Exploration of human movement processing in autism spectrum disorder

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Research

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Abstract

Evidence regarding whether people diagnosed with Autism Spectrum Disorder (ASD) show differences in processing human movement is mixed, with recent findings being both in support and in contrast. To provide more clarity, this study utilised inter-subject correlation (ISC) analysis to quantify similarities in human movement processing in fMRI responses to a naturalistic movie paradigm portraying ballet dance between adults with and without ASD. Moreover, similarities within each individuals fMRI responses over repeated viewings were quantified to see if responses were stable and if idiosyncratic patterns could be determined. One group difference found was a cluster in the right posterior cingulate showing significantly lower ISC for the ASD group, corresponding to extensive literature showing atypical activity in the Default Mode Network in ASD. Idiosyncratic brain activation patterns were found only for a subset of ASD individuals, opening up the possibility to subtypes and a possible link to severity in symptoms.

Background

Autism Spectrum Disorder (ASD) results in a broad range of symptoms, including social impairments, atypical sensory processing, and repetitive movements (American Psychiatric Association, 2013). Although the neural underpinnings of ASD are not well understood, widespread atypical processing and network connectivity seem to contribute to these symptoms. As such, atypical processing of human movement is thought to underlie part of the social difficulties in ASD (Kaiser & Pelphrey, 2012; Kaiser & Shiffrar, 2009), since human movements have been shown to transfer social information (Clarke & Vaughan, 2005; Atkinson, Dittrich, Gemmell, & Young, 2004; Pollick, Paterson, Bruderlin, & Sanford, 2001). More support comes from neuroimaging studies showing recruitment of additional brain areas by ASD subjects when processing biological motion (Kaiser & Pelphrey, 2012). A recent meta-analysis of biological motion processing in autism indicates that performance differences between typical and ASD observers are greater in young participants and when the task involves recognition of high level information such as emotion (Todorova, Hatton & Pollick, 2019). Taken together with results of McKay and colleagues (2012) showing differences in the cortical networks used by adults with ASD, this suggest that the study of brain activity while observing biological motion can inform our understanding of the effects of ASD on brain function.

One technique that is finding increasing use to understand brain function at various stages of development is the viewing of brain activity while observing naturalistic stimuli presented as a movie (Vanderwal, Eilbott, & Castellanos, 2019). An established method to analyse brain activity while viewing movies is Inter-subject Correlation (ISC) analysis, a data-driven approach that can characterise brain activity from viewing real-life interactions. It works by quantifying similarities in evoked fMRI responses across individuals (Hasson, 2004), computing pairwise correlation coefficients on a voxel-by-voxel basis across all subjects for the entire stimulus duration (Kauppi, Pajula, Niemi, Hari, & Tohka, 2017). Naturalistic stimuli have been shown to be capable of eliciting reliable neural responses in humans (Hasson, Malach, & Heeger, 2010; Hasson et al., 2008) and even higher test-retest reliability than typically used resting-state paradigms (Wang et al., 2017). Moreover, naturalistic stimuli can be argued to better represent complex real-life dynamics in comparison to static stimuli and tasks probing isolated functions (Salmi et al., 2013; Frith, 2004).

Previous studies exploring ASD have used ISC to investigate brain responses to watching complex social interactions and have found more variability in the brain responses of the ASD groups than in the typically developed (TD) groups (Hasson et al., 2009; Salmi et al., 2013; Byrge, Dubois, Tyszka, Adolphs, & Kennedy, 2015). Furthermore, when comparing responses over repeated viewings within each individual (intra-SC), Hasson et al. (2009) found highly reliable responses whereas Byrge et al. (2015) found these responses to be driven by a subgroup of ASD participants, with the remaining participants showing inconsistent, unreliable responses. These studies investigated complex social narratives using movie clips containing sophisticated video editing designed to capture and direct attention of the viewer (Hasson et al., 2008). Editing itself has been shown to alter ISC (Herbec Kauppi, Jola, Tohka, & Pollick, 2015) and complex social interactions can be expected to recruit brain activity far beyond that resulting from the perception of biological motion. Thus, in the current study we chose unedited solo dance movies to provide a dynamic display suited to investigate brain response to viewing biological motion.

Dance has previously been used in research examining brain mechanisms of human movement perception and action understanding (Christensen & Calvo-Merino, 2013; Bläsing et al., 2012; Reynolds, Jola, & Pollick, 2011; Cross, Hamilton, & Grafton, 2006). For example, research using dance to study action observation revealed the use of both motor representations and visual inference to understand actions of others (Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006). Moreover, dance has been shown to elicit ISC maps (Pollick et al., 2018; Herbec, et al., 2015; Jola et al., 2013; Reason et al., 2016). In particular, a preliminary study (Pollick, Kim & Jang, 2014) examining typical observers and using 90 s segments of either romantic or classical ballet repertoire found evidence that ISC could be obtained in brain regions associated with action understanding.

