Group-ICA with Functional Connectivity During Inhibition Control in Young Adults With Autistic-like Traits: an fMRI Study of a Stop-Signal Task

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Research

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Abstract

Background

Few studies explored response inhibition in autistic-like traits people, using task fMRI. In this study, we examine the functional connectivity of the brain using a stop-signal task based on fMRI among young adults with autistic-like traits and investigated their ability to achieve inhibition control.

Methods

29 of Chinese individuals measured with AQ. Then applied stop signal task to explore the difference in brain functional connectivity in individuals with autistic-like traits.

Results

The results showed autistic-like traits people the longer the SSRT, the worse the inhibition ability. And we used networks obtained from groupICA analysis at the functional connectivity analysis level, the SN had a negative connection with left SMG; the DAN had a negative connection with left LG; the FPN had a positive connection with left PCG; the LN had a positive connection with vermis 4 5 and negative connection with left ITG. Furthermore, the SMG, LG, PCG, and temporal gyrus were also obtained in ROI-to-ROI analysis.

Limitations

Our sample size smaller, still need to multicenter, large sample confirmed this conclusion. We want to use more task paradigms to explore inhibition control in autistic-like traits people.

Conclusions

We found that autistic-like traits people had atypical functional connectivity within brain networks in the SN, DAN, FPN, and LN, and had atypical brain areas centered on the SMG, LG, PCG, and temporal gyrus. And also highlight the importance of considering executive control function of whole-brain functional connections to better characterize brain connectivity in young adults with autistic-like traits.

Background

“Autistic-like traits” is a term describing a group of subliminal social skills and communication traits and unusual personality features that are believed to be milder manifestations of traits characteristic for clinically diagnosed autism (Constantino et al., 2006; Rutter, 2000). The continuity of population distribution clearly identified the character of autism spectrum disorders (ASD), since the DSM-5 no longer classified ASD in 2013 (A. P. Association, 2013). In other words, the classification of autistic-like traits changed from a categorical classification with or without autism to a quantitative classification with continuity, which also reflects the diversity and heterogeneity to some extent (Lai, Lombardo,

Chakrabarti, & Baron-Cohen, 2013). This group is also thought to have a disability in inhibition control (Agam, Joseph, Barton, & Manoach, 2010; R. K. Kana, T. A. Keller, N. J. Minshew, & M. A. Just, 2007; Rinehart, Bradshaw, Moss, Brereton, & Tonge, 2008). This disability may adversely impact their daily life, mental health and productivity (Foss-Feig et al., 2017). With the development of neuroscience and anatomy, numerous studies showed the inhibition process involved in some brain areas, such as the corpus callosum (Alexander et al.; Giuliano et al., 2018; Just, Cherkassky, Keller, Kana, & Minshew, 2006), thalamus (Daly et al., 2014; Haznedar et al., 2006), anterior cingulate cortex (Chmielewski, Yildiz, & Beste, 2014), prefrontal cortex (T. Xiao et al., 2012), temporal gyrus (Sheikhani, Behnam, Mohammadi, Noroozian, & Mohammadi, 2012), and parietal gyrus (Vara et al., 2014). In addition to abnormalities in voxel-based brain areas, functional connectivity (FC) was also found in specific brain networks. In Just's study, ASDs in inhibition control processes have underconnectivity within brain networks, mostly focused on the functional connectivity between frontal gyrus and other brain areas, especially the FC between frontal-parietal and frontal to posterior brain regions (Di Martino et al., 2009; Di Martino et al., 2013; McKinnon et al., 2019; Shih et al., 2011). Kana used Functional magnetic Resonance Imaging (fMRI) investigate inhibition control ability in ASDs using a go/no-go task, and the results showed poorer integration between the anterior cingulate cortex and frontal-parietal network (FPN), and decreased FC between them (Rajesh K. Kana, Timothy A. Keller, Nancy J. Minshew, & Marcel Adam Just, 2007).

Some studies involved in response inhibition indicated that patients with ASDs are impaired in terms of inhibiting responses (Adams & Jarrold, 2009; Bishop & Norbury, 2005; Lemon, Gargaro, Enticott, & Rinehart, 2011; Semrud-Clikeman, Walkowiak, Wilkinson, & Butcher, 2010; Vaidya et al., 2011; T. Xiao et al., 2012). Other studies claimed that patients with ASDs have deficits in repetitive behavior that might be caused by nondevelopment in cognitive control functions (Langen, Leemans, Johnston, Ecker, Daly, Murphy, dell'Acqua, et al., 2012; Mosconi et al., 2009). Most studies focused on ASD applied many classic experiment paradigms. The stop-signal task (SST) is one of the most widely used (Geurts, van den Bergh, & Ruzzano, 2014). Many studies involved in children (Schmitt, Ankeny, Sweeney, & Mosconi, 2016), young adults (Ting Xiao et al., 2012), and adults (Wilson et al.) with ASD, all with impairment in cognitive control ability. In an ASD study, the ASD group and control group both showed decreased dorsal anterior cingulate cortex activation (dACC) consistent with a role in top–down control, associated with a higher error rate. The ASD group showed that both brain activation and functional connectivity were associated with more severe restricted repetitive behavior (Agam et al., 2010). The other study involved neurocognitive mechanisms of the response delay effect, and the results showed that active braking might explain the neurological mechanisms of the response delay effect at least, which may be similar to the mechanism of stopping responses completely. These results further explain how individuals point to proactive recruitment of a neurocognitive mechanism when responding with restraint, associated with outright stopping (Jahfari, Stinear, Claffey, Verbruggen, & Aron, 2010). Another study used color-word interference tests, trail making tests, verbal fluency tests, and design fluency tests to explore flexibility, fluency, and inhibition in autism and Asperger's disorder. The results showed that participants performed significantly below average on a composite measure of executive functioning adjusted for baseline

cognitive ability (Kleinhans, Akshoomoff, & Delis, 2005). Schmitt used the stop-signal task and showed that ASD had lower correct rates and more reaction time in stop trials (Schmitt et al., 2016).

