Social Neuroscience

ISSN: 1747-0919 (Print) 1747-0927 (Online) Journal homepage: http://www.tandfonline.com/loi/psns20

Autism and psychosis expressions diametrically modulate the right temporoparietal junction

Ahmad M. Abu-Akel, Ian A. Apperly, Stephen J. Wood & Peter C. Hansen

To cite this article: Ahmad M. Abu-Akel, Ian A. Apperly, Stephen J. Wood & Peter C. Hansen (2017) Autism and psychosis expressions diametrically modulate the right temporoparietal junction, Social Neuroscience, 12:5, 506-518, DOI: 10.1080/17470919.2016.1190786

To link to this article: https://doi.org/10.1080/17470919.2016.1190786

SOCIAL NEUROSCIENCE, 2017
VOL. 12, NO. 5, 506–518
https://doi.org/10.1080/17470919.2016.1190786

Autism and psychosis expressions diametrically modulate the right temporoparietal junction

Ahmad M. Abu-Akel[a], Ian A. Apperly[a], Stephen J. Wood[a,b] and Peter C. Hansen[a]

[a]School of Psychology, University of Birmingham, Birmingham, U.K.; [b]Melbourne Neuropsychiatry Centre, University of Melbourne and Melbourne Health, Melbourne, Australia

ABSTRACT

The mentalizing network is atypically activated in autism and schizophrenia spectrum disorders. While these disorders are considered diagnostically independent, expressions of both can co-occur in the same individual. We examined the concurrent effect of autism traits and psychosis proneness on the activity of the mentalizing network in 24 neurotypical adults while performing a social competitive game. Activations were observed in the paracingulate cortex and the right temporoparietal junction (rTPJ). Autism traits and psychosis proneness did not modulate activity within the paracingulate or the dorsal component of the rTPJ. However, diametric modulations of autism traits and psychosis proneness were observed in the posterior (rvpTPJ) and anterior (rvaTPJ) subdivisions of the ventral rTPJ, which respectively constitute core regions within the mentalizing and attention-reorienting networks. Within the rvpTPJ, increasing autism tendencies decreased activity, and increasing psychosis proneness increased activity. This effect was reversed within the rvaTPJ. We suggest that this results from an interaction between regions responsible for higher level social cognitive processing (rvpTPJ) and regions responsible for domain-general attentional processes (rvaTPJ). The observed diametric modulation of autism tendencies and psychosis proneness of neuronal activity within the mentalizing network highlights the importance of assessing both autism and psychosis expressions within the individual.

ARTICLE HISTORY
Received 15 July 2015
Revised 16 April 2016
Published online
2 June 2016

KEYWORDS
Attention-reorienting; diametric model; fMRI; mentalizing; schizophrenia; TPJ

Introduction

Difficulty with inferring the mental states of others ("mentalizing" or "Theory of mind") is a core feature of both autism spectrum disorders (ASD) and schizophrenia spectrum disorders (SSD) (Chung, Barch, & Strube, 2014). Research concerned with understanding the neural system of mentalizing has identified a network of regions that primarily involves the temporoparietal junction (TPJ) and the medial prefrontal/paracingulate cortex (Abu-Akel & Shamay-Tsoory 2011; Saxe & Kanwisher, 2003). Atypical alterations in this network have been observed independently in individuals with ASD (Ciaramidaro et al., 2015; Kana, Keller, Cherkassky, Minshew, & Just, 2009; Lombardo, Chakrabarti, Bullmore, & Baron-Cohen, 2011) and SSD (Ciaramidaro et al., 2015; Walter et al., 2009). These atypicalities have also been observed as a function of subclinical expressions of autism (Nummenmaa, Engell, von dem Hagen, Henson, & Calder, 2012; von dem Hagen et al., 2011) and psychosis (Modinos, Renken, Shamay-Tsoory, Ormel, & Aleman, 2010; van der Meer, Groenewold, Pijnenborg, Aleman, & Mazza, 2013) within the healthy population.

These findings are often interpreted as support for the view positing that ASD and SSD and their extended spectra are overlapping conditions (Dinsdale et al., 2013; King & Lord, 2011; Solomon et al., 2011), with multiple phenotypic similarities and risk factors (Carroll & Owen, 2009; Chisholm, Lin, Abu-Akel, & Wood, 2015; Hamlyn, Duhig, McGrath, & Scott, 2013). This raises important questions about the nature of the relationship of these phenotypes within an individual. An alternative to the model of overlap between ASD and SSD, the diametric model (Abu-Akel & Bailey, 2000; Crespi & Badcock, 2008) conceptualizes ASD and SSD as opposite diametric conditions, such that their constituent traits should specifically not overlap to any large degree. Central to this model is that deficits in both disorders would deviate in opposite directions from typicality. Thus, in considering functionality within the mentalizing network, the overlapping model would predict that both ASD and SSD would affect its neural activity in the same manner, whereas the diametric

CONTACT Ahmad M. Abu-Akel a.m.abu-akel@bham.ac.uk School of Psychology, University of Birmingham, Birmingham B15 2TT, UK
Supplemental data for this article can be accessed here.

model would predict that ASD and SSD would exert effects in opposite directions.

One approach to evaluating these two competing hypotheses regarding the effect of ASD and SSD on the neural activity of the mentalizing network, is to examine its activity as a function of the expression of autistic tendencies and psychosis proneness within nonclinical populations. This approach draws on the notion that autism tendencies and psychosis proneness are dimensions of normal variation (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001; Crespi, Stead, & Elliot, 2010; Del Giudice, Klimczuk, Traficonte, & Maestripieri, 2014; Dinsdale et al., 2013; Nettle, 2006), with the clinical entities being at the extreme of this distribution. This approach also eliminates the confounding effects of medication, chronicity, or active symptomatology (Ettinger et al., 2015; Stefansson et al., 2014). Our approach thus ensures that the observed effects and performance are not due to severe alteration in brain activity and structure often associated with these confounds. To this end, we performed a functional magnetic resonance imaging (fMRI) study in 24 right-handed neurotypical adults while playing the well-known playground game of rock, paper, scissors (RPS) (see Method). This task has been shown to reliably activate the mentalizing network in a competitive context (Chaminade et al., 2012; Gallagher, Jack, Roepstorff, & Frith, 2002) and specifically the right temporoparietal junction (rTPJ) and the medial prefrontal/paracingulate cortex. We thus asked whether variation in the co-occurrence of autism tendencies and psychosis proneness has an impact on the neural activity of these core regions within the mentalizing network of neurotypical brains.

Previous mentalizing studies suggested that ASD and SSD are variably associated with hypo- and hyper-activation within the mentalizing network. For example, studies showed that delusional symptoms in SSD patients (Backasch et al., 2013) were associated with increased activations in the posterior superior temporal sulcus (TPJ adjacent) and the medial prefrontal cortex (MPFC). A more recent study showed that positive symptoms of paranoid schizophrenia patients (Ciaramidaro et al., 2015) were associated with increased activation in the MPFC in conditions where the attribution of intentionality was not warranted (e.g., physical conditions). In the same study, reduced activation in the dorsal MPFC was associated with *hypo-intentionality* in the ASD group, whereas increased activations were associated with *hyper-intentionality* in the paranoid schizophrenia group. In addition, Lombardo and colleagues (Lombardo et al., 2011) reported that the activity of the rTPJ in ASD participants was reduced compared to healthy controls, and predicted their social impairment (see also (Kana et al., 2015)). Furthermore, a meta-analysis of theory of mind (ToM) studies in ASD and SSD, revealed hypo-activation of the TPJ in ASD, and hypo-activation of the MPFC in both ASD and SSD, relative to healthy controls (Sugranyes et al., 2011). Intriguingly, a direct comparison between the ASD and SSD revealed that (i) MPFC hypo-activation was more pronounced in ASD, (ii) somatosensory regions were more active in SSD, and (iii) the insula was more active in ASD. Taken together, we predict that autism tendencies and psychosis proneness would have contrasting effects on TPJ and MPFC activity, such that activity would be negatively associated with autism tendencies and positively associated with psychosis proneness.

