Advances in Autism

Same music, different emotions: assessing emotions and EEG correlates of music perception in children with ASD and typically developing peers

Galina Portnova, Alexandra Maslennikova, Anton Varlamov,

Same music, different emotions: assessing emotions and EEG correlates of music perception in children with ASD and typically developing peers

Galina Portnova, Alexandra Maslennikova and Anton Varlamov

Abstract

Purpose – *The purpose of this paper is to assess emotional response to music and its EEG correlates in children with autism spectrum disorders (ASD).*

Design/methodology/approach – *Six musical fragments eliciting emotional states of calmness/serenity, sadness and anxiety/fear were presented to children with ASD (n = 21, aged 5–9) and typically developing (TD) peers (n = 21), while 19-channel EEG was recorded. Emotion self-reports were assessed using visual analogous scales.*

Findings – *Children with ASD assessed most music fragments similarly to their TD peers, with likelihood of EEG oscillatory patterns closely corresponding to emotion self-reports. Somewhat contrary to the expectations, a major difference was observed for one fragment only, which was identified as sad by TD children and adult neurotypical raters, but found "angry and frightening" by children with ASD, with EEG oscillatory response confirming greater cortical activation, particularly for the right hemisphere.*

Research limitations/implications – *The data suggest that children with ASD may have emotional reactions to music either similar or highly aberrant compared to TD peers, rather than having general difficulties in assessing emotions. The data should be confirmed by further studies, ideally involving high functioning adult autists.*

Practical implications – *The findings may increase the understanding of autists' difficulties in perceiving prosodic nuances and reading emotional cues. The results can be taken into consideration when developing music-based interventions.*

Originality/value – *The findings show that music may be perceived by children with ASD in a unique way, which may be difficult to predict by neurotypical raters.*

Keywords *Autism, Emotion perception, Empathy, EEG, Autism spectrum disorder, Music perception*

Paper type *Research paper*

Galina Portnova is based at the Institut Vyssej Nervnoj Deatel'nosti i Nejrofiziologii RAN, Moscow, Russian Federation and the Pushkin State Russian Language Institute, Moscow, Russian Federation.
Alexandra Maslennikova is based at the Institut Vyssej Nervnoj Deatel'nosti i Nejrofiziologii RAN, Moscow, Russian Federation.
Anton Varlamov is based at the Institute of Higher Nervous Activity and Neurophysiology of RAS and the Pushkin State Russian Language Institute, Moscow, Russian Federation.

Received 6 January 2018
Revised 9 March 2018
Accepted 1 May 2018

The authors would like to thank Mikhail Atanov and Olga Kashevarova for their input into EEG signal analysis, Ksenia Gladun for assistance during EEG recordings and clinical assessment of EEG, Valeria Gusarova and Evgenia Mironova for assisting with EEG data and psychometric data collection, and the team of NGO Psychological Center "Equalize" and, in particular, its Director Elena Filimonova for making this research possible. This study was supported by Grant from the Russian fund of fundamental research No. 16-04-00092 and the Russian Academy of Sciences.

Introduction

Many people with autism spectrum disorders (ASD) do not manifest emotions in ways other people would recognize them and, even more commonly, have difficulties in recognizing emotions in others (Brewer *et al.*, 2016). Several studies show that children with ASD have impaired ability to read social and emotional cues from faces and voices (Downs and Smith, 2004; Gross, 2004). However, these difficulties may be more or less pronounced, and some individuals with ASD may cope successfully with emotion recognition tasks (Castelli, 2005). Another study revealed that children with Asperger syndrome recognized facial and vocal emotions with accuracy similar to their neurotypical peers, whereas children with high-functioning autism performed significantly worse (Mazefsky and Oswald, 2007). The degree of emotion recognition impairments may vary along autism spectrum (Loveland, 2005) but problems with reading subtler emotional cues from other people's speech seems to be an essential feature of ASD stemming from a lack of cognitive empathy (Baron-Cohen, 1995).

Perception of emotions in music can also be impaired in adults and children with ASD. It has been shown that individuals with ASD are less successful in capturing emotional features of music than neurotypical controls and individuals with Williams syndrome, and this impairment was not related to the IQ level of children (Bhatara *et al.*, 2010). On the other hand, a body of literature demonstrates that some individuals with ASD are able to identify the emotional intent of short musical passages (Heaton *et al.*, 1999; Brown, 2016) and long compositions (Heaton *et al.*, 2008), and even more, find pleasure in listening to music, often at a level of a special interest (Darrow and Armstrong, 1999). Despite possible difficulties in perception of nonverbal emotional vocalizations and in capturing affective component of music, many people with ASD are musically gifted, and some successfully perform as professional musicians. Greenberg *et al.* (2015) suggested that this particular feature of autistic personality can be explained within a framework of the Empathizing–Systemizing theory: individuals high in empathizing better deal with emotional aspects of music while individuals high in systemizing can better assess technical aspects of music and can successfully express subtle dynamic nuances of a musical piece. Though individuals with Asperger syndrome were shown to be less accurate at identifying emotions in music than neurotypical peers, they may be more effective in assessing "sonic" or physical parameters of music. Indeed, individuals with ASD have higher accuracy in pitch perception (Miller, 1999), and greater ability to remember and identify pitches (Miller, 1999; Heaton *et al.*, 1998).