In addition to involvement in nontraditional development of neurological mechanisms and poor behavior performance, there are also age-related characteristics (Padmanabhan et al., 2015). Typical development (TD) people have cognitive control ability that improve throughout childhood, and reaches adult levels at age 15, they tend to delay behavior actively, rather than inhibiting it passively when in the young adult state (Luna, Doll, Hegedus, Minshew, & Sweeney, 2007; Vink et al., 2014). ASD have similar development and maturation as TD people, while patients with ASD have obvious deficits in cognitive control ability when in the adolescent and adult state (Geurts et al., 2014). Young adults are thought to be in a significant period of development of cognitive control ability (Humphrey & Dumontheil, 2016; Oberle, Schonert-Reichl, Lawlor, & Thomson, 2012). Padmanabhan's study used an anti-saccade task and visually guided saccade task combined with fMRI to investigate the difference of inhibition control ability between young adults and adults with high functioning autism TD. The results showed that cognitive control ability did not improve with age in the ASD group. An fMRI analysis revealed that in young adults with ASD, the frontal eye field was not activated in the anti-saccade task, in which key brain areas of the inhibition control should be needed, while the putamen was found to have greater activation. This result suggested that the frontal eye field has delayed development in ASD compared with that of TD (Padmanabhan et al., 2015).

As mentioned above, the young adult state is critical in the development of cognitive control. Young adults with ASD might have different activation of brain circuits and functional connectivity, with latent development deficits in cognitive control. During the young adult state, which is a key period of brain maturation, brain functions in ASD might not achieve the key transformation. Most studies focused on ASD patients, while rarely have studies explored inhibition control ability in individuals with autistic-like traits, especially in young adults. In the present study, we explored young adults in normal population with autistic-like traits using a stop-signal task of fMRI, to apply a data-driven method (group-ICA analysis) to identify independent network components, in inhibitory conditions. Then, based on group-ICA results, we took group-ICA network (independent components IC) as a seed, and applied network as a seed to whole-brain connectivity analysis, in order to explore more detailed patterns of autistic-like traits linked functional connectivity in the inhibitory state. Next, a region of ROI-to-ROI analysis was used to explore the neurological mechanisms of brain areas and functional connectivity. Pearson analysis was performed to investigate the relationships between subdimensions of autism spectrum quotient (AQ) and the values of brain areas.

Methods

Participants

A total of 39 people were recruited for this study. 30 subjects with fMRI task results matched to the AQ participated in this study. Due to excessive head movements, 1 participant was excluded (> 3 mm

translation and angular rotation in each axis). Thus, a total of 29 (men: 11; mean age: 19.21 y, SD: 0.41, range: 19–20 y) individuals participated in this research. All methods were in accordance with the Declaration of Helsinki (W. M. Association, 1991). All participants were right-handed, with no history of neurological or psychiatric problems. All participants provided written informed consent and received payment for their time. The study was approved by the Southwest University Brain Imaging Center Institutional Review Board.

Assessment of the AQ

The AQ was used to measure autistic-like traits in individuals from the general population (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). The Chinese version of the AQ (Lau et al., 2013) was used in this study,which consists of tSocial Skill, Communication, Attention Switching, Imagination and Attention to Detail subscales, as represented by fifty statements; participants responded to these statements on a 4-point Likert scale, with "definitely agree" and "slightly agree" responses being scored one point and "slightly disagree" and "definitely disagree" responses being scored one point among the reverse-scored options. In half of the statements, the diagnostic answer was "agree," and in the other half, it was"disagree." One point is awarded for each diagnostic answer, which resulted in a continuous distribution of scores in the population sample. The total score ranged from 0 to 50 points, with higher scores suggesting a higher magnitude of autistic-like traits. Currently available data from research on the properties of this scale indicate that the measurement reliability for the total score is satisfactory (Austin, 2005; Hoekstra, Bartels, Cath, & Boomsma, 2008; Hurst, Mitchell, Kimbrel, Kwapil, & Nelson-Gray, 2007; Ingersoll, Hopwood, Wainer, & Brent Donnellan, 2011; Kloosterman, Keefer, Kelley, Summerfeldt, & Parker, 2011). In the present study we focused on analyzing the total AQ score.

Stop-Signal Task

The stop signal task (Aron & Poldrack, 2006) consists of 32 Stop trials and 96 Go trials. Each trial began with a central fixation cross over 300 ms, and a green arrow pointing left or right was subsequently displayed on a screen. For the Go task, the green arrow lasted for 500 ms, and participants were asked to respond as fast and accurately as possible by pressing the "1" when appeared green left arrow, or "2" button when appeared green right arrow within 1500 ms, then the blank screen lasted for 700 ms. For the Stop task, the stop signal delay (SSD) as the duration of the green arrow, which was dynamically adjusted according to the participant's response, then the stop signal (red arrow) appeared for 300 ms, and participants were asked to withhold the response they already initiated. Specifically, the initial SSD value was 250 ms. If the participant inhibited successfully on a Stop trial, then inhibition was made more difficult on a subsequent stop trial by increasing the SSD by 50 ms; if the participant did not successfully inhibit, then inhibition was made easier by decreasing the SSD by 50 ms. Next, we subtracted the SSD from 1200 ms as the duration of the blank screen. The jitter between trials ranged from 1 s to 4 s (mean,

2.5 s). The duration of the task was 8 min, 46 s. The instructions, the presentation, and a fixation cross were included in each trial (see **Figure 1**).

