, and BIS-11 Motor variables that were found to significantly predict GNG performance in the behavioural experiment were examined. Of these, only BIS-11 Motor Impulsivity significantly and positively correlated with the number of FAs ($r = .541$, $p = .011$).

Table 3 – Correlation coefficients between IC variables for 400 ms trials and psychopathology-related traits (N = 78).

Measure	FAs 400 ms	d' 400 ms	RTs Correct Go 400 ms	RTs FAs 400 ms
	r(p)	r(p)	r(p)	r(p)
O-LIFE Unusual Experiences	.307** (.006)	−.325** (.004)	−.204 (.073)	.102 (.374)
O-LIFE Cognitive Distortions	.069 (.548)	−.047 (.683)	−.106 (.356)	.039 (.738)
O-LIFE Introvertive Anhedonia	−.017 (.882)	.049 (.671)	.135 (.239)	.111 (.335)
O-LIFE Impulsive Nonconformity	.399*** (<.001)	−.305** (.007)	−.102 (.374)	.232*[a] (.041)
TriPM Boldness	.044 (.701)	−.015 (.897)	.034 (.765)	.016 (.892)
TriPM Meanness	.231*[a] (.042)	−.156 (.174)	−.140 (.222)	.134 (.241)
TriPM Disinhibition	.329** (.003)	−.254*[a] (.025)	−.179 (.117)	.180 (.116)
BIS-11 Attention	.071 (.539)	−.113 (.324)	−.110 (.337)	−.065 (.569)
BIS-11 Cognitive Instability	.159 (.165)	−.134 (.243)	−.286*[a] (.011)	−.062 (.591)
BIS-11 Motor	.309** (.006)	−.305** (.007)	−.078 (.498)	.198 (.082)
BIS-11 Perseverance	.104 (.365)	.035 (.758)	−.103 (.371)	−.100 (.384)
BIS-11 Self Control	.165 (.149)	−.118 (.304)	−.107 (.353)	.007 (.955)
BIS-11 Cognitive Complexity	.058 (.615)	−.052 (.652)	.122 (.288)	−.076 (.510)
S-UPPS-P Negative Urgency	.270*[a] (.017)	−.139 (.226)	−.120 (.294)	.138 (.229)
S-UPPS-P Perseverance	−.191 (.093)	.213 (.062)	−.049 (.671)	−.094 (.414)
S-UPPS-P Premeditation	.053 (.642)	.007 (.953)	−.111 (.334)	−.004 (.971)
S-UPPS-P Sensation Seeking	.283*[a] (.012)	−.164 (.150)	−.194 (.088)	.060 (.603)
S-UPPS-P Positive Urgency	.357** (.001)	−.268*[a] (.018)	−.073 (.525)	.171 (.135)

Note. Inhibitory control (IC); Reaction times (RTs); False alarms (FAs); Oxford-Liverpool Inventory of Feelings and Experiences (O-LIFE); Triarchic Psychopathy Measure (TriPM); Barratt Impulsiveness Scale (BIS-11); Impulsive Behavior Scale-Short (S-UPPS-P).
* $p < .05$; ** $p < .01$; *** $p < .001$ (2-tailed).
[a] Did not survive Bonferroni correction for type-I Family-Wise Error (FWE).

Table 4 – Results of 'Stepwise' multiple linear regression analysis with O-LIFE Unusual Experiences and BIS-11 Motor Impulsivity as predictor variables and d' 400 ms as the criterion variable, along with results of the commonality analysis showing unique and common variance explained by Unusual Experiences and Motor Impulsivity in overall accuracy for 400 ms trials.