There is a plenty of evidence that listening to music and musical training can increase empathy (Rabinowitch *et al.*, 2013) and prosocial behavior (Greitemeyer, 2009; Kirschner and Tomasello, 2010), and that music-based intervention can lead to both short-term and long-term benefits in individuals with ASD (Boso *et al.*, 2007). One would presume that the effect of such intervention would be greater in childhood, further, this therapy would benefit from better understanding of musical preferences of children with ASD and from insights on the nature of emotion perception of music. Unfortunately, the literature in this area is very limited. In this paper, we present a pilot study assessing emotional reaction to different music in children with ASD and in their typically developing (TD) peers. We examined participants' emotional self-reports and EEG correlates of music and emotion processing. It has been shown that perception of music eliciting emotions of joy and happiness varies more at an individual level than perception of negative emotions (Weinberg and Joseph, 2017); for this reason, we used a set of six musical fragments known to elicit emotional states of calmness/serenity, sadness and anxiety/fear, two fragments per emotion. We hypothesized that pairs of musical fragments would yield similar emotional profiles and EEG activation patterns in TD children, while in children with ASD less consistent emotion scores or flattening of emotional profiles may occur and this would correlate with changes in EEG oscillatory patterns.

Methods

Participants

In total, 21 children with ASD (ASD group, 5–9 years old, average age 6.28 years, SD $=1.9$, 14 males, 7 females) and 21 typically developing children (TD group, 5–9 years old, average age 6.57 years, SD $=2.0$, 15 males, 6 females) were recruited for the study. ASD was diagnosed according to ICD-10 criteria; all the children in ASD group were diagnosed with autistic disorder (F84.0). Autism severity was assessed with Childhood Autism Rating Scale (CARS) (Schopler *et al.*, 1980); average score in ASD group was 19.6, SD $=5.9$. None of the participants had epilepsy or epileptiform EEG activity. The neuropsychological tests as well asthe Wechsler Intelligence Scales for Children, fourth edition (WISC-IV) (Petermann and Petermann, 2011), were used for determination of intellectual disability. After calculating both the Full Scale IQ and General Ability Index for each participant, we rejected participants with intellectual impairment (score $\leqslant 70$ in at least one scale). Mean WISC scores did not differ significantly between the groups (TD group: 105.1±8.74; ASD group: 101.9±12.1).

Ethic statement

The study has been approved by the Research Ethics Committee of XXX (institution name removed due to anonymity requirements). For each participant, a parent signed an informed consent to approve participation in this study.

EEG registration

During the EEG recording the participants sat in a comfortable position in an armchair in an acoustically and electrically shielded chamber. The participants were instructed to remain calm and listen to music. Brain electrical activity was recorded using a 19-channel EEG recording system "Encephalan" (Medicom MTD, Taganrog, Russian Federation). The bandpass filter during the acquisition was set to 1.6–30 Hz, the sampling rate was 250 Hz. Ag/AgCl electrodes were placed according to the International 10–20 system (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, O2). All the electrodes were referenced to joint mastoid reference. The vertical electrooculogram (EOG) was measured with Ag/AgCl cup electrodes placed 1 cm above and below the left eye, and the horizontal EOG was measured with electrodes placed 1 cm lateral from the outer canthi of both eyes. Electrode impedance was maintained at less than 10 kΩ.

Stimuli and experimental procedure

Six musical fragments were presented to each participant. All the chosen fragments were in the standard 12-tone system. The fragments were selected from a list of 20 musical fragments previously rated by adults ($n = 78$, age $M = 26.2$, SD $= 2.8$), 38 of them had musical education, and 40 had no musical education. The raters assessed emotional characteristics of these 20 fragments using four scales: happiness vs sadness, calmness vs high arousal, no anxiety/fear vs high anxiety/fear and slow vs fast. Stimuli with clearest emotional profiles (high score for target emotion, low or neutral scores for other emotions and low SD by each scale) were selected for the study. The musical fragments are referenced further as sad (S1, S2), calm (C1, C2) and fearful (F1, F2). All the fragments were purely instrumental pieces, their basic musical features are provided in Table I.