MRI Data Acquisition and Preprocessing

All subjects underwent MRI scanning at the Brain Imaging Center of Southwest University. Whole-brain imaging data were obtained using a 3.0-T Siemens Trio MRI scanner with a 12-channel whole-brain coil, functional images including 32 continuous slices were obtained with a T2*-weighted (Siemens Medical, Erlangen, Germany). For each subject, 263 blood oxygen level-dependent (BOLD) images were acquired during the fMRI task with a gradient echo type echo planar imaging (EPI) sequence [echo time (TE) = 30 ms; repetition time (TR) = 2000 ms; flip angle = 90 degrees; slice thickness = 3.0 mm; slices = 32; resolution matrix = 64 * 64; voxel size = 3.4*3.4*4 mm; field of view (FOV) = $220 \times 220\,mm^2$; thickness/inter slice gap =3/1 mm; and sampling bandwidth = 250 kHz].

Preprocessing was performed using the Data Processing Assistant for Resting-state fMRI (DPARSF; http://rfmri.org/DPARSF) (Yan & Zang, 2010), which is a toolbox based on the SPM8 software package (www.fil.ion.ucl.ac/spm). The functional data were realigned and unwrapped to correct for head movement artifacts based on field maps. Whole images underwent temporal processing and slice timing and motion correction to reduce displacement between volumes, spatial normalization to the standard Montreal Neurological Institute (MNI) space with a resampled voxel size of 3 x 3 x 3 mm^3 using the T1 scans as reference images, and spatial smoothing (4 mm full width half maximum, FWHM), band-pass temporal filtering (0.01-0.1Hz). To minimize the effects of head motion, subjects were excluded maximal motion between volumes in each direction > 3 mm, and rotation about each axis > 3°.

Group Independent Component Analysis and Component Selection

Group independent component analysis (ICA) was performed in the preprocessed fMRI data using CONN 18b (Whitfield-Gabrieli & Nieto-Castanon, 2012) with G1 FastICA and GICA3 back-projection in Calhoun's group-ICA algorithm (Calhoun, Adali, Pearlson, & Pekar, 2001), which based on all subjects and all conditions. The number of components we used was 25 through MDL analysis to identify independent components (IC) of cortical and subcortical brain areas that corresponds to functional segmented networks. The timecourses and spatial maps were normalzied into z-scores (Beckmann, DeLuca, Devlin, & Smith, 2005).

16 other ICs were discarded as eyemovements, head motion, cardiac-induced pulsatile artifacts, psychological noise, movement signals, or artifacts of canner (Cordes et al., 2000). 9 ICs inclueded 6 subnetworks identified by the CONN network cortical ROIs (HCP-ICA) through the ICA analysis. These subnetworks were the default mode network (DMN), salience network (SN), dorsalattention network (DAN), frontoparietal network (FPN), language network (LN), and cerebellar network (CN).

Take Network as A Seed to Whole-brain Connectivity Analysis

In the first-level analysis, general linear model (GLM) analysis was used to separately estimate the effects in the three conditions (go task, stop task and base), implemented by boxcar functions convolved with a canonical hemodynamic response function (HRF) performed using the CONN 18b toolbox (Cognitive and Affective Neuroscience Laboratory, Massachusetts Institute of Technology, Cambridge, MA, USA; www.nitrc.org/projects/conn). In addition, age, gender and six head motion parameters were taken as confounders. Then, we calculated “contrast images” for each participant for the stop success and base conditions and then computed the whole-brain activity pattern for this contrast, through which subject-specific effects were estimated using the linear contrasts obtained from the first-level analysis. All fMRI data analyses were performed using SPM8 (www.fil.ion.ucl.ac/spm).

To identify specific brain regions that are more positively or negatively connected to the seed network in inhibitory condition among young adults with autistic-like traits, the seed network to whole-brain connectivity was performed using the CONN toolbox. The seed networks used were based on spatial properties in ICA analysis. The onsets and durations of the task were delineated in order to measure connectivity between the networks and the rest of the brain during each condition of the scanning period. The beta maps were created for each individual at whole session. Only the beta maps that measured network connectivity during stop-signal task “stop success > base” period were entered into second-level analysis in CONN. The spatial masks of cerebrospinal fluid (CSF), white matter, ART-based scrubbing, and 6 rigid-body parameters were regressed out of whole-brain gray matter activity. To reduce the effect of low-frequency drift and high-frequency noise, bandpass filtering ($0.01 < f < 0.1$ Hz) was used. The resulting maps were thresholded at a $p < 0.05$ (p-uncorrected voxel threshold) and $p < 0.05$ (p-FDR (false discovery rate) corrected cluster-size).