Model	R	R^2	R^2 Change	F Change, (df)	p	β (stand.)	p
O-LIFE Unusual Experiences [a]	.325	.105	.105	8.963 (1, 76)	.004	−.255	.026
BIS-11 Motor [b]	.389	.151	.046	4.064 (1, 75)	.047	−.226	.026

	Semi-partialcorrelation	R^2	% Variance	% of Total ExplainedVariance
Unique to O-LIFE Unusual Experiences	−.242	.059	5.86	39
Unique to BIS-11 Motor	−.214	.046	4.58	30
Common to both		.047	4.66	31
Total		.151	15.1	100

Note: [a] Predictors: (Constant), O-LIFE Unusual Experiences; [b] Predictors: (Constant), O-LIFE Unusual Experiences, BIS-11 Motor.

Table 5 – Descriptive statistics for GNG performance and self-report data for the fMRI sample (N = 21).

Variable	Mean(SD)	Min	Max
GNG performance			
Correct Go 500 ms	95.380 (1.596)	89	96
FAs 500 ms	4.330 (3.367)	1	14
d'500 ms	.000 (1.372)	−3.74	1.38
RTs Correct Go 500 ms	455.629 (62.291)	346.66	650.35
RTs FAs 500 ms	399.366 (67.229)	326.58	558.13
Psychopathology-related traits			
O-LIFE Unusual Experiences	8.760 (3.948)	0	17
O-LIFE Impulsive Nonconformity	7.380 (2.854)	2	13
BIS-11 Motor	14.480 (3.723)	9	24

Note. Reaction times (RTs); False alarms (FAs); d prime (d'); Oxford-Liverpool Inventory of Feelings and Experiences (O-LIFE); Barratt Impulsiveness Scale (BIS-11).

4.3. *Post-hoc power calculation*

For a one-tailed test, with 21 participants and the strongest encountered effect (Pearson's correlation $r = .541$, $p = .011$), we obtained 68 % power.

4.4. *fMRI*

4.4.1. *Task-related activations*

Brain activation changes associated with all task contrasts are detailed in Supplementary Table 3. Correct inhibition of No-Go stimuli compared to baseline was associated with activity in the right occipital gyrus, parietal areas to supramarginal gyrus, SMA, and bilaterally fusiform gyrus. FAs bilaterally activated the insula to IFG and cingulate areas (Fig. 2). Correct inhibition (No-Go) in contrast to FAs activated the right post-central gyrus and right middle temporal to middle occipital