However, the precise role of the rTPJ within the mentalizing network has been the subject of competing hypotheses from both the functional and "territorial" perspectives. Functionally, the rTPJ, in addition to its role in mentalizing, has been implicated in saliency, attention-reorienting and self-other distinction (Corbetta, Patel, & Shulman, 2008; Decety & Lamm, 2007). With respect to its territorial integrity, it is not clear whether the rTPJ is a shared neural region for all of these functions, or whether it consists of subregions supporting specific functions (Carter & Huettel, 2013; Corbetta et al., 2008; Decety & Lamm, 2007; Mars et al., 2012). In this regard, Mars and colleagues (Mars et al., 2012), using diffusion-weighted imaging tractography-based parcellation, have shown that the rTPJ consists of at least three subregions with distinct pattern of functional connectivity. These subregions consist of a dorsal subregion (rdTPJ), largely corresponding to the inferior parietal lobule, and a ventral subregion, which is further subdivided into posterior (rvpTPJ) and anterior (rvaTPJ) subregions (see Results, Figure 4). The rdTPJ is functionally connected with a network including the lateral anterior PFC and forms part of the task-positive network. The rvpTPJ and the rvaTPJ are respectively functionally connected with the mentalizing and the attention-reorienting networks. The association of the rvpTPJ and the rvaTPJ with mentalizing and attention-reorienting is consistent with a meta-analysis of 70 functional neuroimaging studies showing that, on average, attention-reorienting activates anteriorly and mentalizing processes posteriorly (Decety & Lamm, 2007) (see also Bzdok et al., 2013; Schurz, Radua, Aichhorn, Richlan, & Perner, 2014). Therefore, as a secondary aim, the current study investigated whether variation in the co-occurrence of autism tendencies and psychosis proneness has a specific impact on the neural activity of these subdivisions of the rTPJ.

Methods

Participants

Twenty-four right-handed, English proficient healthy adults (5 males; 19 females; mean age ± SD = 21.21 ± 4.21) participated in the study. Participants did not have a history of psychiatric illness, epilepsy, neurological disorders, brain injury as well as current alcohol or substance abuse problems. The Research Ethics Committee of the University of Birmingham approved the study, and written informed consent was obtained from all participants.

Materials and procedures

Psychosis proneness, assessed using the positive scale of the Community Assessment of Psychic Experiences (CAPEp) questionnaire (Stefanis et al., 2002), autism tendencies, assessed using the autism spectrum quotient (AQ) questionnaire (Baron-Cohen et al., 2001), English reading proficiency, assessed with the Test of Irregular Word Reading Efficiency (TIWRE) (Reynolds & Kamphaus, 2007) and the Test of Word Reading Efficiency (TOWRE) (Torgesen, Wagner, & Rashotte, 1999) questionnaires, and handedness, ascertained with the modified Annett handedness questionnaire (Annett, 1972), were administered to 27 participants, on average 7–10 days prior to the scanning session. Of the 27 participants, 24 were scheduled for the scanning session during which they performed two tasks. Three participants could not attend the scanning session due to scheduling conflicts. The first task is a computerized version of the rock, paper, scissors game. The second task is Hartwright et al.'s (Hartwright, Apperly, & Hansen, 2012) anglicized variant of Saxe and Kanwisher's (Saxe & Kanwisher, 2003) ToM functional localizer task. At the end of the scanning session, all participants went through a debriefing interview.

The theory of mind (ToM) localizer task

This task was used to reliably identify regions within the mentalizing network, which include the TPJ, the paracingulate/MPFC and precuneus and the temporal pole. In this task, participants read 24 short vignettes that were displayed on the screen for 10 s. Half of the stories described the false belief of a character about the current state of affairs (i.e., the false-belief (FB) stories), and the other half described a physical event that is nonconcurrent with reality such as a photo of a past event (i.e., the false photograph (FP) stories). Each story was followed by a true–false question that was displayed for 4 s, and to which they responded using a response box with two active buttons that was placed in the participant's right hand. The task consisted of four short fMRI runs. In each run, six stories, three FB and three FP, were presented in an alternating order, interleaved with a 12.5-s rest period. All participants went through a practice session of four trials outside the scanner. The task was presented using Presentation (Neurobehavioural Systems, CA), which also recorded the behavioral data (response selection and reaction time).

The rock, paper, scissors (RPS) task

In this task, participants are required to predict the moves of their opponent in order to win. The game has the following simple rules: Rock beats scissors, paper beats rock, and scissors beat paper. The winner of each round is awarded 1 point. A no-response results in an automatic win for the opponent, and identical moves results in a draw and no points are awarded. Here, we orthogonally manipulated the intentional stance during the game in such a way that the participants are led to believe that they are playing under four conditions: (1) against an *active* human agent who is a skilled RPS player, (2) a *passive* human agent who is followed a predetermined script, (3) an *active* intelligent computer program (called AIRPS) that was capable of analyzing the participant's strategy, and (4) a *passive* computer program that followed a predetermined response script. These four conditions thus comprised a 2 × 2 experimental design with one factor being the human versus computer opponent and the other factor being the element of implied agency from the opponent (active versus passive).

Participants were cautioned not to use a stereotyped strategy and to play competitively with the intention of beating their opponent. Feedback was provided during the scan sessions as to how well the participant was scoring at the end of each block of 10 rounds of the game and a summary of the results at the end of each fMRI run. Positive scoring and effort were rewarded with a prize of £10 for the highest performing participant overall at the end of the study. Before each one of the four conditions, participants were provided with on-screen instructions to remind them of what they are required to do and of the opponent against whom they would be playing. To reinforce the impression that the participant was truly playing against a "human" opponent, a 3% fallibility "no-response" measure was embedded during the human conditions.

Crucially, unbeknownst to the participants, the game was always played against a computer program generating moves entirely at random. The design ensured that the only difference across the conditions was the perceived identity of the participant's opponent under the various conditions. To check participants' perception of

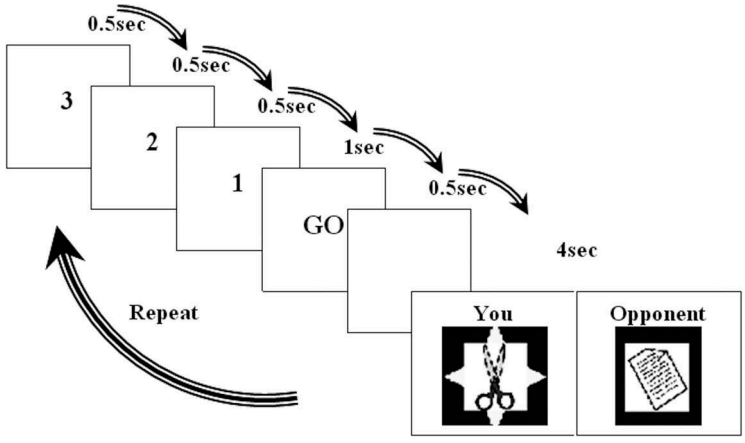

Figure 1. Each trial began with a countdown 3, 2, 1, in 0.5-s intervals, followed by "GO" during which the participants make their moves. The "GO" was present for 1 s followed by a 0.5-s blank screen. The results screen is then displayed for 4 s indicating the moves drawn by both players and the outcome. Winning move is displayed with a yellow star.

their opponents, a debriefing procedure was utilized after the scanning session during which participants were asked to recount how they understood and experienced these conditions. None of the participants expressed doubt regarding the identity of the four opponents.

The RPS experiment consisted of five fMRI runs, each lasting 440 s per run (~40 min total). Each fMRI run consisted of four blocks, representing the four conditions of interest. The sequence of opponents was chosen from eight predetermined player sequences (chosen from the 24 possible sequences) such that on each sequence the human and the computer opponents were presented in alternating order. The sequences the participants' played, in each of the five fMRI runs, were selected in a pseudorandom order.

Each block was preceded by a 10-s period during which the instructions were displayed, and followed by a 30-s rest period. During each block, the participant played 10 trials against one of the four possible opponents. Response selections (i.e., rock, paper, or scissors) were made using a button box with three active buttons that was placed in the participant's right hand. See Figure 1 for a schematic representation of stimuli presentation and timing during each trial. All participants went through a practice session of two blocks outside the scanner. The experiment was presented using Presentation (Neurobehavioral Systems, CA), which also recorded the behavioral data (button pressed and reaction time).