ROI-to-ROI Analysis

To explore more detailed patterns of autistic-like trait-linked functional connectivity in the inhibitory state, all pairwise connections between Power 264 cortical brain regions (Power et al., 2011) and 30 suncortical brain regions from Human Brainnetome Atlas (Fan et al., 2016) were exainmed for subsets of brain regions that have significant connection to one another’s seeds. This approch use ROI-to-ROI analysis in CONN toolbox at second level, age and gender as covariates, A FDR-corrected $p < 0.05$ at the seed-level was adopted in this study.

Correlation Analysis Between AQ Total Score and Subdimentions and brain areas

To identify those dimensions of AQ that have specific close relationships with brain areas, we applied correlation analysis between AQ and the brain values extracted taken from the network as seed-to-voxel of functional connectivity analysis results.

Results

Behavioral Results

The demographic data and behavioral results are shown in **Table. 1**. The mean AQ score of the current sample was 21.83, and the standard deviation was 4.86.

Stop-Signal Task Performance

In this study, we used stop signal reaction time (SSRT) as an important role to measure people's ability in terms of response inhibition: the longer the SSRT, the worse the inhibition ability (Logan, Cowan, & Davis, 1984). The results showed a significant positive association between AQ and SSRT, which means that young adults with high levels of autistic-like traits, have relatively weaker inhibition control, **($p < 0.05$; Table 2).**

Take Network As a Seed to Whole-brain Connectivity Results

Six networks default mode network (DMN), salience network (SN), dorsal attention network (DAN), frontoparietal network (FPN), language network (LN), and cerebellar network (CN) from group-ICA analysis were used as seeds in a whole-brain search to identify specific brain regions that associated with young adults with autistic-like traits in stop success vs base conditions. The results showed that four networks contained SN, DAN, FPN, and LN have significant functional connectivity with other brain areas. Specifically, the SN (IC13, independent component13) had a significant negative connection with left supramarginal gyrus (SMG); the DAN (IC20) had a significant negative connection with left lingural gyrus (LG); the FPN had a significant positive connection with left postcentral gyrus (PCG); the LN (IC7) had a significant positive connection with vermis 4 5 and negative connection with left inferior temporal gyrus (ITG), (**Table 3** and **Figure 2)**.

ROI-to-ROI Results

We obtained more detailed brain areas of autistic-like traits linked functional connectivity in the inhibitory state. At the ROI-to-ROI level, we found three negative connections and four positive connections, including SMG, postcentral gyrus (PCG), lingual gyrus (LG), and temporal gyrus. These four brain areas

are also included in the network as a seed to whole-brain analysis. These four brain areas might have some specific atypical development in individuals with autistic-like traits (**Table 4 and Figure 3)**.

Correlation Results Between AQ and Subdimentions and Brain areas

The correlation results showed that the social skill of AQ had a significant positive relationship with PCG; attention switching of AQ had a significant positive relationship with PCG, and significant negative relationship with ITG and SMG; attention to detail had a significant negative relationship with ITG; communication had a significant positive relationship with PCG, and significant negative relationship with ITG, SMG and LG (**Table 5).**

Discussion

In this study, we examined the atypical functional connectivity in young adults with autistic-like traits when processed response inhibition using stop-signal tasks. The results showed that as the AQ score increased, young adults showed longer the SSRT, which means worse response inhibition control ability. In primary analysis, used a groupICA approach and obtained six brain networks, DMN, SN, DAN, FPN, LN, and CN. And then taken these networks as seeds to the whole brain approach and found some established connectivity networks showing greater significant connections to the left SMG, left LG, left PCG, verimis4 5 and left ITG. ROI-to-ROI analysis showed multiple significant connections, while the left SMG, left LG, left PCG and temporal gyrus were also included in this results, and were indeed important for autistic-like traits associated connectivity.

Stop-Signal Task Performance

The results of the stop signal task performance of the young adults with autistic-like traits showed that the higher AQ score was, the longer the response time of SSRT was. The increase of response time meant poor inhibition and control ability of people with autistic-like traits. Quantitative studies showed that inhibition control ability is one of the core components of executive function (Chung, Weyandt, & Swentosky, 2014; Geurts et al., 2014; Langen, Leemans, Johnston, Ecker, Daly, Murphy, dell'Acqua, et al., 2012). Individuals with better inhibitory control ability avoid some improper or adverse reactions in processing cognitive control task (Coxon, Stinear, & Byblow, 2007). In the process of complex social communication, the ability to screen out unimportant information and focus on critical information has pivotal effects from childhood to adulthood, and these effects are continuous (Barendse et al., 2013; Carlson & Moses, 2001; Carlson, Moses, & Breton, 2002; Hala, Hug, & Henderson, 2003; Pelphrey, Morris, & McCarthy, 2004).

Atypical Functional Connectivity in Young Adults with Autistic-like Traits in Response Inhibition Control Ability

Taking network as seed-to-voxel analysis showed that LN, DAN, FPN, and LN had significant connections with whole-brain areas. First, LN had increased functional connectivity with vermis4 5, and decreased functional connectivity with ITG. Many studies showed that the vermis always had a close relationship with ASD, from brain structure (Hashimoto, Tayama, Miyazaki, Murakawa, & Kuroda, 1993) to functional connectivity (Wang et al., 2019). A study involving ASD showed that the vermis had significant negative association with eye fixation time, suggesting that the vermis plays a key role in processing visual information (Laidi et al., 2017). The results also found that the LN had a decrease connection with ITG. The ITG plays an important role in LN, and decreased functional connectivity suggested that young adults with autistic-like traits have semantic function that is different from that of traditional people (Herringshaw, Ammons, DeRamus, & Kana, 2016).