Musical fragments were presented to participants via earphones while EEG was recorded. The volume levels of all the fragments were set so that the peak volume should not exceed 85 dB; average volume of the fragments was between 58 and 70 dB. Three minutes of eyes-opened rest baseline condition were recorded prior to presenting musical fragments. Each fragment was 50 seconds long and was presented 3 times, the stimuli were presented in a random order with 5 second pauses between the fragments. All the participants were able to tolerate experimental procedures well and yielded behavioral responses to different types of music. After EEG recording and a brief rest all the participants were presented the musical fragments again in order to get the ratings for the self-report.

The participants evaluated the stimuli after the experiment using three paper and pencil visual analogue scales, digitalized afterwards: sad vs happy (21-point scale, −10 to 10), slow vs fast (21-point scale, −10 to 10) and anxiety/fear intensity (11-point scale, 0 to 10). For each of the two emotion scales a pair of faces was depicted: sad vs happy and neutral vs fearful. For slow/fast scale a snail and a cheetah were depicted. The assessment was supervised by a clinical psychologist and an occupational therapist. The supervisors presented instructions to children, explained how to work with the scales, and discussed the meaning of words describing emotions. The participants also provided oral self-reports in an arbitrary form, their speech was recorded by the psychologist. These data were collected for all of the 21 participants from TD group and for 14 participants from ASD group.

Table I Musical fragments and their main characteristics

	Musical fragments	*Tempo/key*	*Emotion*
S1	K.Gluck Melody from the opera "Orpheus and Eurydice"	Slow 58/minor	Sadness
S2	Chopin. Prelude in E-minor (op.28 no. 4)	Slow 44/minor	Sadness
C1	Kenny G. Songbird	Slow 62/major	Calmness
C2	Guru Sax People Can't Stop Chillin	Slow 60/major	Calmness
F1	Javier Navarette. Asturias	Fast 80/minor	Fear
F2	Soundtrack of a horror film. Unknown author	Fast 84/minor	Fear

Data analysis

EEG analysis. EEG epochs for three runs for each fragment were concatenated. Eye movements artifacts were removed using EOG channels in the Encephalan software (linear regression algorithm) or ICA-based algorithm for three participants with faulty EOG. Small intervals affected by muscle activity were rejected manually using visual inspection, with the resulting average artifact-free epoch length of about 150-200 seconds (at least 120 s for each stimulus for each participant). All the following processing was performed using EEGLab 10.0 (Delorme and Makeig, 2004) plugin for MatLab 7.0 (Mathwork Inc., Natick, USA).

For EEG analysis, we have used classical spectral analysis using Fast Fourier Transform (FFT), fractal dimension (FD) as a measure of nonlinear complexity of a signal, and EEG cognitive space mapping method initially developed by Roik and Ivanitskii (2013) enabling assessment of general likelihood of EEG oscillatory patterns for different cognitive tasks or different stimulus conditions.

Spectral analysis. FFT was used to analyze the power spectral density (PSD), i.e. to assess magnitudes of different EEG oscillatory bands. The spectra were estimated for each long epoch and were integrated over the intervals of unit width in the band of interest (2–3 Hz, 3–4 Hz, …, 19–20 Hz).

Fractal dimension. FD of EEG is a measure of nonlinear complexity of a signal and is among most commonly used measures of EEG nonlinearity; this method has also shown its effectiveness in discriminating emotions (Sourina and Liu, 2011). Before assessing FD, the signal was filtered in the wide band of interest (2–20 Hz). Filtering was conducted using forward FFT, zeroing some samples and then reverse FFT. FD was assessed using Higuchi (1988) algorithm.

EEG cognitive space mapping. To assess overall similarity of EEG oscillatory patterns the “cognitive space” approach was used, initially suggested by Roik and Ivanitskii (2013). This approach greatly facilitates qualitative assessment of similarity of EEG spectra by visualizing in a two-dimensional space how close/distant are oscillatory patterns for several experimental conditions for each participant and averaged across groups. The method consists of the following steps:

1. EEG of each long epoch is divided into non-overlapping small epochs of 16 seconds (resulting in about ten epochs).
2. FFT (absolute value) is calculated for the epochs (resulting in ~1/16 Hz resolution). Further processing is conducted in the band of interest 2–20 Hz.
3. The distance between each pair of musical fragments is calculated: for each frequency bin two samples of FFT values (of the epochs of these musical fragments) were compared using Mann-Whitney U-test (threshold $p < 0.05$). The distance is equal to the percentage of differing frequency bins.
4. Musical fragments are placed onto a plane using Sammon projection (Sammon, 1969), so the distances between them on the plane are as similar as possible to the distances calculated by FFT values.
5. The resulting pictures (obtained for each participant) have arbitrary rotation because of Sammon projection algorithm and different sizes because of high individuality of EEG. Before the averaging over group these pictures should be standardized. We used scaling to equalize the size (the sum of squared distances to the stimuli icons from the “center of mass”) and rotation/reflection so that S1 icon was on the top of the picture, F2 and C2 on a horizontal line on the left and right sides correspondingly. These three stimuli were chosen because they showed maximum distances between each other.
6. After standardization individual pictures are averaged over groups. So, these pictures show relational distances between musical fragments based on how much the corresponding EEG data differ in terms of rhythms’ magnitudes.