The current study is exploratory and aims to investigate the feasibility of using ISC analysis of fMRI data obtained while watching brief solo ballet dance videos to illuminate differences with the processing of biological motion in ASD. Additionally, it aims to explore intra-SC in both groups. Based on previous findings using complex, edited movies, the ASD group is expected to show lower ISC overall than the TD group in response to the ballet movies. Moreover, it is expected that within each individual, over repeated viewings, individuals in the ASD group will show idiosyncratic patterns unique to each individual. This is expected to be true for only a subgroup of ASD participants, who are expected to drive more of the variability than others (Byrge et al., 2015).

Method

Participants. A total of twenty-two healthy participants participated in the experiment. The study was conducted with ethical permission from the Greater Glasgow and Clyde National Health Service ethics board. Participants were divided into two groups that were matched on age and Intelligence Quotient (IQ) (full scale Wechsler Abbreviated Scale of Intelligence, Wechsler, 1999), but differed on Autism Quotient (AQ) (Baron-Cohen, Hoekstra, Knickmeyer, & Wheelwright, 2006). All participants divided into the ASD group reported to have a diagnosis of ASD according to DSM-IV criteria from a qualified clinician, which was supported by the AQ. The ASD group consisted of 12 males with an average age of 28.4 (SD = 9.0), an average IQ of 118.33 (SD = 8.7) and an average AQ of 37.8 (SD = 6.7), while the TD group consisted of ten males with an average age of 26.5 (SD = 6.9), an average IQ of 118.6 (SD = 6.83), and an average AQ of 12.8 (SD = 4.6). All participants were right handed, as assessed by the Edinburgh handedness inventory. Written informed consent was obtained from participants before the experiment.

Design. This study used a mixed-design with one dependent variable and two independent variables. The independent between-subjects variable was Autism Quotient (high, low ; for convenience these groups will be referred to as ASD and TD, respectively), the within-subjects factor was the dance movie being shown (Romantic ballet, Classical ballet), and the dependent variable was brain activity of the participants as measured using functional magnetic resonance imaging. Moreover, a repeated measures design was used for the repeated viewings with Autism Quotient (high, low) as the independent between-subjects variable and time (viewing 1, viewing 2) as independent variable.

Stimuli. Participants were shown three dance videos (each 90 seconds long): one Romantic ballet dance video (Giselle's solo dance in Act II of 'Giselle'), one Classical ballet dance video (Odette's solo dance in Act II of 'Swan Lake'), and a repeated viewing of one of the videos in counterbalanced order. All videos were shown at 60 fps, with a 1280 × 720 resolution. Videos were shown without audio in black and white. To control for differences in anything other than human movement, each dance was performed by the same ballerina wearing the same costume in front of the same background. Facial features of the ballerina were blurred out. To avoid bias regarding the type of ballet dance, each video started and ended with the same body posture.

Procedure. Participants were instructed to lie down in the MRI scanner and try to be still while watching the movies as they normally would. First, participants watched the movie clips, and then an anatomical scan was acquired. This procedure had a total duration of fifteen minutes.

Image Acquisition. Data were acquired using a 3T Tim Trio Siemens scanner performing a single functional T2*-weighted acquisition (EPI, TR 2000 ms; TE 30 ms; 32 Slices; 3 mm^3 voxels; FOV of 210, imaging matrix of 70 × 70). The anatomical scan was performed comprising a high-resolution T1-weighted anatomical scan using a 3D magnetization prepared rapid acquisition gradient recalled echo (ADNI-MPRAGE) T1-weighted sequence (192 slices; 1mm^3 isovoxel; Saggital Slice; TR = 1900 ms; TE = 2.52; 256 × 256 image resolution).

The total run of the experiment was 342 seconds, with a total of 90 seconds per dance presentation. At the start of the run, there were 12 seconds of blank screen, however data from the first four seconds (two volumes) were discarded to eliminate possible artefact from the signal not being stable. Between presentations of the different dance movies, there were 16 seconds of blank screen. At the end of the run, there were 28 seconds of blank screen.

Data Pre-processing. The fMRI data were pre-processed in Brain Voyager QX (Version 2.8, Brain Innovation B.V., Maastricht, Netherlands). Pre-processing included 3D Motion Correction with Trilinear/sinc interpolation, slice scan-time correction, linear trend removal, and high-pass filtering with cut-off set to 1 cycle per 90 seconds. Spatial smoothing was applied to the data with a Gaussian kernel of 6 mm FWHM. Functional scans were co-registered to the anatomical data. Using MATLAB, the functional data were trimmed to obtain 45 volumes (90 seconds) for each dance to be used for ISC analysis.