The Community Assessment of Psychic Experiences (CAPE) questionnaire

This self-report questionnaire is based on the Peters et al. Delusions Inventory-21 (PDI-21) (Peters, Joseph, & Garety, 1999) and consists of 42 items measuring the presence of *positive* psychotic experiences (20 items), *negative* psychotic experiences (14 items), and *depressive* experiences (eight items) that an individual may have experienced over the last 12 months (Stefanis et al., 2002). The occurrence of these symptoms is reported on a likert frequency scale from 1 (never) to 4 (nearly always), and the associated distress on a scale ranging from 1 (not distressed) to 4 (very distressed). Cronbach's α for this scale in this study is .89, which indicates high internal consistency.

For current purposes, the 20-item CAPE positive scale is used as a measure of psychosis proneness. The assessment of positive symptoms rather than the general construct of psychosis, which comprises both negative and positive symptoms, is based on evidence for autism-positive symptoms axis in the nonclinical population (Dinsdale et al., 2013), and that negative symptoms do not reliably discriminate between ASD and SSD (Kästner et al., 2015, Searles Quick, Davis, Olincy, & Sikela, 2015; Spek & Wouters, 2010). The internal consistency of this scale in this study is good (Cronbach's α = .75), and falls within the range of values reported in other studies within the general population (Lin et al., 2011). In the current study, participants had a mean score of 25.28 (Range: 20–32; SD = ± 3.57), which are comparable to scores within a community sample of adolescents (Yung et al., 2009) and adults (Abu-Akel, Wood, Hansen, & Apperly, 2015).

The Autism Spectrum Quotient (AQ) questionnaire

This self-report questionnaire consists of 50 items that measure the presence of traits associated with the autistic spectrum within the general population (Baron-Cohen et al., 2001). Each item is given a score of 0 or 1. Higher scores indicate the presence of greater autistic tendencies. The AQ's internal consistency in this

study is good (Cronbach's α = .81), and is comparable to the values reported in other studies (Austin, 2005). In the current study, participants had a mean score of 15.49 (Range: 3–31; SD = ± 6.65). The association of the AQ with the CAPE positive scale was nonsignificant (r = .28, p = .19) (see Supplementary Figure 1).

fMRI data acquisition and analysis

Data were acquired in a single scanning session using a 3 T Philips Achieva scanner. 176 T2*-weighted standard echo planar imaging (EPI) volumes were obtained in each of the RPS task runs, using a 32 channel head coil. Parameters used to achieve whole brain coverage are as follows: TR = 2.5 s, TE = 35 ms, acquisition matrix = 80 × 80, flip angle = 83°, isotropic voxels 3 × 3 × 3 mm^3, 42 slices axial acquisition obtained consecutively in a bottom-up sequence. Using the same parameters, 71 EPI volumes were acquired for each block of the localizer task. A T1-weighted scan was then acquired as a single volume at higher spatial resolution as a 3-D turbo field echo image (matrix size 288 × 288, 175 slices, sagittally acquired and reconstructed to 1 × 1 × 1 mm^3 isotropic voxels. TE = 3.8 ms; TR = 8.4 ms).

Preprocessing and statistical analyses of the data were performed using the FMRIB software library (FSL version v.5.0.6; FMRIB, Oxford, www.fmrib.ox.ac.uk/fsl). For both experiments, initial preprocessing of the functional data consisted of slice timing correction and motion correction (MCFLIRT). The blood oxygen level-dependent (BOLD) signals were high-pass filtered using a Gaussian weighted filter to remove low-frequency drifts in the BOLD signal. Spatial smoothing of the BOLD signal was performed using a 5-mm full-width-half-maximum kernel. The functional data were registered to their respective structural images and transformed to a standard template based on the Montreal Neurological Institute (MNI) reference brain, using a 6-DoF linear transformation (FLIRT).

RPS task experiment analysis

Playing against a computer or a human, with either agency or by following a script, provided the four baseline conditions. These four conditions comprised a 2 × 2 analysis of variance (ANOVA) experimental design with factor 1 being the human versus computer opponent and factor 2 being the element of implied agency from the opponent (active versus passive). Condition regressors were convolved with the canonical hemodynamic response function within a general linear model framework (GLM). A high-pass filter with a cut-off of 105 s was used. Motion parameters were treated as regressors of no interest in order to account for unwanted motion effects. Session data were aggregated per participant using a second-level fixed effects model. Third-level modelling was used to aggregate the data across participants in a 2 × 2 repeated measures ANOVA with active versus passive and human versus computer as within subjects factors, employing a mixed effects analysis with cluster-based thresholding at $Z > 2.3$, $pcorr < 0.05$. An overlap analysis between the thresholded data ($Z > 2.3$, $p$corr < 0.05) for the human > computer and the active > passive contrasts was then conducted to identify shared activations across the two thresholded contrasts.

Regions of Interest (ROI) analysis

ROI analysis focused on the rTPJ and the paracingulate cortex since only these two regions were active in both the active > passive as well as in the human > computer contrasts during the RPS task as revealed by the overlap analysis. Masks for these two regions were generated from the ToM localizer task (Hartwright et al., 2012). For each of these ROIs, the mean percentage signal change in each of the four RPS experimental conditions (i.e., the active and passive human as well as active and passive computer) was extracted from the aggregate data of each participant across the five runs (i.e., the 24 second-level models) using FSL Featquery (www.fmrib.ox.ac.uk/fsl/feat5/featquery.html).

Statistical analysis

To evaluate the association of autism tendencies and psychosis proneness on the hemodynamic response of the region (namely, the paracingulate and the rTPJ and its subdivisions), we utilized generalized linear models, with robust estimator, where the active versus passive and human versus computer were entered as fixed factors, and the participants' standardized Z scores on the AQ, CAPEp, and their interaction were entered as covariates. Robust regression guards against violation of statistical assumptions and the unduly affects of outliers. Significant interactions were probed using MODPROBE method for SPSS (Hayes & Matthes, 2009). The interactions are unpacked by depicting simple regression lines, whereby the effect of one predictor (AQ/CAPEp scores) is examined at the mean (M), one standard deviation below the mean (−1 SD) and one standard deviation above the mean (+1 SD) of the other predictor (CAPEp/AQ scores). These cutoff points (i.e., M,−1SD, +1SD) are used here in keeping with the tradition of unpacking interactions using this method. It is noteworthy that this regression procedure does not

involve splitting the sample into smaller groups using these cutoff points. Rather, it estimates the effect of a predictor on the dependent variable, while holding constant the other predictor at a discrete point. Accordingly, this approach allows us to infer from the model what the effect of autism tendencies/psychosis proneness on brain activity, in a population with certain expressions of psychosis proneness/autism tendencies.

Results

An overlap analysis between the thresholded data ($Z > 2.3$, $p\text{corr} < 0.05$) for the human > computer and the active > passive contrasts revealed shared activations in the paracingulate cortex and the rTPJ. Masks for these two regions were generated from the ToM localizer task (Hartwright et al., 2012; Saxe & Kanwisher, 2003) (see Figure 2).

First, we examined the impact of autism tendencies and psychosis proneness and their interaction on the hemodynamic response of the paracingulate cortex and the rTPJ using generalized linear models as specified above. With respect to the hemodynamic response of the paracingulate cortex, the omnibus test showed that the overall model was nonsignificant ($\chi^2 = 9.50$, df = 5, $p = .091$). However, when the data for the rTPJ were subject to the same analysis, the overall model was significant ($\chi^2 = 19.51$, df = 5, $p = .002$, $R^2 = .18$). Activity within the rTPJ was negatively associated with AQ scores (β(se) = -.070(.028), df = 1, $\chi^2 = 6.54$, $p = .011$), and positively with both CAPEp scores (β(se) = .102 (.027), df = 1, $\chi^2 = 13.72$, $p < .001$) and the interaction term (β(se) = .077(.022), df = 1, $\chi^2 = 11.80$, $p = .001$) (Figure 3). This modulation was observed in the active versus passive condition ($\chi^2 = 3.84$, df = 1, $p = .050$), but not in the human versus computer condition ($\chi^2 = 1.48$, df = 1, $p = .23$) (see Supplementary Table 1).