Statistical analysis

Subjective ratings were assessed with three-factor repeated measures ANOVA (Group 2× Experimental condition 6× Emotion 3). Repeated measures ANOVA with Bonferroni correction for multiple comparison, $p < 0.05$, were performed to determine group effects on EEG metrics. Correlation between EEG parameters and autism severity was calculated by Spearmen ($p < 0.05$). Mann-Whitney U-tests ($p < 0.05$) were performed to determine group effects on EEG differences between conditions (musical fragments and background) in each electrode.

Results

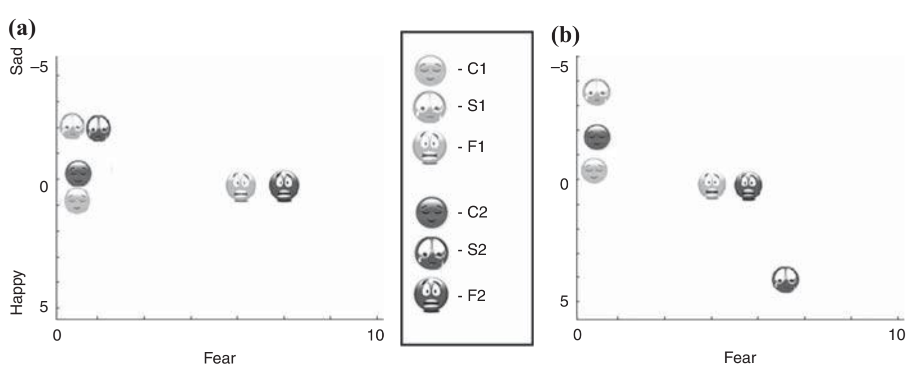
Emotional response to music (self-report data)

The results of participants' self-report on their reaction to music fragments are shown in Table II and Figure 1. The repeated measures ANOVA yielded a highly significant interaction Group × Experimental condition × Emotion (F (10, 340) = 5.70, $p < 0.00001$). Analysis of means and standard deviations reveals that, contrary to the expectations, participants from both groups provided similar emotional ratings for all of the musical fragments, except for S2 fragment (Chopin's Prelude in E-minor, op.28 no. 4), and that children with ASD neither had flattened emotional profiles nor yielded higher standard deviations prompting less consistent ratings at an individual level. The difference in emotional response to S2 fragment was quite drastic: it was identified as "sad" and "sorrowful" by participants from TD group, but was recognized as "angry," "evil" and "frightening" by the majority of children with ASD. This was a completely unexpected result for the psyshologists assisting in rating the music; expanded verbal responses were sought and they confirmed the ratings. Moreover, many children with ASD rated this fragment high on happiness scale, commenting that "somebody is laughing" or "somebody is happy over there."

Table II Mean and SD for emotional self-report scores for ASD and TD groups for three scales for each of the six musical fragments

Groups		*TD group*			*ASD group*	
Emotional features	*Sad-happy*	*Tempo*	*Fear*	*Sad-happy*	*Tempo*	*Fear*
S1	–3.3±2.6	–1.9±1.9	0.1±0.3	–3.5±2.1	–1.1±1.9	0.1±0.3
S2	–3.0±2.4	–2.0±2.3	0.1±0.3	4.5±2.9	0.1±0.4	6.9±3.2
C1	1.0±1.7	–1.6±2.5	0.3±0.6	–0.4±1.3	–0.1±0.5	0.0±0.5
C2	0.1±0.6	–1.0±1.7	0.4±0.6	–2.0±2.1	0.1±0.4	2.8±2.5
F1	0.1±1.4	3.5±3.0	5.1±4.0	–0.1±0.5	3.2±2.5	5.0±3.6
F2	0.0±1.3	1.0±1.7	7.5±2.5	0.0±0.4	0.1±0.4	6.9±3.2

Figure 1 Graphic representation of emotional self-report scores for each of the six musical fragments



Notes: Vertical axis: fear scale (from 0 to +10), Y—from sad (–10) to joy (+10). A—TD group (n=21), B—ASD group (n=14)

12–13 Hz spectrum power

A significant between-group difference was found for musical fragments F1 and S2 in narrow band 12–13 Hz: PSD in this band in the right hemisphere was higher in ASD group compared to TD group (*U*-test, $p_{\text{corr}} < 0.05$ for F1 fragment, $p_{\text{corr}} < 0.001$ for S2 fragment) (Figure 2(a)). Moreover, there was significant positive correlation (Spearmen, $p < 0.05$) for S2 fragment between PSD value for a group of right hemisphere electrodes and CARS scores of participants (Figure 2(b)).