We also found SN had decreased functional connectivity with SMG. The SMG is a part of the superior parietal lobule (SPL) (Stoeckel, Gough, Watkins, & Devlin, 2009). The SN is responsible for screening received information and then allocating it to other functions of the brain. The SPL is part of the SN (Bressler & Menon, 2010; Seeley et al., 2007). Decreased within-network functional connectivity in the SN suggests that it does not play a fully role in allocating stimuli (Winston et al., 2013).

In addition, the DAN had decreased functional connections with the LG, providing top-down attention orientation (Lei, Wang, Yuan, & Mantini, 2014). . In task states, individuals were prompted to respond in what form, where and when; the DAN was continuously activated to ensure the task was completed well (Bogousslavsky, Miklossy, Deruaz, Assal, & Regli, 1987). The LG is responsible for visual memory, visual representation and involved in formation of visual image (Belardinelli et al., 2009). Decreased functional connectivity between the DAN and the LG suggested that young adults with autistic-like traits did not concentrate well during the process of response inhibition task, leading to longer SSRT in young adults with autistic-like traits.

Finally, the right FPN has increased functional connectivity with the PCG. The right FPN is responsible for executive control (Duan et al., 2017; Just, Cherkassky, Keller, Kana, & Minshew, 2007; Smallwood, Brown, Baird, & Schooler, 2012), while the PCG is one the main brain areas of the sensorimotor system (Corkin, Milner, & Rasmussen, 1970; Paakki et al., 2010), and this connection suggests that young adults with autistic-like traits when processing response inhibition task might be disturbed by other functional regions, and they might not avoid this interference effectively. We also found these four brain areas appeared in ROI-ROI analysis, which also suggests that these four brain areas play specific pivotal roles and might also be hallmarks of executive control in young adults with autistic-like traits.

Subdimensions of AQ Have an Association with Specific Brain Areas

The correlation results showed that, first, social skill, attention switching, and communication of AQ had a significant positive relationship with the PCG. The PCG is responsible for sensorimotor brain function (Corkin et al., 1970; Paakki et al., 2010), and this suggests that young adults with autistic-like traits, whose typical characteristics include stereotyped behavior, might not screen out irrelevant stimuli well in the inhibition task state. This finding means that increased functional connectivity with the PCG can predict the severity of social skill deficits at some point. We then found that attention switching, attention to detail, and communication had significant negative relationships with the ITG. The ITG is included in the language network and has a key role as a bridge in performing various tasks (Herringshaw et al., 2016). The LN is constantly adjusted in task processing, the previously activated parts are suppressed, and the newly activated parts keep appearing until the task is successfully completed (Sachs et al., 2008). The decreased functional connectivity with the ITG also suggests that young adults with autistic-like traits have deficits in linkage mechanisms of the brain networks, possibly reducing the degree of cooperation between networks. The third one was that attention switching and communication of AQ had decreased functional connectivity with the SMG, and the last one was communication of AQ had decreased functional connectivity with the LG. The SMG is included in the superior parietal lobule (SPL) (Stoeckel et al., 2009), which is involved in executive control and attention shifting (de Wit, 2018; Takarae, Luna, Minshew, & Sweeney, 2014). The decreased tendency in the SPL indicated that the deficits of these areas may explain the nonsocial difficulties in individuals with autistic-like traits, such as repetitive, poorly controlled, poor goal-directed action (Salmi et al., 2013). The LG is responsible for visual memory and visual representation and is involved in the formation of visual image (Belardinelli et al., 2009). The decreased functional connection with the LG suggests that young adults with autistic-like traits have poor inhibition control ability and that they might not concentrate well during the process of response inhibition tasks

Limitations

In the present study, we investigated response inhibition control ability using stop-signal task of fMRI in individuals with autistic-like traits. The results showed that individuals with autistic-like traits have deficits in response inhibition control ability and have atypical functional connectivity. While our sample size smaller, still need to multicenter, large sample confirmed this conclusion. We want to use more classical experimental paradigms like go\no go task, stroop task to explore autistic-like traits people’different types of executive functions in the future study.

Conclusion

The current findings support adopting a mainstream perspective to help reconcile the heterogeneous findings of functional connectivity in young adults with autistic-like traits. These results demonstrated differences specific to certain ages, highlighting the utility of carefully considering age in studies of functional connectivity in autistic-like trait groups. We found that young adults with autistic-like traits had atypical functional connectivity within brain networks in the SN, DAN, FPN, and LN, and had atypical

brain areas centered on the SMG, LG, PCG, and temporal gyrus. Post-hoc analysis found that subdimensions of AQ had significant associations with functional connectivity of brain areas. Both brain networks and brain regions in young adults may help to explain some of the altered functions often found in young adults with autistic-like traits. These results also highlight the importance of considering executive control function of whole-brain functional connections to better characterize brain connectivity in young adults with autistic-like traits.

Abbreviations

Group-ICA: Group Independent Component Analysis

IC: independent components

fMRI: Functional magnetic Resonance Imaging

AQ: Autism spectrum Quotient

SSRT: stop signal reaction time

FC: functional connectivity

DMN: networks default mode network

SN: salience network

DAN: dorsal attention network

FPN: frontoparietal network

LN: language network

CN: cerebellar network

SMG: supramarginal gyrus

LG: lingural gyrus

PCG: postcentral gyrus

ITG: inferior temporal gyrus

ROI: Region of Interests

GLM: general linear model

HRF: hemodynamic response function

Declarations

Ethics approval and consent to participate

All methods were in accordance with the Declaration of Helsinki. All participants provided written informed consent and received payment for their time. The study was approved by the Southwest University Brain Imaging Center Institutional Review Board.