Data Quality Assessment. After pre-processing, the functional data were transformed to Matlab files to undergo a quality assessment using the tools available in the ISC toolbox[1] (Kauppi, Pajula, & Tohka, 2014), as between group ISC analysis has been observed to be very sensitive to fMRI artefacts. As such, it is important to remove subjects whose scans are compromised by such artefacts. These tools do not use group information in any way as to not introduce a bias to the results. Moreover, these tools are not sensitive to local changes as they use averages across the entire brain. First, the time series of each voxel was de-averaged and normalised to the unit variance after which it was averaged over the brain mask. Time series for all participants were visually inspected for data that might be corrupt (indicated by large peaks in the time series). This process is based on our experience in ICA based artefact removal (Tohka et al., 2008), where we successfully used a feature concerning the largest spike in ICA time course to detect within-TR motions. This tool uses normalised time-series as these are closely related to ISC analysis (at a given voxel, ISC between two subjects is an inner product of their time courses). Second, the averaged ISC-metric over the entire brain mask was inspected. ISC averages below 0 indicated differential reaction to the stimulus in comparison to other participants, thus leading to removal from the dataset. For movie stimuli, we expect positive correlations. Negative corelations are not to be expected and are thus indicative of corrupt data. After quality assessment, two subjects from the TD group and two subjects from the ASD were removed due to bad data quality. In order to maintain equal group sizes, which was necessary for the ISC group comparison to run, the data of two additional participants from the ASD group were arbitrarily chosen to not be included in the analysis.

The remaining ASD group consisted of eight males with an average age of 28.5 (SD = 8.1), an average IQ of 118.9 (SD = 6.0), and an average AQ of 38.1 (SD = 6.9), while the TD group consisted of eight males with an average age of 27.5 (SD = 7.4), an average IQ of 119.0 (SD = 7.7), and an average AQ of 12.5 (SD = 5.1).

Inter-subject Correlation Analysis. Inter-subject correlation (ISC) analysis was done following the methods described in previous research (Tohka, Pollick, Pajula, and Kauppi, 2019; Kauppi et al., 2014, 2010; Pajula et al., 2012) using the ISC toolbox[2]. ISC was computed using an unpaired studentised between-group analysis (ASD-TD) for each movie separately and a paired between-movie analysis (Romantic-Classical) for each group separately. Additionally, global signal regression removal was applied in all analyses. Each ISC analysis yielded two types of maps: comparison maps and single maps. ISC analysis yielded correlation coefficients for each voxel, which were then Z-transformed to form a full z-statistic brain map for the comparison between groups and between movies (i.e., comparison maps) and for each group in each condition (i.e., single maps). The single maps were thresholded at q(FDR) = 0.001. Brain maps containing Fischer's z-values were converted to volume maps for visualisation in Brain Voyager using in house MATLAB scripts.

Intra-subject Correlation Analysis. Intra-SC analysis was done to compare brain responses across viewings within each participant using Brain Voyager. GLM analysis was done to create a design matrix fitted to the time course of each voxel for the first viewing, thus, creating a prediction model for each voxel in the second viewing (Goebel, 2017). Analysis yielded a voxel-by-voxel map of beta values that can be directly interpreted as correlation values between the first and second viewing. The individual contrasts resulting from the GLM analysis were combined into one probability map for the ASD and TD group separately. Note that the individual contrasts were not separated by the ballet movie in order to maintain equal groups (n = 8 for ASD and TD). This probability map then represents the probability of brain areas showing ISC to be synchronised amongst individuals belonging to that group. Clusters were then determined using Voxel of Interest (VOI) analysis, ignoring clusters smaller than 108 mm^3. These clusters were arranged according to their synchronisation probabilities into a percentage range (0–10, …, 91–100) and presented as a proportion of the total amount of voxels resulting from VOI analysis.

Statistical Tests of ISC maps. ISCs between groups were compared with a voxel-null permutation test with subject-wise permutations (Tohka, Pollick, Pajula, and Kauppi, 2019). This test provides uncorrected p-values which were transformed into Z-values using p-to-Z transform. FSL's easythresh plugin (Flitney and Jenkinson, 2000) was used for cluster-extent based correction of comparison maps using Gaussian Random Field (GRF) based corrections. In cluster thresholding, statistically significant clusters are detected on the basis of the number of contiguous voxels with values above a predetermined primary threshold (Woo et al., 2014). A cluster defining threshold (CDT) of p = 0.001 was used to calculate FWER at p = 0.05. The between-movie comparison was done separately for each group following the method performed by Herbec et al. (2015). The comparison maps were thresholded with p(FWER) = 0.05 and clusters smaller than 108 mm^3 are not reported.

Results

ISC Single Maps. The results yielded from the single maps for the Romantic ballet movie are shown in Table 1. Figure 1 shows an overlay of the single maps for the two groups for the Romantic ballet movie. The results from the single maps for the Classical ballet movie are shown in Table 2. Figure 2 shows an overlay of the single maps for the two groups for the Classical ballet movie. The single maps for both movies show fewer clusters for the ASD than for the TD group (five in the Romantic and four in the Classical ballet dance for ASD, 12 in the Romantic and five in the Classical ballet dance for TD).