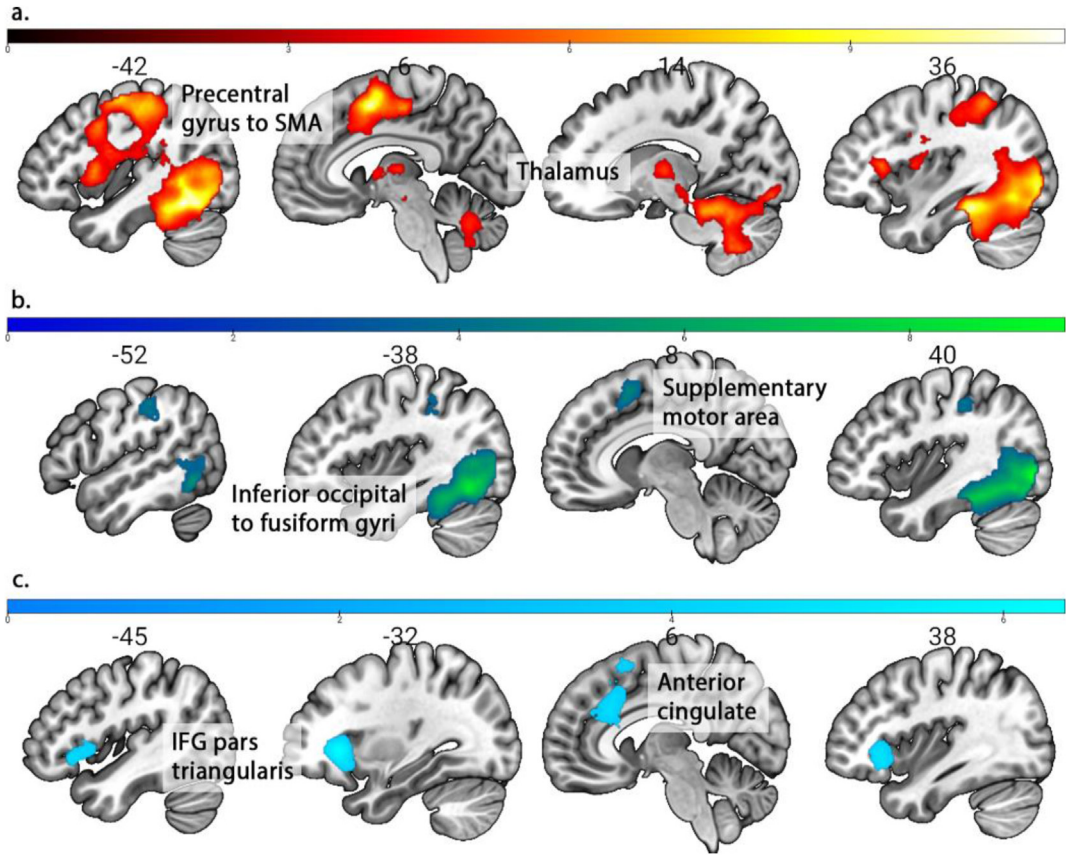

Fig. 2 – Areas of higher brain activity over baseline for: (a) correct Go trials (red), (b) correct No-Go trials (blue-green), (c) FAs (cyan), (N = 21) at x-axis (sagittal view), left to right. *Note.* Supplementary motor area (SMA); Inferior frontal gyrus (IFG)

gyrus. Incorrect, compared to correct, inhibition (FAs over No-Go) activated the left insula, right cingulate, and the right IFG.

4.4.2. *Relationship between GNG brain activations and psychopathology-related traits*

All brain areas associated with one or more psychopathology-related traits are described in Table 6. Higher O-LIFE Impulsive Nonconformity was associated with weaker BOLD responses for correct inhibition over Go stimuli bilaterally in the left caudate and ACC. Higher O-LIFE Unusual Experiences correlated with lower activity in superior frontal gyrus (SFG) bilaterally and right ACC for correct Go stimuli (Fig. 3). For failed (FAs) over correct inhibition, higher Unusual Experiences showed a tendency towards lower activity in right frontal areas and right postcentral gyrus (Fig. 4). Similarly, FAs over correct Go showed a tendency towards lower activity in frontal areas bilaterally and right ACC in elevated Unusual Experiences.

Higher Motor Impulsivity correlated with lower activity in the right cerebellum to lingual gyrus, left ACC, and left inferior parietal, supramarginal, and postcentral gyri for correct Go stimuli and correct inhibition was associated with lower activations in the left occipital areas and right cerebellum.

Higher Unusual Experiences together with Motor Impulsivity were associated with lower activations in the left temporal and superior frontal areas for correct Go and left lingual gyrus for correct inhibition. Activations for FAs over correct Go or No-Go showed only a tendency, mainly in the right ACC in relation to higher Unusual Experiences.

5. Discussion

In this study, we examined IC with a novel GNG featuring models of human avatars and its relationship to psychopathology-related traits of schizotypy, psychopathy, and impulsivity in a non-clinical sample at behavioural and neural levels. We used a novel GNG paradigm involving complex stimuli (i.e., human avatar images with different attributes as Go and No-Go stimuli) and low No-Go probability (20 % No-Go stimuli) (Criaud and Boulinguez, 2013). The behavioural results showed that O-LIFE Impulsive Nonconformity was a significant predictor of failed inhibition (FAs). Unusual Experiences and Motor Impulsivity were significant predictors of the overall IC performance (d'). The overall model of these significant predictors from the behavioural experiment was tested at the neural level using fMRI in a separate experiment.

In this experiment, IC-related activations occurred in the parietal, frontal, and occipital network of regions including SMA, fusiform gyrus, and IFG. Higher Motor Impulsivity uniquely and also together with higher Unusual Experiences

Table 6 – Negative associations between task-related activations and psychopathology-related traits (height threshold $p < .005$ unc.).