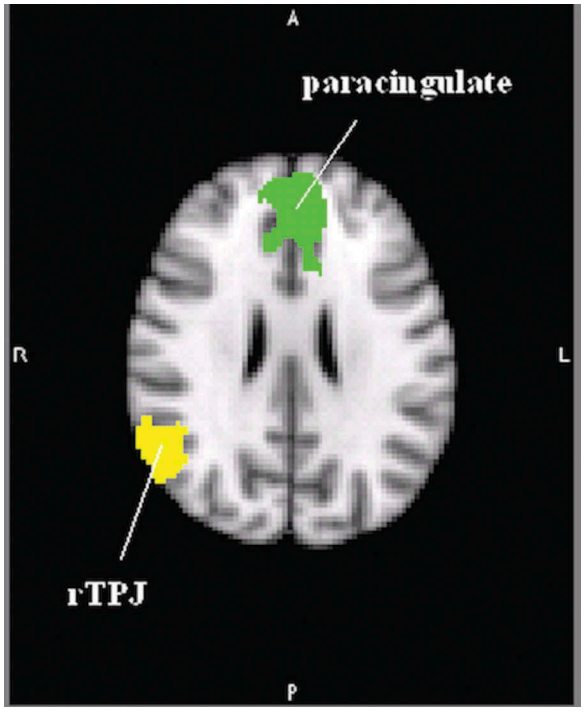

Figure 2. Masks for the overlapping regions between the human > computer and the active > passive contrasts. Coordinates of the mask for the paracingulate cortex (in green) are [−4, 50, 20] and for the rTPJ (in yellow) are [58, −52, 28].

As can be seen from Figure 3a, rTPJ activity is greater in psychosis-prone individuals compared to autism-prone individuals (see also Supplementary Figure 2A, which depicts the raw data of the model presented in Figure 3a). Intriguingly, the rTPJ activates to a similar degree in individuals presenting with high scores as well as in individuals presenting with low scores on both scales. In order to examine if rTPJ activity is modulated by the relative expression of psychosis vis-à-vis autism, the participants' psychosis bias was calculated by subtracting their *z*-normalized AQ scores from their *z*-normalized CAPEp scores. A regression analysis confirmed that the Psychosis-Bias scores positively predicted rTPJ activity (β(se) = .072(.020), df = 1, $\chi^2 = 13.37$, $p < .001$, Exp(β) = 1.075, $R^2 = .11$).

Next, we probed the interaction term using the method by Hayes and Matthes (2009) described above. The positive relationship between psychosis proneness and rTPJ activity (Figure 3(b)) was significant when AQ scores were at the mean (β = 0.102, $p = 0.003$) as well as when they were high (+1 SD) (β = 0.177, $p < .001$), but not when they were low (−1 SD) (β = 0.026, $p = 0.53$). Conversely, the negative relationship between autism tendencies and rTPJ activity (Figure 3(c)) was significant when CAPEp scores were low (β = −0.146, $p = 0.003$) as well as when they were at the mean (β = −0.076, $p = .038$), but not when they were high (β = 0.006, $p = 0.89$). This pattern suggests that activity within the rTPJ is diametrically modulated, such that autism tendencies were associated with decreased activity and psychosis proneness with increased it.

To shed light on the rTPJ debate, we utilized the masks from Mars et al. (2012) to further examine the neural activity of the rdTPJ and rvaTPJ as a function of autism tendencies and psychosis proneness. Note that the rvpTPJ, as defined in Mars et al. (2012), overlaps considerably with the region within which we conducted our analyses in Figure 3 above (see Figure 4(b)). For this reason, we only ran post hoc tests on the rdTPJ and the rvaTPJ subregions delineated in Mars et al. (2012). In addition, in order to highlight the distinction between

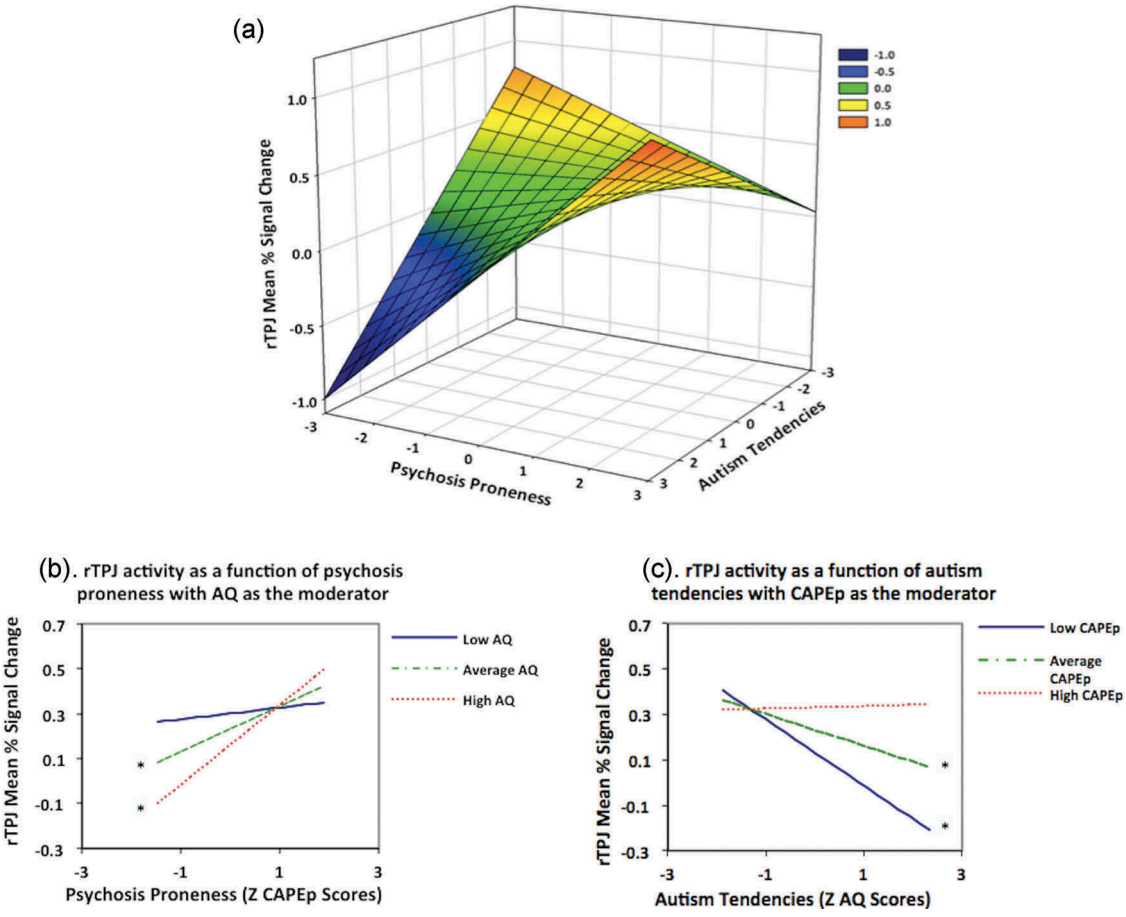

Figure 3. (a) 3-D representation of the interactive effect of autism tendencies and psychosis proneness on mean percent signal change of the rTPJ. (b) Visualizes the association between psychosis and rTPJ activity by plots of simple regression lines with low (−1 SD), average, and high (+1 SD) AQ scores as moderators, showing an increase in the positive effect of psychosis proneness on rTPJ activity with increasing autism tendencies. (c) Visualizes the association between autism tendencies and rTPJ by plots of simple regression lines with low (−1 SD), average, and high CAPEp (+1 SD), showing a decrease in the negative effect of autism tendencies on rTPJ activity with increasing psychosis proneness. Asterisk = *p*-value <.05.

the anterior and posterior divisions of the rTPJ, we now refer to *our* rTPJ (from the analysis in Figure 3) the rvpTPJ in the discussion, in order to be consistent with the labeling from Mars et al. (2012).

The omnibus test for the rdTPJ was nonsignificant (χ^2 = 9.44, df = 5, p = .093), but significant for the rvaTPJ (χ^2 = 16.89, df = 5, p = .005, R^2 = .16). Parameter estimates indicated that rvaTPJ activity was negatively associated with CAPEp scores (β(se) = -.052(.018), df = 1, χ^2 = 8.17, p = .004) and positively with the interaction term (β(se) = .073(.015), df = 1, χ^2 = 24.48, p < .001). The association with AQ scores was negative but nonsignificant (β(se) = -.013(.020), df = 1, χ^2 = .38, p = .54). Note, that this modulation is not specific to either the active versus passive condition (χ^2 = 1.56, df = 1, p = .21) or the human versus computer condition (χ^2 = .14, df = 1, p = .70) (see Figure 5 and Supplementary Table 2).