ISC Comparison Maps. For the between-group comparison, cluster thresholding revealed one cluster for the Romantic ballet movie only. This cluster of 567 mm^3 corresponds to the right posterior cingulate (peak Talairach coordinates 4, -42, 25).

Results for the between-movie comparison are shown in Table 3 and the location of the clusters for the ASD and TD group are shown in Fig. 3 and Fig. 4, respectively. In the ASD group three clusters remained after ignoring clusters smaller than 108 mm^3, all showing higher correlations for the Romantic ballet movie than for the Classical ballet movie. In the TD group, six clusters remained. Two clusters showed higher ISC in the Classical ballet movie while the other four showed higher ISC in the Romantic ballet movie.

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Insert Fig. 1 about here

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Table 1

Clusters from the single maps for the ASD and TD group for the Romantic ballet movie. Peak statistics reported in this table are correlation values.

Anatomical region	Structure	Hemi-sphere	Talairach – Coordinate (x,y,z)	Number of Voxels	Peak Statistic	BA
Romantic ASD						
Temporal Temporal	Superior Temporal Gyrus Superior Temporal Gyrus	Right Right	(53, -40, 13) (48, -43, 11)	245 110	0.193 0.179	22 22
Temporal Parietal Parietal	Middle Temporal Gyrus Superior Parietal Lobule Precuneus	Left Right Right	(-48, -64, 4) (18, -55, 58) (20, -67, 43)	64522 3458 133	0.468 0.275 0.195	37 7 7
Romantic TD						
Parietal	Postcentral Gyrus	Right	(53, -28, 43)	213	0.219	2
Sub-Lobar	Insula	Right	(54, -31, 19)	330	0.239	13
Occipital	Middle Occipital Gyrus	Left	(-45, -73, -2)	71464	0.530	19
Frontal	Precentral Gyrus	Right	(42, 5, 37)	658	0.219	9
Parietal	Precuneus	Right	(39, -70, 40)	1095	0.235	19
Frontal Temporal Parietal Frontal Limbic Parietal Sub-Lobar	Middle Frontal Gyrus Fusiform Gyrus Precuneus Middle Frontal Gyrus Cingulate Gyrus Superior Parietal Lobule Insula	Right Right Right Right Left Left Left	(33, -2, 58) (35, -46, -14) (18, -58, 58) (24, -13, 52) (0, -25, 28) (-27, -52, 61) (-45, -37, 19)	246 209 6986 403 479 2412 108	0.227 0.242 0.428 0.251 0.226 0.285 0.194	6 37 7 6 23 7 13

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Insert Fig. 2 about here

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Table 2

Clusters from the single maps for the ASD and TD group for the Classical ballet movie. Peak statistics reported in this table are correlation values.

Anatomical region	Structure	Hemi-sphere	Talairach – Coordinate (x,y,z)	Number of Voxels	Peak Statistic	BA
Classical ASD						
Occipital Posterior	Inferior Temporal Gyrus Declive	Right Right	(45, -67, -2) (28, -55, -11)	57520 131	0.518 0.175	37
Limbic Parietal	Parahippocampal Gyrus Precuneus	Right Left	(21, -40, -8) (-36, -77, 34)	157 417	0.188 0.210	36 19
Classical TD						
Occipital Parietal	Lingual Gyrus Superior Parietal Lobule	Right Right	(6, -73, 7) (15, -57, 61)	47932 203	0.500 0.213	18 7
Parietal Temporal Parietal	Superior Parietal Lobule Inferior Temporal Gyrus Inferior Parietal Lobule	Left Left Left	(-23, -61, 55) (-48, -73, -2) (-47, -34, 37)	127 2606 163	0.205 0.383 0.210	7 19 40

Table 3
Clusters from the comparison map between the Romantic ballet movie and the Classical ballet movie. Peak statistics reported in this table are correlation values. Brodmann's Area is abbreviated to BA.

Anatomical region	Structure	Hemi-sphere	Talairach – Coordinate (x,y,z)	Number of Voxels	Peak Statistic	BA
ASD Between Movies						
Parietal Anterior	Sub-Gyral Culmen	Right Right	(24, -46, 55) (9, -49, -2)	890 125	42.440 39.050	7
Temporal	Middle Temporal Gyrus	Left	(-48, -64, 7)	186	39.470	37
TD Between Movies						
Temporal Parietal	Middle Temporal Gyrus Superior Parietal Lobule	Right Right	(45, -61, -2) (27, -55, 58)	137 618	37.747 42.870	37 7
Occipital	Cuneus	Right	(18, -91, 19)	121	-36.193	18
Occipital	Cuneus	Right	(3, -73, 25)	1296	44.070	18
Occipital	Cuneus	Right	(3, -73, 7)	680	-44.316	30
Limbic	Parahippocampal Gyrus	Left	(-15, -43, 1)	956	45.894	30

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Insert Fig. 3 about here

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Insert Fig. 4 about here

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Intra-SC. The intra-SC between repeated viewings resulted in 112 clusters for the ASD and 84 clusters for the TD group after ignoring clusters smaller than 108 mm^3. Results of the probability of a voxel being found in an individual's Intra-SC map are shown in Table 4, Fig. 5, and Fig. 6. Note that in Fig. 6, visualisation of z-slices for the TD group differs slightly from those for the ASD group in order to correctly visualise the area containing voxels at 100 percent probability. Overall, the ASD group showed a more dispersed pattern of Intra- when compared to the TD group.