Fractal dimension

FD was significantly lower in ASD group compared to TD in central, parietal and frontal areas ($p < 0.05$) for every musical fragment but no difference was found for eyes opened baseline condition.

EEG cognitive space mapping

The results of cognitive space mapping (Figure 3) have supported the subjective emotion self-report data, revealing very similar patterns and fragment-to-fragment distances for the both groups for all the fragments except for S2 fragment which was similar to S1 (sad) fragment for TD group but was more similar to F1 and F2 (fear) fragments for ASD group.

Discussion

The results of this pilot study suggest that children with ASD may have emotional reactions to music either similar or highly aberrant compared to TD peers, rather than having general difficulties in assessing emotions. The experimental hypothesis stating that children with ASD would either generally have flattened emotional profiles or inconsistent emotional ratings was not supported: children from ASD group rated most musical fragments similarly to children from TD group. Only one musical fragment (S2) was rated in a very different manner: while TD group and adult neurotypical experts identified it as sad, children with ASD rated it as "frightful and angry," akin to two other fear-inducing fragment. It should be stressed that this effect was not predicted by the researchers and all further explanations should be treated

Figure 2 A—EEG 12-13 Hz power spectrum in TD and ASD groups, channel C4, B—EEG channels showing significant correlation of 12-13 Hz power with CARS scores

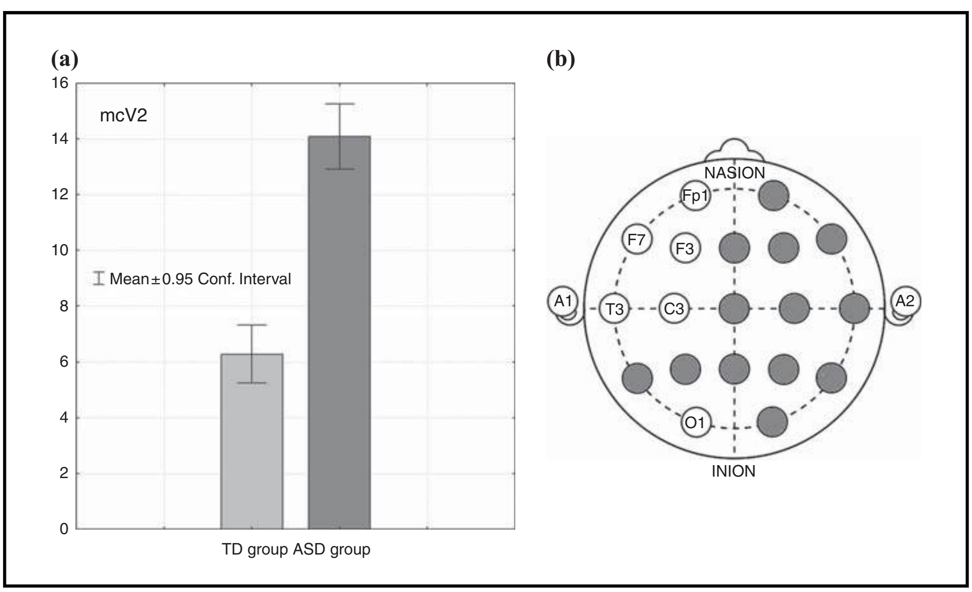
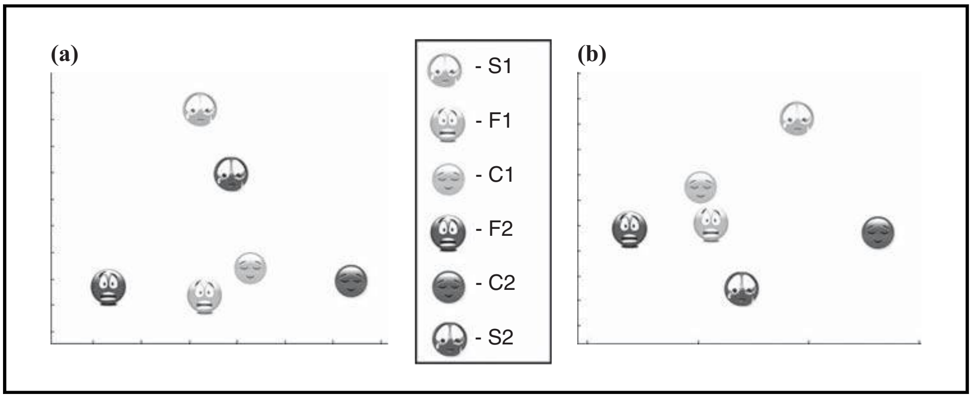