Psychopathology-related traits/Contrast	Cluster level					Peak voxel level		MNI coordinates (mm)		
Area name	BA	Side	P_{FWE}	K_E	$P_{uncor.}$	$P_{uncor.}$	T	x	y	z
O-LIFE Impulsive Nonconformity										
Correct No-Go > Correct Go										
Caudate nucleus/Thalamus		Left	<.001	2368	<.001	<.001	6.56	−16	−2	16
		Right				<.001	5.94	32	12	20
Anterior cingulates	48	Left				<.001	5.50	−14	12	32
O-LIFE Unusual Experiences										
Correct Go > Baseline										
Superior medial frontal gyrus	10	Left	.001	875	<.001	<.001	6.61	−10	56	20
Anterior cingulate	32	Right				<.001	4.82	4	52	22
Superior medial frontal gyrus	8	Right				.001	3.82	10	38	56
FAs > Baseline (small volume correction 5 mm sphere)										
Superior frontal gyrus	10	Right	.017	34	.450	<.001	4.07	18	62	10
						.001	3.84	18	64	14
Medial superior frontal gyrus						.001	3.63	14	62	8
Thalamus		Right	.025	13	.656	.002	3.41	4	−4	−16
Precentral gyrus	4	Right	.023	17	.604	.002	3.41	24	−30	70
FAs > Correct Go (small volume correction 5 mm sphere)										
Superior frontal gyrus	10	Right	.015	42	.392	<.001	4.09	18	62	10
	10					.001	3.53	18	60	6
Superior medial frontal gyrus	10					.001	3.52	14	62	8
Postcentral gyrus	4	Right	.019	29	.001	3.640	3.09	26	−32	70
	4				.001	3.520	3.01	30	−34	68
FAs > Correct No-Go (small volume correction 5 mm sphere)										
Superior frontal gyrus	10	Right	.016	37	.393	<.001	4.53	18	62	10
Superior medial frontal gyrus	10					<.001	4.26	14	62	8
	10					<.001	4.18	20	64	14
	10					.001	3.92	14	64	12
Postcentral gyrus	4	Right	.016	39	.380	<.001	3.51	26	−32	70
	4					<.001	3.36	22	−32	72
	4					<.001	3.35	30	−32	68
BIS-11 Motor										
Correct Go > Baseline										
Cerebellar vermis	18	Right	<.001	937	<.001	<.001	6.97	2	−60	−2
Lingual gyrus	17					<.001	5.88	4	−82	−8
	18					<.001	4.44	14	−74	−12
White matter to caudate	48	Left	.019	490	.001	<.001	6.05	−22	24	12
Anterior cingulate						<.001	4.57	−14	30	18
Paracingulate gyrus	32					<.001	4.38	−16	30	26
Inferior parietal gyrus	40	Left	<.001	947	<.001	<.001	5.11	−46	−40	42
Supramarginal gyrus	48					<.001	4.76	−50	−36	32
Postcentral gyrus	4					<.001	4.58	−52	−20	46
Correct No-Go > Baseline										
Lingual gyrus	19	Left	.001	1076	<.001	<.001	5.41	−24	−64	0
Cerebellum	18	Right				<.001	4.24	8	−74	−12
Middle occipital gyrus	19	Left				<.001	4.05	−28	−80	4
O-LIFE Unusual Experiences & BIS-11 Motor										
Correct Go > Baseline										
Inferior temporal gyrus	20	Left	.031	441	.001	<.001	5.28	−58	−20	−22
Middle temporal gyrus	20					<.001	5.02	−58	−28	−10
	21					.001	3.82	−62	−22	−14
Superior medial frontal gyrus	32	Left	<.001	1508	<.001	<.001	5.21	−12	54	22
	8					<.001	4.64	−10	28	52
	10	Right				<.001	4.56	14	58	18
Correct No-Go > Baseline										
Lingual gyrus	19	Left	.005	780	<.001	<.001	6.42	−24	−64	0
	19					<.001	5.58	−22	−72	4
	18					<.001	4.50	−18	−74	−6
FAs > Correct Go (small volume correction 5 mm sphere)										
Anterior cingulate		Right	.036	1	.925	.005	2.91	6	12	24