Table 4
The percentage of voxels in each group at different levels of probability.

Probability of Intra-SC voxel	100	90	80	70	60	50	40	30	20	10
ASD	0.000	0.000	47.074	0.000	34.161	0.000	3.736	8.077	6.952	0.000
TD	53.148	0.000	0.000	0.000	22.930	0.000	7.819	4.911	11.191	0.000

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Insert Fig. 5 about here

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Insert Fig. 6 about here

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Discussion

The present study aimed to explore the potential use of ISC analysis of fMRI data and

ballet dance videos to characterise differences in Autism Spectrum Disorder in regard to biological motion processing. Three comparisons were made: between groups (ASD, TD), between dance videos (Classical, Romantic), and between repeated viewings (within-subject).

For the between-group comparison, we expected to find less synchronisation amongst ASD participants than amongst TD participants. This was expected to be reflected in lower ISC for the ASD group than for the TD group. The two groups differed only for the Romantic ballet movie in one cluster spanning the posterior cingulate. This area indeed showed lower ISC in the ASD group, indicating less synchronisation amongst ASD participants than amongst TD participants while watching the Romantic ballet. This finding suggests that ISC analysis of fMRI data while watching ballet dance movies might be a feasible way of extracting differences between people with and without ASD.

Possible interpretations of this finding relate to broader findings of atypical functioning/activation of the Default Mode Network (DMN) in ASD groups. The posterior cingulate has been identified as a key node in the DMN, and is suggested to act as a cortical hub Leech & Sharp, 2013; Greicius, Krasnow, Reiss, & Menon, 2003) that is involved in multiple functional networks (van den Heuvel & Sporns, 2013). Previous studies have discussed the involvement of hub areas in watching dance (Pollick et al., 2018). Furthermore, recent work has shown engagement of the DMN in social tasks (Mars et al., 2012; Schilbach, Eickhoff, Rotarska-Jagiela, Fink, & Vogeley, 2008) and lower ISC in the DMN in autism while watching complex social interactions (Salmi et al., 2013). A possible reason for the finding of lower synchronisation in this area might lie in variability, with several studies finding greater inter-individual variability in ASD groups in network connectivity (Nunes, Peatfield, Vakorin, & Doesburg, 2019), watching social interactions (Hasson et al., 2009; Byrge et al., 2015), and coherent motion thresholds (Koldewyn, Whitney, & Rivera, 2011). What is more, a growing body of work discusses atypical functioning within the DMN in ASD subjects (Washington et al., 2014; Assaf et al., 2010; Monk et al., 2009; Weng et al., 2010), with some linking resting-state hyperconnectivity of the posterior cingulate to the severity of social impairments in ASD (Lynch et al., 2013) and others linking lower functional connectivity of the posterior cingulate to the severity of autistic traits (Yerys et al., 2015; Jung et al., 2014).

Furthermore, previous research by McKay et al. (2012) found that adults diagnosed with ASD use two distinct networks for biological motion processing, differing from the one network utilised by TDs. The ISC single maps for the Romantic ballet movie correspond to this notion, showing highly synchronised areas for the TD group corresponding to the regions found by McKay et al. (2012), but not for the ASD group. Some of these highly synchronised areas, Middle Occipital Gyrus and Fusiform Gyrus, are known to be involved in biological motion processing (Freitag et al., 2008; Peelen & Downing, 2005; Peelen, Wiggett, & Downing, 2006). Others, such as Precuneus, Middle Frontal Gyrus (MFG), are known to respond to stimuli containing configural information (Downing, Peelen, Wiggett, & Tew, 2006; Saygin, Wilson, Hagler, Bates, & Sereno, 2004; Vaina, Solomon, Chowdhury, Sinha, Belliveau, 2001). Other highly synchronised areas like the Superior Parietal Lobule (SPL) are implicated in the human MNS (Grafton, Arbib, Fadiga, & Rizzolatti, 1996; Grèzes et al., 1998; Iacaboni et al., 1999; Lestou, Pollick, & Kourtzi, 2008). Single maps for the Classical ballet movie show a similar pattern, although to a lesser extent. For the ASD group, McKay et al. (2012) found that biological motion information was not passed on to parietal regions, but stayed in temporal regions (also see Koldewyn et al., 2011). Our single maps for the ASD group for the Romantic ballet movie display high synchronisation in a large number of voxels in the temporal lobe. Other clusters, however, also showed high synchronisation in parietal areas, such as the SPL. These regions have been implicated in the MNS and Theory of Mind (Rajmohan & Mohandas, 2007), systems that are suspected to dysfunction in ASD (Ramachandran & Oberman, 2008; Dapretto et al., 2005; Oberman & Ramachandran, 2015). Moreover, temporal lobe disruptions would affect the MNS, with recent work suggesting a delay in the progression of MNS activity within temporal regions in ASD (Oberman & Ramachandran, 2008). A possible reason why this was not found in the current study is that this delay would not show up in ISC analysis, as ISC is averaged across the entire time course series.