Figure 3 Film fragment distances according to EEG "cognitive spaces" A—TD group ($n = 21$), B—ASD group ($n = 21$)



as *post hoc* reasoning. This effect can hardly be attributed to purely sensory features of the musical fragment and overall auditory hypersensitivity of children with ASD, as all of the musical fragments shared similar sensory characteristics, therefore we suggest that this aberrant emotional reaction should be related to musical or sensory-cognitive features of the piece. The fragment in question is the beginning of Chopin's Prelude in E-minor, for piano, op.28 no. 4 performed by Serhan Özhan. In general, this piece is perceived as very sad and sorrowful, and so far there has been no major disagreement between experts on emotional content of the prelude. This piece in this particular interpretation can be characterized by particularly prominent tempo changes, high rhythmic complexity and low predictability. While this rhythmic uncertainty is usually interpreted by as adding more dramatic nuances into a generally very sad piece, children with ASD may perceive this unpredictability as anxiety inducing. This was supported with EEG data, indicating similarity of amplitudes of EEG rhythms during this fragment to other fear-inducing fragments in ASD group. Higher amplitudes in 12–13 Hz frequency band (corresponding to beta-1 frequency band in adult EEG) observed in ASD group in response to S2 fragment also point to higher cortical activation and higher "cognitive load" (Mundy-Castle, 1951), typical for anxiety/fear but not for sadness (see also Aftanas and Varlamov, 2007); this increase was found predominantly over right hemisphere involved in processing of emotionally relevant information (Cacioppo *et al.*, 1996; Aftanas *et al.*, 2002). Moreover, this 12–13 Hz rhythm power positively correlated with ASD severity (the less severe ASD is, the more similar EEG is to the TD group). On the other hand, high rhythmic complexity of the music may appeal to individuals high in systematizing (Greenberg *et al.*, 2015) and therefor yield higher ratings on happy–sad scale. These results correspond to previous findings: individuals with autism show impairment in emotional expression recognition and understanding of emotion (Attwood, 1998; Capps *et al.*, 1993) as well as labeling basic prototypic expressions (Tantam *et al.*, 1989). Further research should be sought to clarify this unusual perception, and help of adult experts from autistic community may provide helpful insights into the reasons of this misreading of musical emotional cues. If the initial findings get confirmed and find a reasonable explanation this may provide some clues to how and why individuals with ASD can misinterpret emotional cues in other peoples' speech.

Another important implication may be drawn from EEG FD data. FD, a measure of EEG complexity and nonlinearity, was significantly lower in ASD group compared to TD group when listening to all musical fragments, but not during the rest (eyes opened baseline condition). Sourina and Liu (2011) showed that FD is highly sensitive to emotional load of musical stimulation. It seems plausible to suggest that lower FD in ASD group evidence lesser emotional engagement of ASD participants. As music-based interventions have proved useful in increasing empathy, this FD marker may change over time corresponding to greater emotional engagement and serving as an indicator of success of a music-based intervention.

Summing up, the data suggest that children with ASD may have emotional reactions to music either similar or highly aberrant compared to TD peers, rather than having general difficulties in assessing emotions. Some musical pieces may be perceived by children with ASD in a unique way, which may be difficult to predict by neurotypical raters. The findings and our initial interpretations of the causes for misreading emotional cues should be confirmed by further research, ideally involving high functioning adult autists. The results can be taken into consideration when developing music-based interventions.

References

Aftanas, L.I. and Varlamov, A.A. (2007), "Effects of alexithymia on the activity of the anterior and posterior areas of the cortex of the right hemisphere in positive and negative emotional activation", *Neuroscience and Behavioral Physiology*, Vol. 37 No. 1, pp. 67-73.

Aftanas, L.I., Varlamov, A.A., Pavlov, S.V., Makhnev, V.P. and Reva, N.V. (2002), "Time-dependent cortical asymmetries induced by emotional arousal: EEG analysis of event-related synchronization and desynchronization in individually defined frequency bands", *International Journal of Psychophysiology*, Vol. 44 No. 1, pp. 67-82.

Attwood, T. (1998), *Asperger's Syndrome: A Guide for Parents and Professionals*, Jessica Kingsley Publishers, London.

Baron-Cohen, S. (1995), *Mindblindness: An Essay on Autism and Theory of Mind*, MIT Press, Cambridge.

Bhatara, A., Quintin, E.M., Levy, B., Bellugi, U., Fombonne, E. and Levitin, D.J. (2010), "Perception of emotion in musical performance in adolescents with autism spectrum disorders", *Autism Research*, Vol. 3 No. 5, pp. 214-25.

Boso, M., Emanuele, E., Minazzi, V., Abbamonte, M. and Politi, P. (2007), "Effect of long-term interactive music therapy on behavior profile and musical skills in young adults with severe autism", *The Journal of Alternative and Complementary Medicine*, Vol. 13 No. 7, pp. 709-12.