Table 6 – (*continued*)

Psychopathology-related traits/Contrast		Cluster level				Peak voxel level		MNI coordinates (mm)		
Area name	BA	Side	P_{FWE}	K_E	$P_{uncor.}$	$P_{uncor.}$	T	x	y	z
FAs > Correct No-Go (small volume correction 5 mm sphere)										
Fusiform gyrus	20	Right	.025	15	.600	.001	3.66	38	−6	−30
Anterior cingulate		Right	.030	8	.714	.002	3.23	4	12	24

Note. Brodmann area (BA); Family-Wise Error (FWE); uncorrected (unc.); Montreal Neurological Institute coordinate system (MNI); False alarms (FAs); Inferior frontal gyrus (IFG); Oxford-Liverpool Inventory of Feelings and Experiences (O-LIFE); Barratt Impulsiveness Scale (BIS-11).

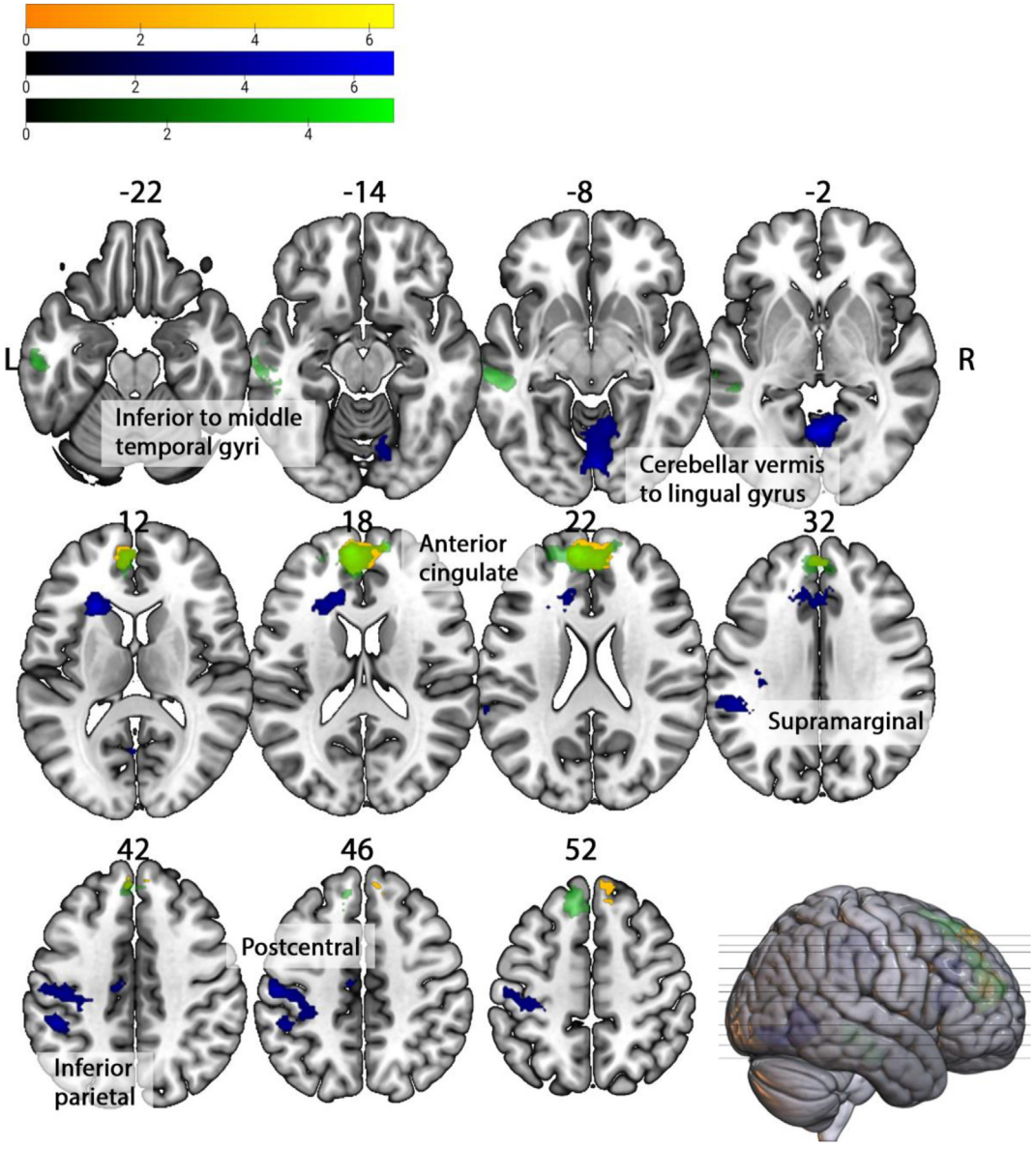