Consent for publication

No application

Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request

Competing interests

The authors declared no competing interests.

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Author contributions

Yu and Wang conducted the experiments, analyzed the results and carried on paper writing, Qiu proposed many constructive advises in manuscript. All authors reviewed the manuscript.

Yaxu Yu and Li He contributed equally to this work. Qiu is the corresponding author.

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Tables

Table1. A summary of the demographic information in the present study

	N = 29		
Measure	Mean	SD	range
Age	19.21	0.41	19-20
AQ(total)	21.83	4.86	14-30
Social skill	4.14	2.10	1-8
Attention switching	5.55	2.08	1-9
Attention to detail	5.86	2.29	0-9
Communication	3.00	1.77	0-7
Imagination	3.34	1.14	1-6

Notes: AQ = Autism Spectrum Quotient; SD = standard deviation; N = number

Table2. The partial correlation between AQ and SSRT value (one-tailed test)

	N = 29						
Measure	1	2	3	4	5	6	7
1 SSRT	-						
2 AQ(total)	**.044***	-					
3 Social skill	.452	.000	-				
4 Attention switching	**.003***	.000	.012	-			
5Attention to detail	.404	.139	.040	.371	-		
6 Communication	.051	.000	.001	.026	.091	-	
7 Imagination	.483	.135	.344	.451	.141	.154	-

*Notes: AQ = Autism Spectrum Quotient; *p < 0.05. SSRT = Stop Signal Reaction Time; N = number*

Table3. Seed network to whole-brain connectivity analysis at stop success > base condition

Seed network	Cluster size	MNI coordinates	P-$_{FWE}$
LN			
Vermis 4 5 (+)	202	0, -52, 6	0.03
ITG_L (-)	172	-54, -46, -16	0.01
SN			
SMG_L (-)	425	-54, -42, 44	0.006
DAN			
LG_L (-)	466	-12, -72, 2	0.004
FPN			
PCG_L (+)	178	-20, -40, 56	0.008

Notes*: salience network (LN)); salience network (SN); dorsal attention network (DAN); frontoparietal network (FPN); inferior temporal gyrus (ITG); supramarginal gyrus (SMG); lingual gyrus (LG); postcentral gyrus (PCG); L: left; R: right; MNI: Montreal Neurological Institute*.

Table 4. ROI-to-ROI functional connectivity analysis at stop success > base condition

ROI	Approximate brain area	Power atlas network assignment	MNI coordinates	Statistic	p_{FDR}
(69)[a]-(209)	SMG_L-insula_R	SN - SN	(-53, -22, 23) (36, 22, 3)	6.12	0.0005
(134)-(255)[a]	Precuneus_L-PCG_R	Memory - FPN	(-7,-71,42) (47, -30,49)	-5.35	0.0040
(80)-(124)	MOG_R – PHG_L	DMN - DMN	(43, -72, 28) (-26, -40, -8)	5.00	0.0101
(191)-(117)[a]	IPL_L -MTG_L	DAN-DMN	(-28, -58, 48) (-56, -13, -10)	4.85	0.0151
(263)-(79)[a]	SPL_L – MTG_L	DAN - DMN	(-17, -59, 64) (-46, -61, 21)	4.78	0.0180
(89)-(255)[a]	Precuneus_R - PCG_R	DMN - FPN	(6, -59, 35) (47, -30, 49)	-4.78	0.0182
(110)-(226)	OFC_R – Brainstem_L	DMN-Subcortical	(8, 42, -5) (-5, -28, -4)	-4.45	0.0427
(239)-(151)[a]	MTG_R – LG_L	VAN - Visual	(51, -29, -4) (-15, -71, -8)	4.39	0.0499

Notes: *ROI are defined by Power Atlas; [a] identified in seed network to whole-brain analysis*

SMG: supramarginal gyrus; PCG: postcentral gyrus; MOG: middle occipital gyrus; PHG: parahippocampal gyrus; IPL: inferior parietal gyrus; MTG: middle temporal gyrus; SPL: superior parietal gyrus; OFC: orbitalfrontal cortex; LG: lingual gyrus SN: salience network; FPN: frontoparietal network; DMN: default mode network; DAN: dorsal attention network; VAN: ventral attention network. L: left; R: right; MNI: Montreal Neurological Institute.

Table5 The correlation between AQ total and sub-dimensions and brain areas

Items	PCG	ITG	SMG	LG
AQ total	0.000/0.694	0.000/-0.686	0.000/-0.669	0.003/-0.529
Social skill	0.002/0.547	-	-	-
Attention switching	0.000/0.654	0.008/-0.481	0.005/-0.503	-
Attention to detail	-	0.034/-0.395	-	-
communication	0.024/0.415	0.028/-0.408	0.003/-0.536	0.033/-0.397
imagination	-	-	-	-

Note: p/r.