In contrast to the pattern of activation we observed in the rvpTPJ (Figure 3(a)), Figure 5(a) shows that autism-prone individuals compared to psychosis-prone individuals tend to have higher rvaTPJ activity (Supplementary Figure 2B depicts the raw data of the model presented in Figure 5A). Intriguingly, here too, we see that the rvaTPJ activates to somewhat a similar degree in individuals scoring high as well as in individuals scoring low on both scales. In contrast to the rvpTPJ, where the Psychosis-Bias scores were positively associated with activity, a regression analysis controlling for rvpTPJ activity revealed that the Psychosis-Bias scores were negatively associated with rvaTPJ activity (β(se) = -.056(.018), df = 1, χ^2 = 9.26, p = .002, Exp (β) = .946, R^2 = .09).

Furthermore, when probing the interaction between AQ and CAPEp scores, the positive relationship between psychosis proneness and rvaTPJ activity (Figure 5(b)) was significant when AQ scores were low (β = −0.124, p < 0.001) as well as when AQ scores were at the mean (β = −0.052, p = .048), but nonsignificant

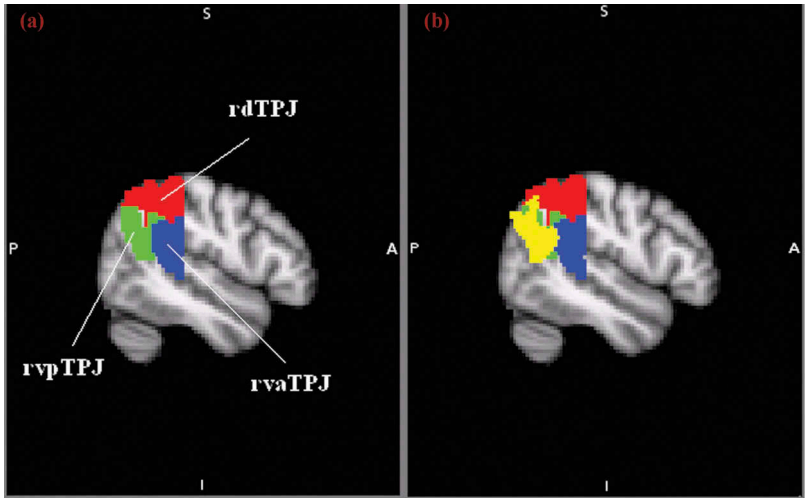

Figure 4. (a) Mars et al.'s (Mars et al., 2012) parcellation of the right TPJ into dorsal (center of gravity [49, −46, 46]) (rdTPJ), ventral posterior [54, −55, 26] (rvpTPJ), and ventral anterior [59, −37, 30] (rvaTPJ) subdivisions. Masks were obtained from *www.rbmars.dds.nl/CBPatlases.htm*. (b) An overlay of the rTPJ (in yellow), defined by the ToM localizer task, over the rTPJ, as delineated by Mars et al., shows that our localized rTPJ [56, −64, 30] significantly matches the rvpTPJ, with minimal overlaps with the rdTPJ and the rvaTPJ. Regions are superimposed on a sagittal section, $x = 20$.

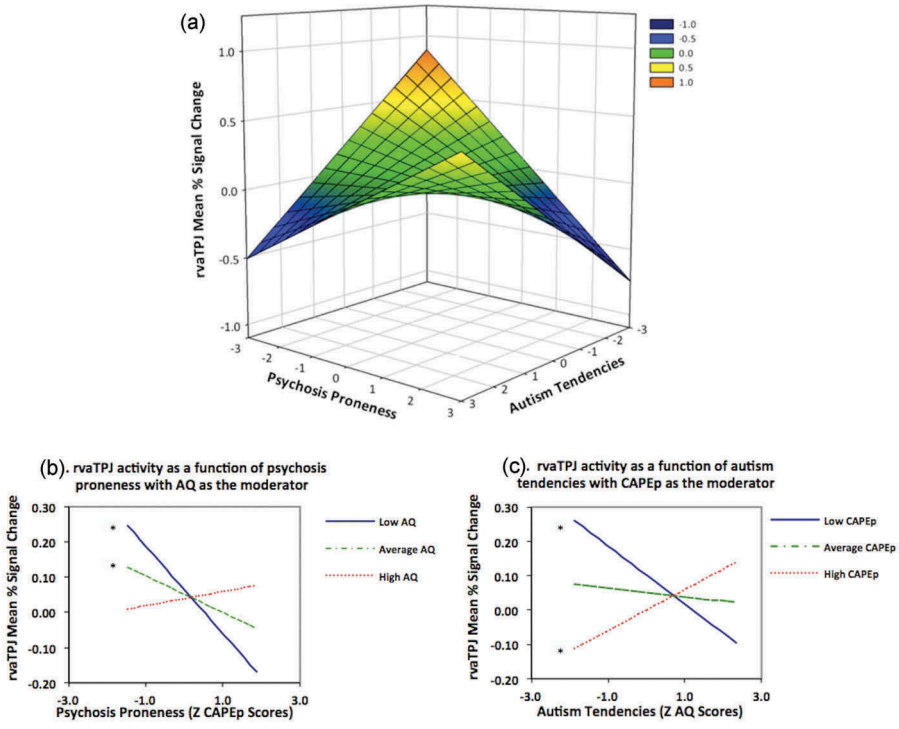

Figure 5. (a) 3-D representation of the interactive effect of autism tendencies, psychosis proneness on mean percent signal change of the rvaTPJ. (b) Visualizes the association between psychosis and rvaTPJ activity by plots of simple regression lines with low (−1 SD), average, and high (+1 SD) AQ scores as moderators, showing a diminishing of the negative effect of psychosis proneness on rvaTPJ activity with increasing autism tendencies. (c) Visualizes the association between autism and rvaTPJ by plots of simple regression lines with low (−1 SD), average, and high CAPEp (+1 SD), showing a reversal of the negative effect of autism tendencies on rvaTPJ activity with increasing psychosis proneness. Asterisk = p-value <.05.

when they were high (β = 0.020, p = 0.50). Conversely, there was a negative relationship between autism tendencies and rvaTPJ activity (Figure 5(c)) when CAPEp scores were low (β = −0.084, p = 0.030), none at the mean (β = −0.012, p = .64), and trending toward a positive relationship when CAPEp scores were high (β = 0.060, p = 0.063), but which becomes significant (p < .05) in individuals scoring above a Z value of 1.056

(which roughly corresponds to a score of 29 on the CAPEp scale). This pattern suggests that activity within the rvaTPJ is also diametrically modulated by autism tendencies and psychosis proneness, but in different, and largely opposite pattern when compared to the rvpTPJ (Figure 3).

Discussion

In this study, we examined the effect of co-occurring autism tendencies and psychosis proneness on the neural activity of core regions within the mentalizing network of neurotypical adults while performing a social competitive game. The results indicated that autism tendencies and psychosis proneness have diametric influences on the neural activity within the ventral posterior (mentalizing) and anterior (attention-reorienting) subdivisions of the rTPJ. Specifically, while autism tendencies were associated with decreased activity in the ventral posterior rTPJ, psychosis proneness was associated with increased activity. Intriguingly, this pattern was reversed for the ventral anterior subdivision of the rTPJ, such that activity was positively associated with autism tendencies and negatively with psychosis proneness. Contrary to our expectations, task-related activations within the paracingulate cortex were unrelated to interindividual differences in autism tendencies or psychosis proneness. While this null finding may simply be due to not having sufficient power, an intriguing possibility for future research is to examine whether autism and psychosis expressions affect activity of posterior regions within the mentalizing network, which are involved in the representation of mental states, differently than anterior regions, which are more involved in the application and deployment of represented mental states (Abu-Akel & Shamay-Tsoory 2011; McCleery, Surtees, Graham, Richards, & Apperly, 2011).