Brewer, R., Biotti, F., Catmur, C., Press, C., Happé, F., Cook, R. and Bird, G. (2016), "Can neurotypical individuals read autistic facial expressions? Atypical production of emotional facial expressions in autism spectrum disorders", *Autism Research*, Vol. 9 No. 2, pp. 262-71.

Brown, L.S. (2016), "The influence of music on facial emotion recognition in children with autism spectrum disorder and neurotypical children", *Journal of Music Therapy*, Vol. 54 No. 1, pp. 55-79.

Cacioppo, J.T., Petty, R.E., Feinstein, J.A. and Jarvis, W.B.G. (1996), "Dispositional differences in cognitive motivation: the life and times of individuals varying in need for cognition", *Psychological Bulletin*, Vol. 119 No. 2, p. 197.

Capps, L., Kasari, C., Yirmiya, N. and Sigman, M. (1993), "Parental perception of emotional expressiveness in children with autism", *Journal of Consulting and Clinical Psychology*, Vol. 61 No. 3, pp. 475-84.

Castelli, F. (2005), "Understanding emotions from standardized facial expressions in autism and normal development", *Autism*, Vol. 9 No. 4, pp. 428-49.

Darrow, A.A. and Armstrong, T. (1999), "Research on music and autism implications for music educators", *Update: Applications of Research in Music Education*, Vol. 18 No. 1, pp. 15-20.

Delorme, A. and Makeig, S. (2004), "EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis", *Journal of Neuroscience Methods*, Vol. 134 No. 1, pp. 9-21.

Downs, A. and Smith, T. (2004), "Emotional understanding, cooperation and social behavior in high-functioning children with autism", *Journal of Autism and Developmental Disorders*, Vol. 34 No. 6, pp. 625-35.

Greenberg, D.M., Rentfrow, P.J. and Baron-Cohen, S. (2015), "Can music increase empathy? Interpreting musical experience through the empathizing-systemizing (ES) theory: implications for autism", *Empirical Musicology Review*, Vol. 10 Nos 1/2, p. 80.

Greitemeyer, T. (2009), "Effects of songs with prosocial lyrics on prosocial thoughts, affect and behavior", *Journal of Experimental Social Psychology*, Vol. 45 No. 1, pp. 186-90.

Gross, T.F. (2004), "The perception of four basic emotions in human and nonhuman faces by children with autism and other developmental disabilities", *Journal of Abnormal Child Psychology*, Vol. 32 No. 5, pp. 469-80.

Heaton, P., Hermelin, B. and Pring, L. (1998), "Autism and pitch processing: a precursor for savant musical ability?", *Music Perception: An Interdisciplinary Journal*, Vol. 15 No. 3, pp. 291-305.

Heaton, P., Hermelin, B. and Pring, L. (1999), "Can children with autistic spectrum disorders perceive affect in music? An experimental investigation", *Psychological Medicine*, Vol. 29 No. 6, pp. 1405-10.

Heaton, P., Allen, R., Williams, K., Cummins, O. and Happé, F. (2008), "Do social and cognitive deficits curtail musical understanding? Evidence from autism and down syndrome", *British Journal of Developmental Psychology*, Vol. 26 No. 2, pp. 171-82.

Higuchi, T. (1988), "Approach to an irregular time series on the basis of the fractal theory", *Physica D: Nonlinear Phenomena*, Vol. 31 No. 2, pp. 277-83.

Kirschner, S. and Tomasello, M. (2010), "Joint music making promotes prosocial behavior in 4-year-old children", *Evolution and Human Behavior*, Vol. 31 No. 5, pp. 354-64.

Loveland, K.A. (2005), "Social-emotional impairment and self-regulation in autism spectrum disorders", in Nadel, J. and Muir, D. (Eds), *Emotional Development*, Oxford University Press, New York, NY, pp. 365-82.

Mazefsky, C.A. and Oswald, D.P. (2007), "Emotion perception in Asperger's syndrome and high-functioning autism: the importance of diagnostic criteria and cue intensity", *Journal of Autism and Developmental Disorders*, Vol. 37 No. 6, pp. 1086-95.

Miller, L.K. (1999), "The savant syndrome: intellectual impairment and exceptional skill", *Psychological Bulletin*, Vol. 125 No. 1, pp. 31-46.

Mundy-Castle, A.C. (1951), "Theta and beta rhythm in the electroencephalograms of normal adults", *Electroencephalography and Clinical Neurophysiology*, Vol. 3 No. 4, pp. 477-86.

Petermann, F. and Petermann, U. (2011), *Wechsler Intelligence Scale for Children®*, 4th ed., Pearson Assessment and Information GmbH, Frankfurt am Main.