Figures

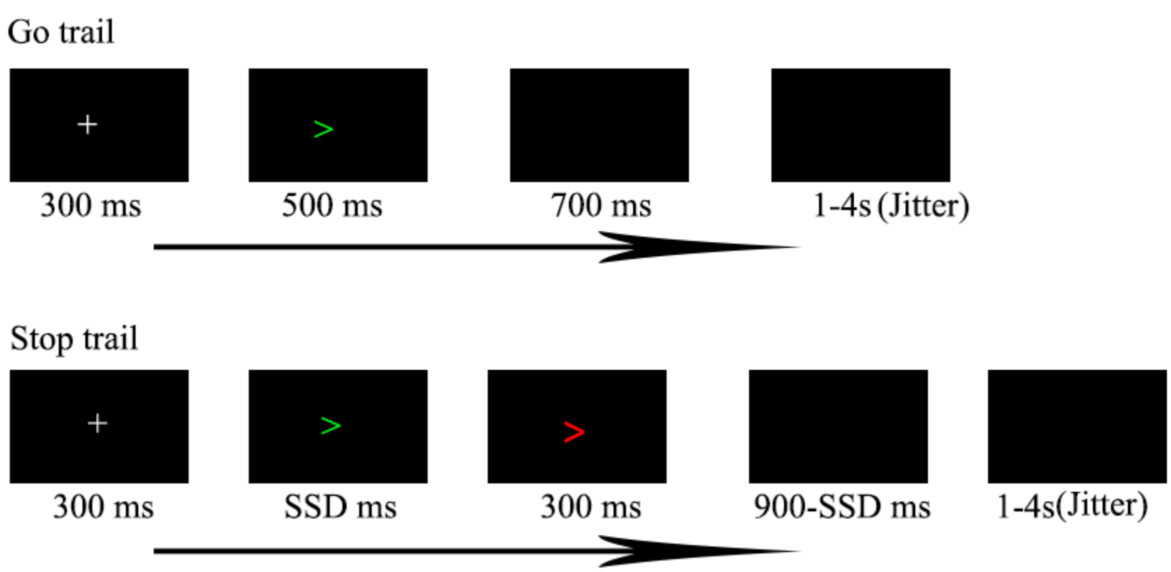

Figure 1

The stop-signal task. Each trail began with a central fixation cross during 300ms, then a green arrow pointing left or right was displayed on the screen. For the Go trail, when appeared green left arrow lasted for 500ms, participants were asked to respond by pressing the “1”, or “2” button when appeared green right arrow within 1500ms, then the blank screen lasted for 700ms. For the Stop trail, participants were asked to withhold the response they already initiated. The jitter between trails ranged from 1s to 4s (mean, 2.5s). Which consists of 32 Stop trials and 96 Go trials. The duration of the task was 8 min 46 s.