The nature of the interactive effect of autism and psychosis expressions on rTPJ activity is consistent with the diametric model positing that autism and schizophrenia spectrum disorders are etiologically and phenotypically diametrical, exerting opposing influences on activity and behavior (Abu-Akel & Bailey, 2000; Abu-Akel et al., 2015; Crespi & Badcock, 2008; Crespi et al., 2010). We propose that the diametric modulation of the rvpTPJ might be reflective of the neural effort to balance the tendency of psychosis to lead to overmentalizing and autism to undermentalizing (Abu-Akel & Bailey, 2000; Bara, Ciaramidaro, Walter, & Adenzato, 2011; Crespi & Badcock, 2008; Crespi et al., 2010). Indeed, several mentalizing studies associated overactive rTPJ activity with overmentalizing in schizophrenia spectrum disorders (Backasch et al., 2013; Ciaramidaro et al., 2015; Walter et al., 2009), and contrastingly an underactive rTPJ with undermentalizing in autism spectrum disorders (Ciaramidaro et al., 2015; Kana et al., 2015; Lombardo et al., 2011).

This neural pattern was not observed in all studies, however. For example, hypo-activation was observed in the rTPJ of schizophrenia patients compared to controls (Lee, Quintana, Nori, & Green, 2011), and no differences were observed between low versus high psychosis-prone groups (Modinos et al., 2010; van der Meer et al., 2013). However, dividing the participants into low and high groups is not amenable to assess the effect of individual differences on the degree of neural activation. It is also unknown the extent to which unmeasured autism expressions might have influenced these results. Similarly, ASD studies also reported positive association between AQ scores and rTPJ activity (Nummenmaa et al., 2012; von dem Hagen et al., 2011). However, the positive correlation found in the Nummenmaa et al. study was during an attentional/gaze perception task, and that of the von dem Hagen et al. study was in a region whose coordinates [52, −42, 12] fall within the rvaTPJ. It is noteworthy that the AQ scores in the Nummenmaa et al. study also correlated positively with the supramarginal gyrus, which constitutes part of the rvaTPJ as defined in our study. As such, the results reported in Nummenmaa et al. (2012) and von dem Hagen et al. (2011) are consistent with our current finding showing that activity in the attentional rvaTPJ is positively associated with autism tendencies.

Similarly, we propose that the diametric modulation of autism tendencies and psychosis proneness of the rvaTPJ (Figure 5) appears to reflect the neural effort to balance the inability to filter unimportant and distracting information associated with psychosis and the tendency for increased focus of attention associated with autism. This interpretation is consistent with findings showing that deactivation in this region reflects the filtering of irrelevant and distracting information, and that such deactivation ceases once a target has been detected (Shulman, Astafiev, McAvoy, d'Avossa, & Corbetta, 2007). Although attention reorienting was not measured behaviorally in our study, we tested whether the autism-related up-regulation of the rvaTPJ might reflect increased focus of attention. A regression analysis showed that activity of the rvaTPJ was positively associated with the attention-switching subscale of the AQ questionnaire, where higher scores reflect stronger focus of attention (β(se) = .069(.024), $\chi^2 = 8.19$, df = 1, $p = .004$) (see Supplementary Table 3). This finding is consistent with Nummenmaa et al. (2012) who also reported positive association between the attention-switching subscale and rTPJ activity while

performing an attentional/gaze perception task. It is important to note that the attention-switching subscale was not associated with rvpTPJ activity (χ^2 = 0.06, df = 1, p = .81).

Taken together, we hypothesize that higher psychosis proneness leads to an increase in the availability of information due to reduced information filtering (reflected in deactivation in rvaTPJ) and consequently greater effort when trying to mentalize with this information (reflected in greater rvpTPJ activity). These consequences of psychosis proneness are countered by the relative expression of the autistic traits associated with attentional focus, which restricts the amount of information available for mentalizing in the rvpTPJ. This interpretation is consistent with the opposing domains hypothesis positing reciprocal interaction between regions involved in social cognition and regions involved in attentional processing (Jack, Dawson, Begany, Leckie, & Barry et al., 2012; Kubit & Jack, 2013). Future research can test this hypothesis by examining performance on attentional and mentalizing paradigms following stimulation of key regions within the attentional and mentalizing networks in individuals with varying degrees of autism and psychosis expressions.

Based on the strong interactive effect between autism and psychosis expressions in the rTPJ, we suggest that such interindividual variation within and across disorders can be accounted for in terms of the relative expression of one disorder vis-à-vis the other. However, given that our findings are based on the relative expression of autism and psychosis traits among neurotypical adults, a further critical step is to examine whether these findings generalize to their respective clinical entities. Nonetheless, the impact of these sub-threshold clinical traits on neural functioning in a manner similar to what has been observed in patients with these disorders suggests that neural abnormalities are not necessarily a consequence of the disorders. This also raises the possibility that an important difference between patients and non-patients is in the relative expression of autism and psychosis traits. Our findings thus provide a framework that could reconcile discrepant results such that hypo- or hyper-activation in either disorder (Ciaramidaro et al., 2015; Lee et al., 2011; Sugranyes et al., 2011) may be due to failure to capture the diametric influence of the other disorder. Additionally, the effect of individual differences in autism and psychosis expressions in neurotypicals on neural activity raises concerns regarding hitherto findings reported in studies comparing clinical and nonclinical groups (Brunet, Sarfati, Hardy-Baylé, & Decety, 2003, Modinos et al., 2010; van der Meer et al., 2013). Might differences (or lack thereof) between clinical and healthy controls be confounded by the relative expression of autism and psychosis in "healthy" controls? That is, it is reasonable to assume that the extent of the difference between the healthy and the clinical populations is a function of the extent of subclinical expressions in the healthy group. This should be of particular concern when the distribution of traits in the healthy sample is skewed.

Our findings may also have implications in relation to the wider social brain/mentalizing network. We suggest that a fuller understanding of its functionality requires an examination of the extent to which it is interactively linked with regions that are responsible with domain general processing. This is particularly important for research concerned with understanding the causal links between regions responsible for higher level social cognitive processing and regions associated with domain-general attentional processes. In this regard, delineation of the causal links among subdivisions within the TPJ would be an important step forward in understanding their role within the mentalizing network. Furthermore, the opposite effects of autism and psychosis on neural activity within the TPJ suggest that these conditions influence independent yet interacting systems, which may be precipitated by discrete genetic mechanisms (Crespi & Badcock, 2008; Crespi et al., 2010). Answering this question requires research that examines the effect of autism and/or psychosis genetic risk factors with clear links to the development and functionality of brain regions within the mentalizing network. This could build on existing research showing, for example, that the zinc finger protein 804A (*ZNF804A*) single nucleotide polymorphisms (SNPs), which confer risk for both autism and schizophrenia (Anitha et al., 2014), affect brain activations within the mentalizing network in a dose-dependent manner (Walter et al., 2011).

Our study is the first to show that the postulated diametric modulation of autism tendencies and psychosis proneness on behavior and performance are detectable at the neural level in a region that is a core component of social functioning (Chien, Lin, Lai, Gau, & Tseng, 2015; Lombardo et al., 2011). The association of the neural response in the socio-cognitive and attention-reorienting networks with the extended autism and psychosis spectra in the neurotypical population further suggests that the assessment of both spectra in the "control group" could have important consequences for establishing baseline measures of behavior and brain phenotypes in the clinical groups. Furthermore, the contrastive modulation of the ventral

anterior versus the ventral posterior rTPJ underscores the distinct functionality of these subdivisions (Corbetta et al., 2008; Mars et al., 2012; Scholz et al., 2009), and provides an insight for the debate surrounding the functional link between regions responsible for higher level social cognitive processing and regions associated with domain-general attentional processes.

Acknowledgments

We thank Rogier Mars and Matthew Rushworth for use of masks. Hannah Widdman for helping prototype an initial version of the RPS task.

Author contributions

A.M.A. designed the study, collected and analyzed the data and wrote the manuscript. I.A.A. and S.J.W. designed the study. P.C.H. designed the study, collected and analyzed the data. All authors discussed the results and commented on the manuscript.

Disclosure statement

The authors declare no conflict of interest.