Rabinowitch, T.C., Cross, I. and Burnard, P. (2013), "Long-term musical group interaction has a positive influence on empathy in children", *Psychology of Music*, Vol. 41 No. 4, pp. 484-98.

Roik, A.O. and Ivanitskii, G.A. (2013), "A neurophysiological model of the cognitive space", *Neuroscience and Behavioral Physiology*, Vol. 43 No. 2, pp. 193-9.

Sammon, J.W. (1969), "A nonlinear mapping for data structure analysis", *IEEE Transactions on Computers*, Vol. 100 No. 5, pp. 401-09.

Schopler, E., Reichler, R.J., DeVellis, R.F. and Daly, K. (1980), "Toward objective classification of childhood autism: Childhood Autism Rating Scale (CARS)", *Journal of Autism and Developmental Disorders*, Vol. 10 No. 1, pp. 91-103.

Sourina, O. and Liu, Y. (2011), "A fractal-based algorithmof emotion recognition from EEG using Arousal-Valence model", in Babiloni, F., Fred, A., Filipe, J. and Gamboa, H. (Eds), *Biosignals, 2011—Proceedings of the International Conference on Bio-inspired Systems and Signal Processing*, BIOSTEC, Rome, pp. 209-14.

Tantam, D., Monaghan, L., Nicholson, H. and Stirling, J. (1989), "Autistic children's ability to interpret faces: a research note", *Journal of Child Psychology and Psychiatry*, Vol. 30 No. 4, pp. 623-30.

Weinberg, M.K. and Joseph, D. (2017), "If you're happy and you know it: music engagement and subjective wellbeing", *Psychology of Music*, Vol. 45 No. 2, pp. 257-67.

Further reading

Cacioppo, J.T. and Gardner, W.L. (1999), "Emotion", *Annual Review of Psychology*, Vol. 50 No. 1, pp. 191-214.

Campbell, I.G. (1942), "Basal emotional patterns expressible in music", *The American Journal of Psychology*, Vol. 55 No. 1, pp. 1-17.

Dmitrieva, E.S., Gelman, V.Y., Zaitseva, K.A. and Orlov, A.M. (2009), "Influence of human personal features on acoustic correlates of speech emotional intonation characteristics", *I.P. Pavlov Journal of Higher Nervous Activity*, Vol. 59 No. 5, pp. 538-46 (in Russian).

Flores-Gutiérrez, E.O., Díaz, J.L., Barrios, F.A., Favila-Humara, R., Guevara, M.Á., del Río-Portilla, Y. and Corsi-Cabrera, M. (2007), "Metabolic and electric brain patterns during pleasant and unpleasant emotions induced by music masterpieces", *International Journal of Psychophysiology*, Vol. 65 No. 1, pp. 69-84.

Krumhansl, C.L. (2001), *Cognitive Foundations of Musical Pitch*, Oxford University Press, New York, NY.

Ktonas, P.Y. and Papp, N. (1980), "Instantaneous envelope and phase extraction from real signals: theory, implementation and an application to EEG analysis", *Signal Processing*, Vol. 2 No. 4, pp. 373-85.

Leyfer, O.T., Folstein, S.E., Bacalman, S., Davis, N.O., Dinh, E., Morgan, J., Tager-Flusberg, H. and Lainhart, J.E. (2006), "Comorbid psychiatric disorders in children with autism: interview development and rates of disorders", *Journal of Autism and Developmental Disorders*, Vol. 36 No. 7, pp. 849-61.

Peretz, I. and Gagnon, L. (1999), "Dissociation between recognition and emotional judgements for melodies", *Neurocase*, Vol. 5 No. 1, pp. 21-30.

Peretz, I., Gagnon, L. and Bouchard, B. (1998), "Music and emotion: perceptual determinants, immediacy and isolation after brain damage", *Cognition*, Vol. 68 No. 2, pp. 111-41.

Portnova, G.V. and Atanov, M.S. (2016), "Age-dependent changes of the EEG data: comparative study of correlation dimension D2, spectral analysis, peak alpha frequency and stability of rhythms", *International Journal of Innovative Research in Computer Science and Technology*, Vol. 4 No. 2, pp. 56-61.

Schmidt, L.A. and Trainor, L.J. (2001), "Frontal brain electrical activity (EEG) distinguishes valence and intensity of musical emotions", *Cognition and Emotion*, Vol. 15 No. 4, pp. 487-500.

Whipple, J. (2004), "Music in intervention for children and adolescents with autism: a meta-analysis", *Journal of Music Therapy*, Vol. 41 No. 2, pp. 90-106.

Ziv, N. and Goshen, M. (2006), "The effect of 'sad' and 'happy' background music on the interpretation of a story in 5 to 6-year-old children", *British Journal of Music Education*, Vol. 23 No. 3, pp. 303-14.

Corresponding author

Galina Portnova can be contacted at: caviter@list.ru