For the comparison over repeated viewings, we expected to find more idiosyncratic patterns for individuals belonging to the ASD group than for those belonging to the TD group. Although the Intra-SC analysis revealed consistent idiosyncratic patterns for all participants, individuals in the ASD group showed a more disperse pattern of Intra-SC in brain areas. This is apparent in the total amount of clusters showing ISC in each group (112 clusters in the ASD group, 84 clusters in the TD group). The probability maps, showing the probability of a voxel appearing in a participant's individual Intra-SC-map, were consistent with informal examination of individual participants that showed more variability and more dispersed patterns of Intra-SC amongst ASD individuals than amongst TD individuals. Connecting these findings to the between-group findings, the lower overall synchronisation for the ASD group might lie in the greater inter-individual variability within the ASD group. This finding would be consistent with other studies reporting greater inter-individual variability in ASD groups, such as network connectivity (Nunes et al., 2019), watching social interactions (Hasson et al., 2009; Byrge et al., 2015), and in coherent motion thresholds (Koldewyn et al., 2011). What is more, idiosyncratic patterns were found for only a subset of individuals in the ASD group– some participants showed more widespread and unique patterns in brain activity for repeated viewings while others showed no deviations from group-level brain activity. This is consistent with findings by Byrge et al. (2015), who found that variability within the ASD group was driven by a subset of participants while other participants did not deviate from group activity.

These idiosyncratic patterns may elucidate the variability in symptoms amongst individuals with ASD. Furthermore, the finding that only a subset of ASD participants showed idiosyncratic patterns supports the potential for sub-typing within the spectrum. Moreover, this highlights the informational value of investigating individual differences (Koldewyn et al., 2011; Byrge et al., 2015), as idiosyncrasy in responses have been linked to behavioural symptoms in ASD (Hahamy, Behrmann, & Malach, 2015; Byrge et al., 2015; Salmi et al., 2013). In addition, Dinstein et al. (2012) suggest a possible role of unreliable responses in the unpredictable perception of the environment, which over the course of development may contribute to the behavioural consequences experienced later in life.

In conclusion, this study shows support for the possibility of using ISC in fMRI data obtained and the use of dance videos to study differences in the processing of biological motion in autism. The use of a more entertaining form of naturalistic stimuli to study differences in groups that are difficult to study using neuroimaging could help in making the process more efficient and easier for both participant and researcher.

Some trends in the data suggests that some types of dance are better suited to extract these differences than others. For the ASD group, a comparison between the movies showed higher ISC in the Romantic ballet movie than in the Classical ballet movie for three clusters. For the TD group, two clusters showed higher ISC in the Classical ballet movie while four showed higher ISC in the Romantic ballet movie. These results replicate previous findings suggesting selective activation for the two movies in TD groups (Pollick, Kim, & Jang, 2014) and additionally generalise these findings to ASD groups.

The differential activation for the two movies seems to follow the model of biological movement recognition by Giese (2004), which proposes that the ventral pathway is selective for sequences of body configurations whereas the dorsal pathway is selective for complex optic flow patterns. The two dances used in the current study conform to this selectiveness, with the Classical ballet focusing more on form and body position and the Romantic ballet focusing more on motion and emotion (Pollick et al., 2014; Clarke & Vaughan, 1977). However, results found in the current study show more support for this distinction in the dorsal pathway than for the ventral pathway, thus remaining inconclusive about this model.

Interestingly, selective activation for the two movies seems to be apparent even on individual-level. More robust idiosyncratic patterns for the ASD group were found for the Romantic ballet movie, whereas those for the TD group were found for the Classical ballet movie. Another interesting finding is that some areas that are not uniquely correlated for either group, still seem to show selective activation for the two movies. For example, the Inferior Frontal Gyrus, MFG, and Superior Frontal Gyrus appear equally in each individual participant’s Intra-SC map. In the ASD group, however, these areas are more synchronised for the Romantic ballet movie, whereas in the TD group these areas are more synchronised for the Classical ballet movie.