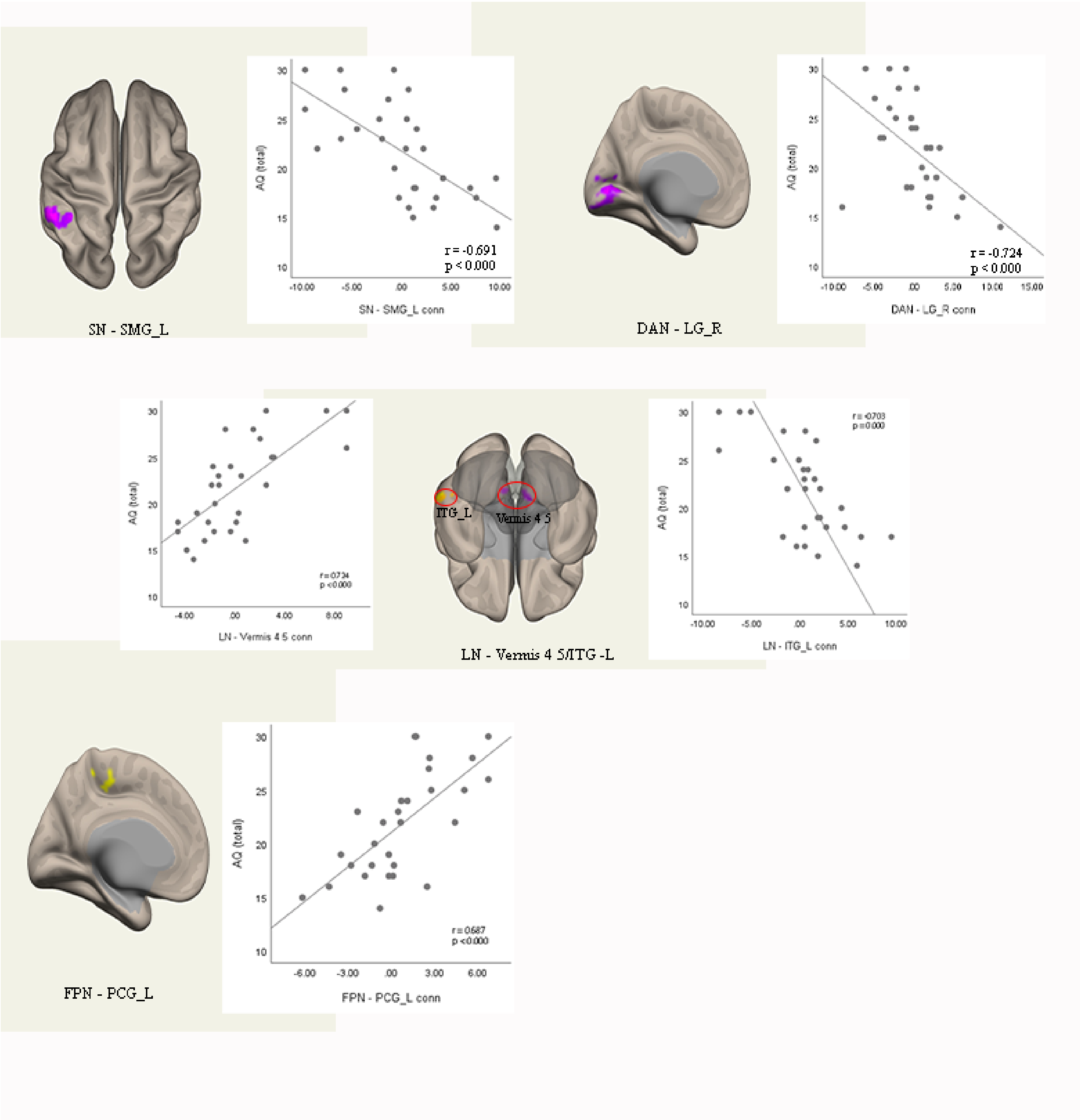

Figure 2

The take network as seed to voxel analysis showed that the saliance network (SN) has a significant nagetive connection with left supramarginal gyrus (SMG); dorsal attention network (DAN) has significant negative connection with left lingural gyrus (LG); frontoparietal network (FPN) has a significant positive connection with left postcentral gyrus (PCG); lauguage network (LN) have significant positive connection with vermis 4 5 and negatice connection with left inferior temporal gyrus (ITG).

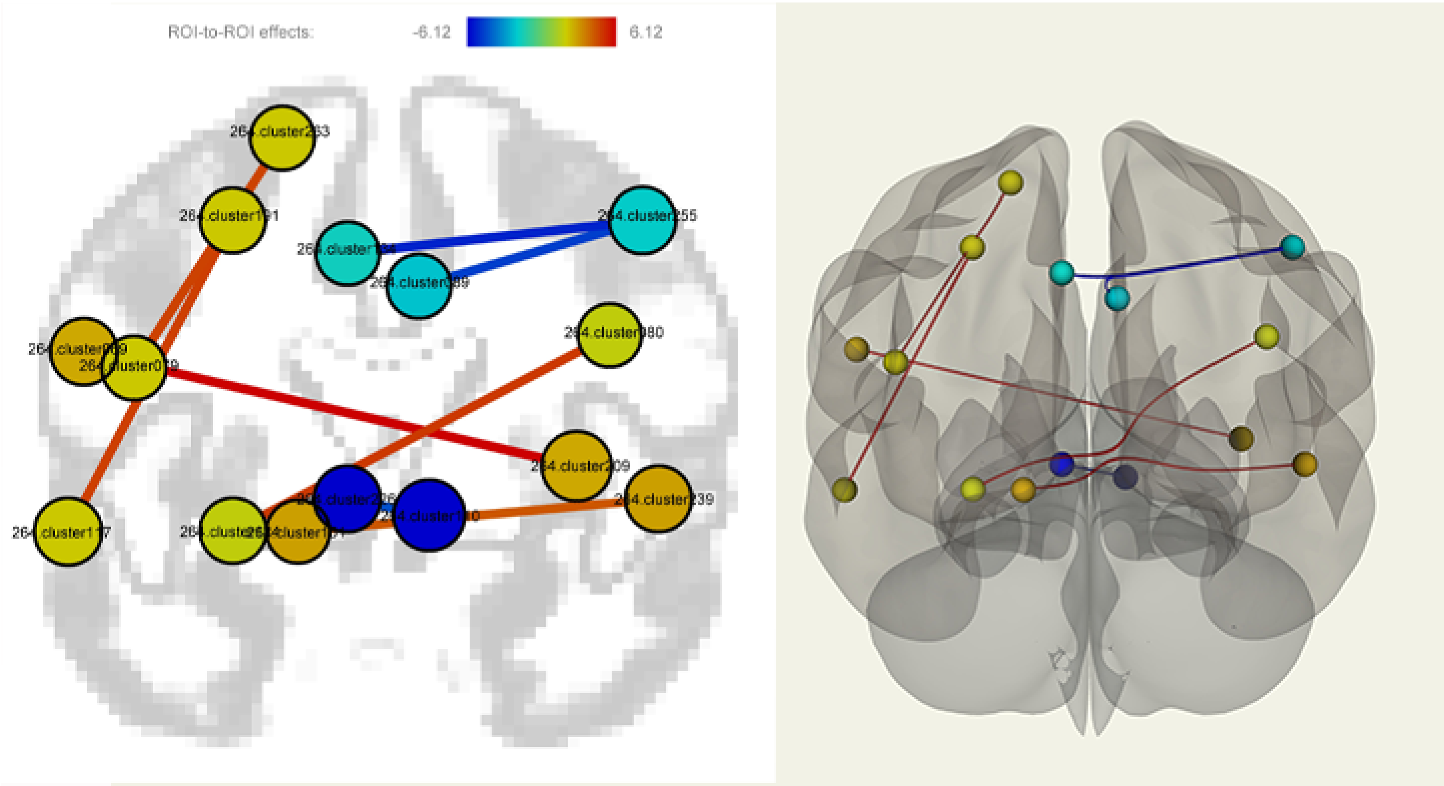

Figure 3

In ROI-to-ROI level, we found three negative connections and four positive connections, supramarginal gyrus (SMG), postcenral gyrus (PCG), lingural gyrus (LG), and temporal gyrus are also included in seed network to whole-brain analysis. The red curve shows positive functional connectivity, The blue curve shows negative functional connectivity.