Fig. 3 – Areas of lower brain activity for Go trials over resting baseline associated with higher: (d) O-LIFE Unusual Experiences (yellow), (e) BIS-11 Motor (blue), (f) O-LIFE Unusual Experiences and BIS-11 Motor (green), (N = 21) at z-axis (axial view).

were associated with lower activity in left lower occipital regions (lingual gyrus) during successful inhibition (correct No-Go over Baseline). Additionally, higher Impulsive Nonconformity correlated with lower activity in the caudate nucleus and ACC during correctly inhibited No-Go over correctly responded Go stimuli.

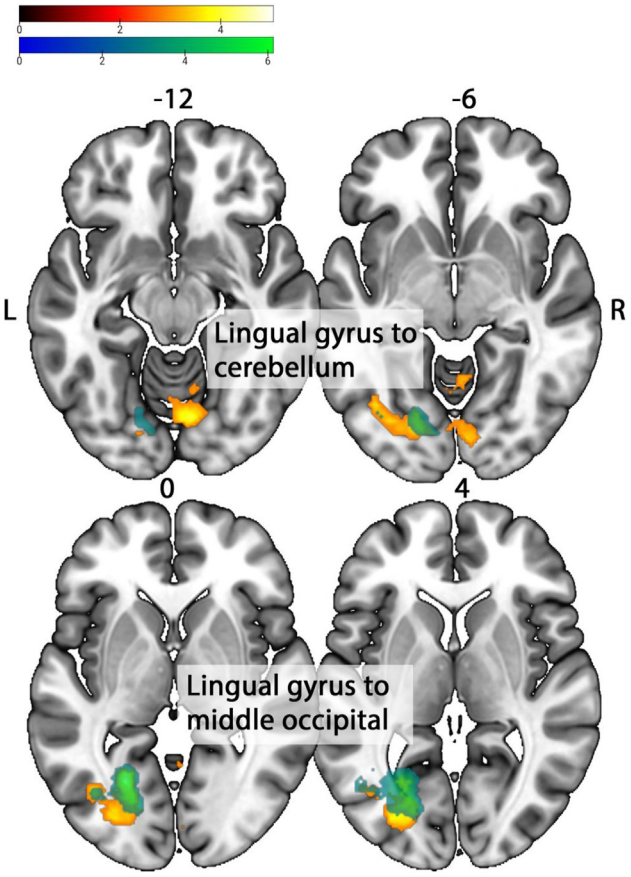

Fig. 4 – Areas of lower brain activity for No-Go stimuli over resting baseline associated with higher: (g) BIS-11 Motor Impulsivity (yellow), (h) O-LIFE Unusual experiences and BIS-11 Motor Impulsivity (blue), (n = 21) at z-axis (axial view).