Limitations

The main limitation in this study is sample size. More robust results might be found with a larger sample size. Moreover, the unedited nature of the stimuli used in this study might account for variations between previous studies using ISC to investigate ASD processing. Studies such as Hasson et al. (2009), Salmi et al. (2013), and Byrge et al. (2015) used highly edited videos showing complex social interactions. The editing in these videos is designed to capture and direct attention, for example using cuts and changing of scenes– something which is absent in real-life situations. Previous studies have shown differences in ISC when using edited or unedited stimuli, wherein the areas of ISC were found to be more extended and robust for edited movies than for unedited movies (Herbec et al., 2015; Hasson et al., 2008). Lastly, Bolton, Jochaut, Giraud, & Van de Ville (2018) found that idiosyncrasy in ASD responses is specific to short-lived episodes of long-range functional interplays. As ISC was averaged across the time series of the entire movie, this might explain the less robust findings of the current study.

Conclusion

This study aimed to explore differences in human movement processing between autistic participants and typically developed participants, both on group level and on individual level. Between-group results showed less synchronisation of the posterior cingulate in the autism group than in the typically developed group. Intra-SC results showed more disperse idiosyncratic patterns for individuals belonging to the autism group than for those belonging to the typically developed group. In addition, only a subset of participants in the ASD group showed idiosyncratic patterns. Although no obvious pattern was found, selective activation for the two movies was found both on group-level and on individual-level.

Taken together, these results contribute to our understanding of the mechanisms underlying both social and motor impairments experienced in Autism Spectrum Disorder. Furthermore, these results guide future research in the use of dance video for extracting group differences or for possible diagnostic use. For example, future research might focus on choreographing a specific type of dance that is able to extract differences that are characteristic to individuals with ASD.

Abbreviations

ASD
Autism Spectrum Disorder; AQ:Autism Quotient; DMN:Default Mode Network ;fMRI:Functional Magnetic Resonance Imaging; Intra-SC:Intra-subject Correlation; ISC:Inter-subject Correlation; IQ:Intelligent Quotient; MFG:Middle Frontal Gyrus; MNS:Mirror Neuron System; MRI:Magnetic Resonance Imaging; SPL:Superior Parietal Lobule; TD:Typically Developed.

Declarations

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Author's Contributions

DN performed the statistical analysis, helped in interpretation of the output and drafted the manuscript. PR participated in the data collection. NK and SJ participated in the conception of the study and its design and coordination and provided stimulus material. JT and J-PK participated in the statistical analysis and provided critical advice regarding the analysis. FEP conceived the study, participated in its design, coordination, and study evaluations, provided critical advice regarding the interpretation of the results, and participated in the drafting of the manuscript.

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Availability of data and materials

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

Ethics approval

The study was conducted with ethical permission from the Greater Glasgow and Clyde National Health Service ethics board.

Consent for publication

Written consent has been obtained from participants.

Competing interests

The authors declare that they have no competing interests.

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Figures

Figure 1

Overlay of the single maps for the ASD and TD group for the Romantic ballet movie. Red represents ISC in the ASD group, and yellow represents ISC in the TD group. Note that orange indicates overlap between the two maps.

Figure 2

Overlay of the single maps for the ASD and TD group for the Classical ballet movie. Red represents ISC in the ASD group, and yellow represents ISC in the TD group. Note that orange indicates overlap between the two maps.

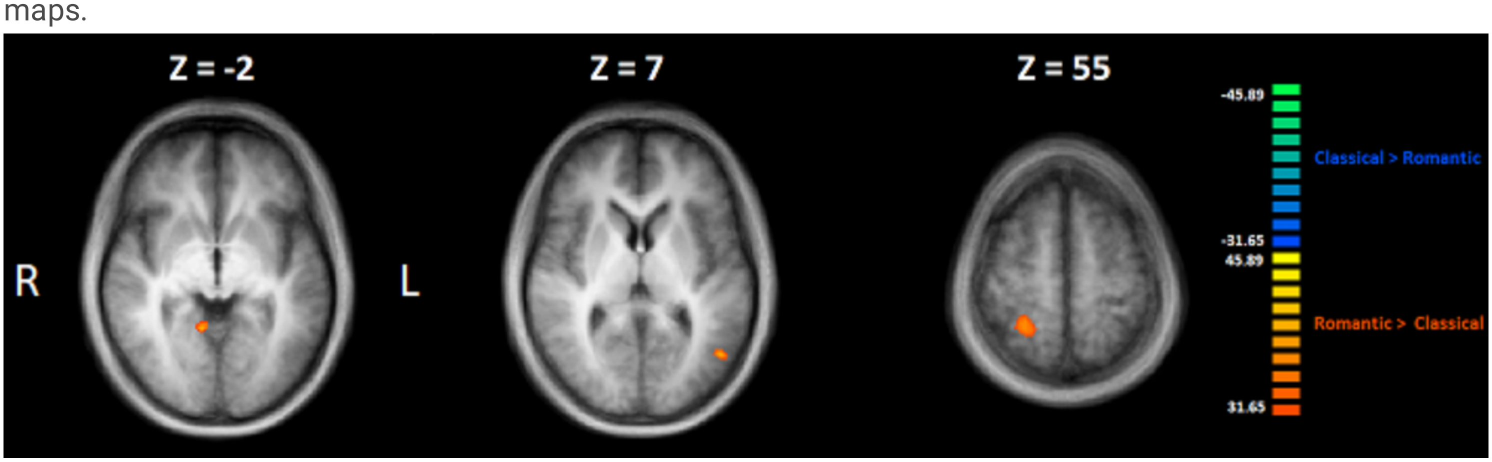

Figure 3

The location of the three clusters from the between-movie comparison for the ASD group.