References

Abu-Akel, A., & Bailey, A. L. (2000). The possibility of different forms of theory of mind impairment in psychiatric and developmental disorders. *Psychological Medicine*, *30*, 735–738. doi:10.1017/S0033291799002123

Abu-Akel, A., & Shamay-Tsoory, S. (2011). Neuroanatomical and neurochemical bases of theory of mind. *Neuropsychologia*, *49*, 2971–2984. doi:10.1016/j.neuropsychologia.2011.07.012

Abu-Akel, A., Wood, S. J., Hansen, P. C., & Apperly, I. A. (2015). Perspective-taking abilities in the balance between autism tendencies and psychosis proneness. *Proceedings of the Royal Society B: Biological Sciences*, *282*, 20150563. doi:10.1098/rspb.2015.0563

Anitha, A., Thanseem, I., Nakamura, K., Vasu, M. M., Yamada, K., Ueki, T., … Mori, N. (2014). Zinc finger protein 804A (ZNF804A) and verbal deficits in individuals with autism. *Journal of Psychiatry & Neuroscience*, *39*, 294–303. doi:10.1503/jpn

Annett, M. (1972). The distribution of manual asymmetry. *British Journal of Psychology*, *63*, 343–358. doi:10.1111/bjop.1972.63.issue-3

Austin, E. J. (2005). Personality correlates of the broader autism phenotype as assessed by the Autism Spectrum Quotient (AQ). *Personality and Individual Differences*, *38*, 451–460. doi:10.1016/j.paid.2004.04.022

Backasch, B., Straube, B., Pyka, M., Klöhn-Saghatolislam, F., Müller, M. J., Kircher, T. T. J., & Leube, D. T. (2013). Hyperintentionality during automatic perception of naturalistic cooperative behavior in patients with schizophrenia. *Social Neuroscience*, *8*, 489–504. doi:10.1080/17470919.2013.820666

Bara, B. G., Ciaramidaro, A., Walter, H., & Adenzato, M. (2011). Intentional minds: A philosophical analysis of intention tested through fMRI experiments involving people with schizophrenia, people with autism, and healthy individuals. *Frontiers in Human Neuroscience*, *5*, 7. doi:10.3389/fnhum.2011.00007

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): Evidence from Asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders*, *31*, 5–17. doi:10.1023/A:1005653411471

Brunet, E., Sarfati, Y., Hardy-Baylé, M.-C., & Decety, J. (2003). Abnormalities of brain function during a nonverbal theory of mind task in schizophrenia. *Neuropsychologia*, *41*, 1574–1582. doi:10.1016/S0028-3932(03)00119-2

Bzdok, D., Langner, R., Schilbach, L., Jakobs, O., Roski, C., Caspers, S., … Eickhoff, S. B. (2013). Characterization of the temporo-parietal junction by combining data-driven parcellation, complementary connectivity analyses, and functional decoding. *NeuroImage*, *81*, 381–392. doi:10.1016/j.neuroimage.2013.05.046

Carroll, L. S., & Owen, M. J. (2009). Genetic overlap between autism, schizophrenia and bipolar disorder. *Genome Medicine*, *1*, 102. doi:10.1186/gm102

Carter, R. M., & Huettel, S. A. (2013). A nexus model of the temporal-parietal junction. *Trends in Cognitive Sciences*, *17*, 328–336. doi:10.1016/j.tics.2013.05.007

Chaminade, T., Rosset, D., Da Fonseca, D., Nazarian, B., Lutcher, E., Cheng, G., & Deruelle, C. (2012). How do we think machines think? An fMRI study of alleged competition with an artificial intelligence. *Frontiers in Human Neuroscience*, *6*, 103. doi:10.3389/fnhum.2012.00103

Chien, H.-Y., Lin, H.-Y., Lai, M.-C., Gau, S. S.-F., & Tseng, W.-Y. I. (2015). Hyperconnectivity of the right posterior temporo-parietal junction predicts social difficulties in boys with autism spectrum disorder. *Autism Research: Official Journal of the International Society for Autism Research*, *8*, 427–441. doi:10.1002/aur.2015.8.issue-4

Chisholm, K., Lin, A., Abu-Akel, A., & Wood, S. J. (2015). The association between autism and schizophrenia spectrum disorders: A review of eight alternate models of co-occurrence. *Neuroscience & Biobehavioral Reviews*, *55*, 173–183. doi:10.1016/j.neubiorev.2015.04.012

Chung, Y. S., Barch, D., & Strube, M. (2014). A meta-analysis of mentalizing impairments in adults with schizophrenia and autism spectrum disorder. *Schizophrenia Bulletin*, *40*, 602–616.

Ciaramidaro, A., Bolte, S., Schlitt, S., Hainz, D., Poustka, F., Weber, B., … Walter, H. (2015). Schizophrenia and autism as contrasting minds: Neural evidence for the hypo-hyper-intentionality hypothesis. *Schizophrenia Bulletin*, *41*, 171–179. doi:10.1093/schbul/sbu124

Corbetta, M., Patel, G., & Shulman, G. L. (2008). The reorienting system of the human brain: From environment to theory of mind. *Neuron*, *58*, 306–324. doi:10.1016/j.neuron.2008.04.017

Crespi, B., & Badcock, C. (2008). Psychosis and autism as diametrical disorders of the social brain. *The Behavioral and Brain Sciences*, *31*, 241–261; discussion 61–320. doi:10.1017/S0140525X08004214

Crespi, B., Stead, P., & Elliot, M. (2010). Evolution in health and medicine Sackler colloquium: Comparative genomics of autism and schizophrenia. *Proceedings of the National Academy of Sciences of the United States of America*, *107* (Suppl 1), 1736–1741. doi:10.1073/pnas.0906080106

Decety, J., & Lamm, C. (2007). The role of the right temporoparietal junction in social interaction: How low-level computational processes contribute to meta-cognition. *The Neuroscientist: A Review Journal Bringing Neurobiology, Neurology and Psychiatry*, *13*, 580–593. doi:10.1177/1073858407304654

Del Giudice, M., Klimczuk, A. C. E., Traficonte, D. M., & Maestripieri, D. (2014). Autistic-like and schizotypal traits in a life history perspective: Diametrical associations with impulsivity, sensation seeking, and sociosexual behavior. *Evolution and Human Behavior*, *35*, 415–424. doi:10.1016/j.evolhumbehav.2014.05.007

Dinsdale, N. L., Hurd, P. L., Wakabayashi, A., Elliot, M., Crespi, B. J., & Whitehouse, A. (2013). How are autism and schizotypy related? Evidence from a non-clinical population. *Plos One*, *8*, e63316. doi:10.1371/journal.pone.0063316

Ettinger, U., Mohr, C., Gooding, D. C., Cohen, A. S., Rapp, A., Haenschel, C., & Park, S. (2015). Cognition and brain function in schizotypy: A selective review. *Schizophrenia Bulletin*, *41*(Suppl 2), S417–26. doi:10.1093/schbul/sbu190

Gallagher, H. L., Jack, A. I., Roepstorff, A., & Frith, C. D. (2002). Imaging the intentional stance in a competitive game. *NeuroImage*, *16*, 814–821. doi:10.1006/nimg.2002.1117

Hamlyn, J., Duhig, M., McGrath, J., & Scott, J. (2013). Modifiable risk factors for schizophrenia and autism–shared risk factors impacting on brain development. *Neurobiology of Disease*, *53*, 3–9. doi:10.1016/j.nbd.2012.10.023

Hartwright, C. E., Apperly, I. A., & Hansen, P. C. (2012). Multiple roles for executive control in belief-desire reasoning: Distinct neural networks are recruited for self perspective inhibition and complexity of reasoning. *NeuroImage*, *61*, 921–930. doi:10.1016/j.neuroimage.2012.03.012

Hayes, A. F., & Matthes, J. (2009). Computational procedures for probing interactions in OLS and logistic regression: SPSS and SAS implementations. *Behavior Research Methods*, *41*, 924–936. doi:10.3758/BRM.41.3.924

Jack, A. I., Dawson, A. J., Begany, K. L., Leckie, R. L., Barry, K. P., … Snyder, A. Z. (2012). fMRI reveals reciprocal inhibition between social and physical cognitive domains. *NeuroImage*, *66C*, 385–401.