5.1. *Inhibitory control-related activations*

As hypothesised, correct inhibition (No-Go over Baseline) activated the right inferior parietal and supramarginal gyri, with SMA bilaterally, which are part of the frontoparietal network associated with action withholding (Zhang et al., 2017). However, the strongest activation was observed in the right inferior occipital areas and fusiform gyrus bilaterally, the visual association regions that are functionally connected with ventral and dorsal attention networks (Simmonds et al., 2008) and involved in conflict resolution (Fan et al., 2005).

Insula and IFG bilaterally, and right cingulate areas that we predicted would be associated with IC (Criaud and Boulinguez, 2013), were strongly activated during failed inhibition (FAs over Baseline). Additionally, FAs also activated the right orbitofrontal gyrus and IFG pars triangularis, when compared to correct No-Go (successful inhibition). The IFG, insula, and supramarginal gyrus are parts of ventral and dorsal attention networks that are co-activated when shifting visuospatial attention (Corbetta and Shulman, 2011). This indicates that the production of FAs was associated with stronger activity in the ventral attention network, responsible for monitoring and reorienting attention to infrequent and unexpected events (Vossel et al., 2014). Therefore, shifting between the voluntary top-down ventral network and involuntary stimulus-driven dorsal attention network was associated with higher production of FAs. Successful over failed inhibition (No-Go over FAs) strongly activated the right postcentral and temporal gyri, the areas that are positively associated with trait impulsivity (Pan et al., 2021), and also the middle occipital gyrus that is involved in inhibitory responses to No-Go signals (Zheng et al., 2008).

5.2. *Psychopathology-related traits and neural activity*

5.2.1. *Impulsive Nonconformity*

In people with higher Impulsive Nonconformity, representing impulsive, antisocial, and eccentric behaviours (Mason and Claridge, 2006), correct inhibition was associated with lower activity in the left ACC regions that regulate sustained attention between an object and a distractor (Wu et al., 2017). Lower activation in the attention network involving the ACC and caudate has been observed in individuals with a high risk of developing schizophrenia (first-degree relatives) (Diwadkar et al., 2011). The ACC is responsible for attention orienting and monitoring conflict (Bush et al., 2000; Kerns et al., 2004) for demanding and task-relevant stimuli (Weissman et al., 2004) and shows hypoactivation in people with schizophrenia (Carter et al., 2010). Moreover, the connection between the caudate nucleus and frontal cortices shows dysfunction and disconnectivity in people with a high risk of developing schizophrenia during attention-demanding tasks (Diwadkar et al., 2014). Thus, the important IC areas appear underactive in people with impulsive schizotypy, explaining their attention lapses when presented with attention-demanding stimuli.

5.2.2. *Positive schizotypy and Motor Impulsivity*

Lower activity for correct Go responses was observed in association with higher Unusual Experiences (positive schizotypy) and higher Motor Impulsivity in the left temporal and superior medial frontal areas bilaterally. Higher Unusual Experiences uniquely contributed to lower activity in medial frontal areas bilaterally and right ACC, whereas Motor Impulsivity uniquely was associated with lower activations in the right lingual gyrus, left ACC, and left parietal, supramarginal, and postcentral gyri. The left inferior parietal, supramarginal, and postcentral gyri have been previously associated with increased proactive control, the anticipation regulating attention and motor reactions, in association with higher Motor Impulsivity (Gavazzi et al., 2019; Huang et al., 2017). The lower activation of these areas could indicate a sudden drop in the proactive control once the Go stimulus is presented and a motor response is required (Correct Go over baseline).

People with positive schizotypy solely, and in combination with Motor Impulsivity, are reported to show weaker responses in frontal areas of the ventral attention system, activated when relevant stimuli occur unexpectedly (Vossel et al., 2014). Applied to the current findings, this may suggest a weaker expectation of Go stimuli (or switching between Go and No-Go stimuli) in association with higher psychopathology-related traits as a result of lower activity in parts of the ventral attention network.