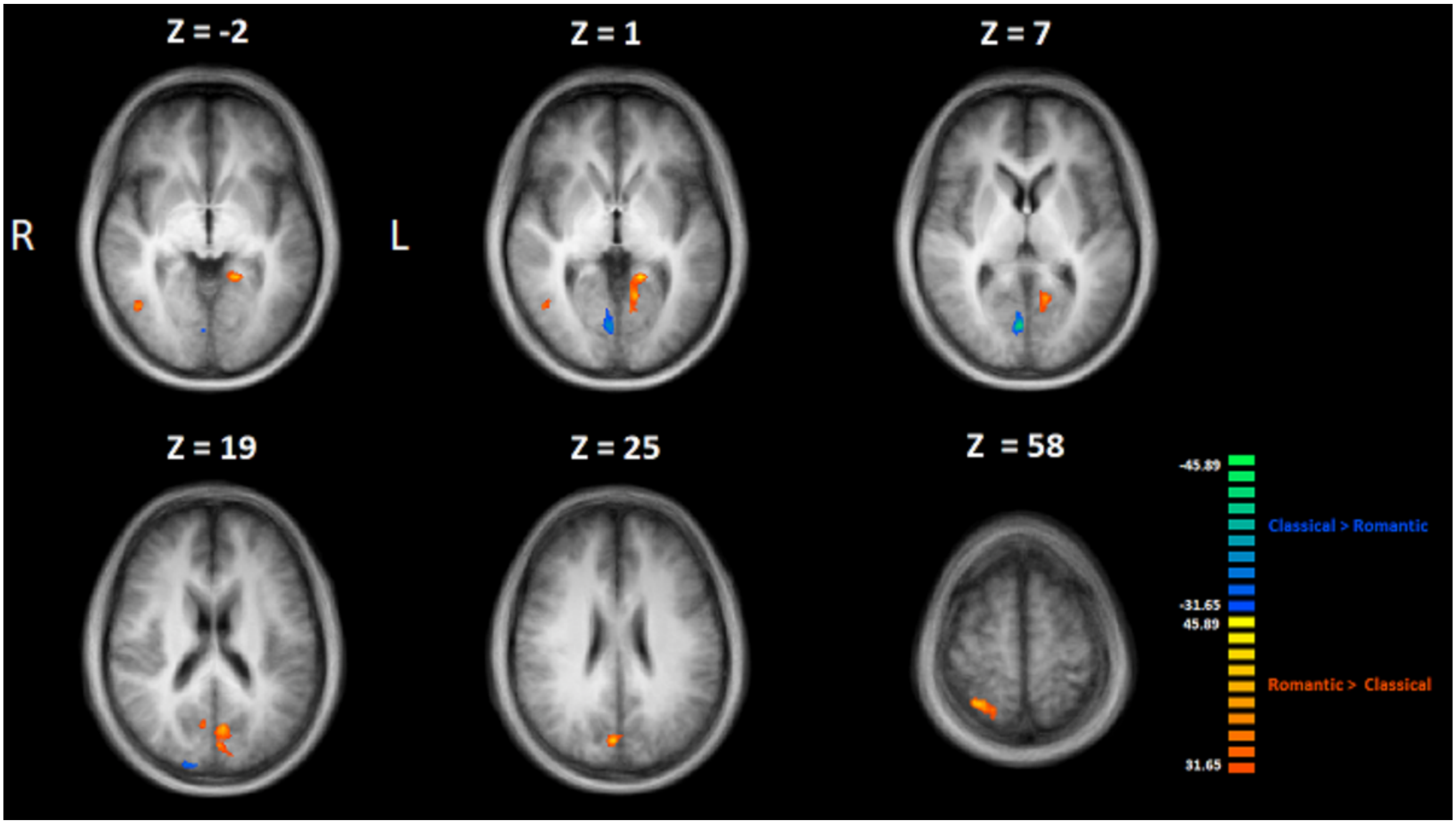

Figure 4

The location of the six clusters from the between-movie comparison for the TD group.

Figure 5

The probability maps of voxels appearing in a participant’s Intra-SC map for the ASD group.

Figure 6

The probability maps of voxels appearing in a participant’s Intra-SC map for the TD group.

Supplementary Files

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