Kana, R. K., Keller, T. A., Cherkassky, V. L., Minshew, N. J., & Just, M. A. (2009). Atypical frontal-posterior synchronization of theory of mind regions in autism during mental state attribution. *Social Neuroscience*, *4*, 135–152. doi:10.1080/17470910802198510

Kana, R. K., Maximo, J. O., Williams, D. L., Keller, T. A., Schipul, S. E., Cherkassky, V. L., … Just, M. A. (2015). Aberrant functioning of the theory-of-mind network in children and adolescents with autism. *Molecular Autism*, *6*, 59. doi:10.1186/s13229-015-0052-x

Kästner, A., Begemann, M., Michel, T. M., Everts, S., Stepniak, B., Bach, C., … Ehrenreich, H. (2015). Autism beyond diagnostic categories: Characterization of autistic phenotypes in schizophrenia. *BMC Psychiatry*, *15*, 115. doi:10.1186/s12888-015-0494-x

King, B. H., & Lord, C. (2011). Is schizophrenia on the autism spectrum? *Brain Research*, *1380*, 34–41. doi:10.1016/j.brainres.2010.11.031

Kubit, B., & Jack, A. I. (2013). Rethinking the role of the rTPJ in attention and social cognition in light of the opposing domains hypothesis: Findings from an ALE-based meta-analysis and resting-state functional connectivity. *Frontiers in Human Neuroscience*, *7*, 323. doi:10.3389/fnhum.2013.00323

Lee, J., Quintana, J., Nori, P., & Green, M. F. (2011). Theory of mind in schizophrenia: Exploring neural mechanisms of belief attribution. *Social Neuroscience*, *6*, 569–581. doi:10.1080/17470919.2011.620774

Lin, A., Wigman, J. T., Nelson, B., Vollebergh, W. A., Van Os, J., Baksheev, G., … Yung, A. R. (2011). The relationship between coping and subclinical psychotic experiences in adolescents from the general population - a longitudinal study. *Psychological Medicine*, *41*, 2535–2546. doi:10.1017/S0033291711000560

Lombardo, M. V., Chakrabarti, B., Bullmore, E. T., & Baron-Cohen, S. (2011). Specialization of right temporo-parietal junction for mentalizing and its relation to social impairments in autism. *NeuroImage*, *56*, 1832–1838. doi:10.1016/j.neuroimage.2011.02.067

Mars, R. B., Sallet, J., Schuffelgen, U., Jbabdi, S., Toni, I., & Rushworth, M. F. (2012). Connectivity-based subdivisions of the human right "temporoparietal junction area": Evidence for different areas participating in different cortical networks. *Cerebral Cortex*, *22*, 1894–1903. doi:10.1093/cercor/bhr268

McCleery, J. P., Surtees, A., Graham, K. A., Richards, J., & Apperly, I. A. (2011). The neural and cognitive time-course of theory of mind. *Journal of Neuroscience*, *31*, 12849–12854.

Modinos, G., Renken, R., Shamay-Tsoory, S. G., Ormel, J., & Aleman, A. (2010). Neurobiological correlates of theory of mind in psychosis proneness. *Neuropsychologia*, *48*, 3715–3724. doi:10.1016/j.neuropsychologia.2010.09.030

Nettle, D. (2006). Schizotypy and mental health amongst poets, visual artists, and mathematicians. *Journal of Research in Personality*, *40*, 876–890. doi:10.1016/j.jrp.2005.09.004

Nummenmaa, L., Engell, A. D., von dem Hagen, E., Henson, R. N. A., & Calder, A. J. (2012). Autism spectrum traits predict the neural response to eye gaze in typical individuals. *NeuroImage*, *59*, 3356–3363. doi:10.1016/j.neuroimage.2011.10.075

Peters, E. R., Joseph, S. A., & Garety, P. A. (1999). Measurement of delusional ideation in the normal population: Introducing the PDI (Peters et al. delusions inventory). *Schizophrenia Bulletin*, *25*, 553–576. doi:10.1093/oxfordjournals.schbul.a033401

Reynolds, C., & Kamphaus, R. (2007). *Test of irregular word reading efficiency*. Odessa, FL: PAR.

Saxe, R., & Kanwisher, N. (2003). People thinking about thinking people. The role of the temporo-parietal junction in "theory of mind". *NeuroImage*, *19*, 1835–1842. doi:10.1016/S1053-8119(03)00230-1

Scholz, J., Triantafyllou, C., Whitfield-Gabrieli, S., Brown, E. N., Saxe, R., & Lauwereyns, J. (2009). Distinct regions of right temporo-parietal junction are selective for theory of mind and exogenous attention. *Plos One*, *4*, e4869. doi:10.1371/journal.pone.0004869

Schurz, M., Radua, J., Aichhorn, M., Richlan, F., & Perner, J. (2014). Fractionating theory of mind: A meta-analysis of functional brain imaging studies. *Neuroscience & Biobehavioral Reviews*, *42*, 9–34. doi:10.1016/j.neubiorev.2014.01.009

Searles Quick, V. B., Davis, J. M., Olincy, A., & Sikela, J. M. (2015). DUF1220 copy number is associated with schizophrenia risk and severity: Implications for understanding autism and schizophrenia as related diseases. *Translational Psychiatry*, *5*, e697. doi:10.1038/tp.2015.192

Shulman, G. L., Astafiev, S. V., McAvoy, M. P., d'Avossa, G., & Corbetta, M. (2007). Right TPJ deactivation during visual search: Functional significance and support for a filter hypothesis. *Cerebral Cortex*, *17*, 2625–2633. doi:10.1093/cercor/bhl170

Solomon, M., Olsen, E., Niendam, T., Ragland, J. D., Yoon, J., Minzenberg, M., & Carter, C. S. (2011). From lumping to splitting and back again: Atypical social and language development in individuals with clinical-high-risk for psychosis, first episode schizophrenia, and autism spectrum disorders. *Schizophrenia Research*, *131*, 146–151. doi:10.1016/j.schres.2011.03.005

Spek, A. A., & Wouters, S. G. M. (2010). Autism and schizophrenia in high functioning adults: Behavioral differences and overlap. *Research in Autism Spectrum Disorders*, *4*, 709–717. doi:10.1016/j.rasd.2010.01.009

Stefanis, N. C., Hanssen, M., Smirnis, N. K., Avramopoulos, D. A., Evdokimidis, I. K., Stefanis, C., … Van Os, J. (2002). Evidence that three dimensions of psychosis have a distribution in the general population. *Psychological Medicine*, *32*, 347–358. doi:10.1017/S0033291701005141

Stefansson, H., Meyer-Lindenberg, A., Steinberg, S., Magnusdottir, B., Morgen, K., Arnarsdottir, S., … Stefansson, K. (2014). CNVs conferring risk of autism or schizophrenia affect cognition in controls. *Nature*, *505*, 361–366. doi:10.1038/nature12818

Sugranyes, G., Kyriakopoulos, M., Corrigall, R., Taylor, E., Frangou, S., & Baune, B. T. (2011). Autism spectrum disorders and schizophrenia: Meta-analysis of the neural correlates of social cognition. *Plos One*, *6*, e25322. doi:10.1371/journal.pone.0025322

Torgesen, J., Wagner, R., & Rashotte, C. (1999). *Test of word reading efficiency*. Austin, TX: Pro-Ed.

van der Meer, L., Groenewold, N. A., Pijnenborg, M., Aleman, A., & Mazza, M. (2013). Psychosis-proneness and neural correlates of self-inhibition in theory of mind. *Plos One*, *8*, e67774. doi:10.1371/journal.pone.0067774

von dem Hagen, E. A., Nummenmaa, L., Yu, R., Engell, A. D., Ewbank, M. P., & Calder, A. J. (2011). Autism spectrum traits in the typical population predict structure and function in the posterior superior temporal sulcus. *Cerebral Cortex*, *21*, 493–500. doi:10.1093/cercor/bhq062

Walter, H., Ciaramidaro, A., Adenzato, M., Vasic, N., Ardito, R. B., Erk, S., & Bara, B. G. (2009). Dysfunction of the social brain in schizophrenia is modulated by intention type: An fMRI study. *Social Cognitive and Affective Neuroscience*, *4*, 166–176. doi:10.1093/scan/nsn047

Walter, H., Schnell, K., Erk, S., Arnold, C., Kirsch, P., Esslinger, C., … Meyer-Lindenberg, A. (2011). Effects of a genome-wide supported psychosis risk variant on neural activation during a theory-of-mind task. *Molecular Psychiatry*, *16*, 462–470. doi:10.1038/mp.2010.18

Yung, A. R., Nelson, B., Baker, K., Buckby, J. A., Baksheev, G., & Cosgrave, E. M. (2009). Psychotic-like experiences in a community sample of adolescents: Implications for the continuum model of psychosis and prediction of schizophrenia. *The Australian and New Zealand Journal of Psychiatry*, *43*, 118–128. doi:10.1080/00048670802607188