Higher Motor Impulsivity solely and also together with higher Unusual Experiences were associated with activity aberrations during successful inhibition in the left lingual gyrus, an area known to be involved in inhibition (Menon et al., 2001). The left occipital area has been found to be relatively less activated in higher schizotypy during IC tasks, suggesting poor early information processing (Aichert et al., 2012). It is also anatomically connected with fusiform gyrus, IFG and temporal areas facilitating the processing of visual representations and inhibition (Palejwala et al., 2021). The left middle temporal areas also facilitate working memory and spatial attention shifts (LaBar et al., 1999). This indicates that in individuals with higher Motor Impulsivity and positive schizotypy, the corresponding attention processing system may not be appropriately engaged in visual IC tasks with more complex visual stimuli.

Higher positive schizotypy was associated with lower activation in the right frontal and postcentral gyri for all FAs contrasts (significant only with a small volume correction), indicating problems with engaging the ventral attention network (Bernard et al., 2020). People with Motor Impulsivity showed lower FAs-related activation in the right ACC. A different study also showed lower activity in the right ACC during reactive control in healthy individuals with higher Motor Impulsivity (Huang et al., 2017), indicating problems in self-regulation (Posner et al., 2007) and response withdrawal (Criaud and Boulinguez, 2013).

5.3. *Limitations*

Moderate sample sizes and limited score ranges on some schizotypal (Impulsive Nonconformity, Introvertive Anhedonia) and all TriPM psychopathy subscales may have resulted in reduced power. Future studies should include larger samples of participants with a wider range of psychopathology-related trait scores to replicate and extend our findings. A potential limitation could be the use of 3D human avatars as the Go and No-Go stimuli in our task. Some studies reported deficits in embodied cognition, sense of self, and sensorimotor representations in higher schizotypy (Currò et al., 2023; Fotia et al., 2022). As this study did not include a neutral GNG condition for comparison, we cannot exclude any potential interactions between the identification of embodied stimuli and higher schizotypal traits that could lead to a potential impact on the task performance. Future studies that aim to introduce embodied stimuli should consider this limitation.

5.4. *Conclusions*

Higher schizotypal traits of Impulsive Nonconformity and Unusual Experiences (O-LIFE), and Motor Impulsivity (BIS-11), significantly predict failed inhibitory reaction (commission errors - FAs) and overall reduced IC performance (sensitivity index - d'), respectively, on a novel and complex GNG featuring models of human avatars as Go and No-Go stimuli. At the neural levels, these associations were expressed as altered brain activity in the ventral attention network during this novel GNG.

Open practices section

The study in this article earned Open Data and Open Materials badge for transparent practices. All stimuli and behavioural data are available at (https://doi.org/10.17633/rd.brunel.23669310.v1), and the fMRI data with analysis codes at (https://doi.org/10.6084/m9.figshare.23680593)

CRediT authorship contribution statement

Martina Vanova: Conceptualization of this study, Methodology, Formal analysis, Writing. **Ulrich Ettinger:** Supervision, Writing - review & editing. **Luke Aldridge-Waddon:** Project administration. **Ben Jennings:** Formal analysis, Supervision. **Ray Norbury:** Formal analysis, Supervision, Writing - review & editing. **Veena Kumari:** Conceptualization, Methodology, Formal analysis, Resources, Writing - review & editing, Supervision, Funding acquisition.

All stimuli and behavioural data (https://doi.org/10.17633/rd.brunel.23669310.v1), and the fMRI data with analysis codes (https://doi.org/10.6084/m9.figshare.23680593) are available from the Brunel University London research repository. Legal copyright restrictions prevent public archiving of [O-LIFE, TriPM, BIS-11, and S-UPPS-P] which can be obtained from the copyright holders in the cited references. We reported how we determined our sample size, all data exclusions, all inclusion/exclusion criteria established prior to data analysis, all manipulations, and all measures in this study. No part of this study (procedures or analyses) was pre-registered prior to the research being conducted.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cortex.2023.08.017.

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