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ORIGINAL PAPER

The Effects of Autism and Alexithymia on Physiological and Verbal Responsiveness to Music

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Abstract It has been suggested that individuals with autism will be less responsive to the emotional content of music than typical individuals. With the aim of testing this hypothesis, a group of high-functioning adults on the autism spectrum was compared with a group of matched controls on two measures of emotional responsiveness to music, comprising physiological and verbal measures. Impairment in participants ability to verbalize their emotions (type-II alexithymia) was also assessed. The groups did not differ significantly on physiological responsiveness, but the autism group was significantly lower on the verbal measure. However, inclusion of the alexithymia score as a mediator variable nullified this group difference, suggesting that the difference was due not to absence of underlying emotional responsiveness to music in autism, but to a reduced ability to articulate it.

Keywords Autism · Music · Alexithymia · Emotion

Introduction

Music is a universal feature of human culture and its value in social bonding and mood management is widely acknowledged: Huron (2001) summarises evidence on both these aspects; see also comments on the social functions of music in North et al. (2004, p. 75). It has become a cliché that music is the "language of the emotions" (see for example Heaton 2009, p. 2897). Rare individuals are found to be quite immune to the charms of music, and the study of this condition, known as amusia, is a growing field of research (for a recent summary, see Stewart 2011). However, up to now the question of whether it is possible for a person to have intact low-level musical perception of music (i.e., not to be amusic) but at the same time to be emotionally less responsive to music than normal, has received little attention. This paper endeavours to answer this question in the case of high-functioning adults with autism spectrum condition (ASC). ASC is a condition which is associated with deficits in emotional processing (Hill et al. 2004; Begeer et al. 2008) but in which low-level sensory perception is, if anything, enhanced (Mottron and Burack 2001, though see also Falkmer et al. 2011). It is therefore plausible that a preserved low-level appreciation of music, together with a reduction in emotional responsiveness to it, will be found in this group. To resolve this question we compared an ASC group with a matched control group on two measures of emotional response, those of autonomic nervous system arousal, and of willingness and ability to identify verbal emotional descriptors. We also controlled for a possible additional explanatory factor—alexithymia, or reduced awareness of the nature of one's emotions—which is common in autism (85 % of the sample in Hill et al. 2004, met criteria for at least some degree of alexithymia; for further evidence see also Berthoz and Hill 2005; Lombardo et al. 2007; Allen and Heaton 2010; Bird et al. 2010).

Much published work in music psychology is based on listener self-report, and this has indicated that music induces emotions in the listener that at the least overlap with normal, everyday emotions (Juslin and Vastfjall 2008;

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Zentner et al. 2008). Listeners respond to music with arousal of the autonomic nervous system, in particular with measurable changes in skin conductance (GSR, Galvanic Skin Response: Krumhansl 1997; Khalfa et al. 2002; Salimpoor et al. 2009). They also show activation of certain brain circuits shared by naturalistic emotions (Blood and Zatorre 2001; Koelsch 2010; Salimpoor et al. 2011). Whilst some have argued that music cannot induce genuine emotions (e.g., Konecni 2005), for the purposes of this paper we will assume that music can cause changes in listeners' affective state, involving some of the physiological changes associated with normal emotions, and that when tasked with giving verbal reports of their experiences in response to music, listeners respond using a wide range of common mood and emotion terms. In what follows, we will use the term "emotion" to refer to any one of a broad spectrum of affective states.

Autism is defined in DSM IV-TR (American Psychiatric Association 2000) in terms of a triad of impairments, which include social and communication difficulties. It has been claimed that music evolved in humans due to its value in social bonding (Huron 2001), and this has given rise to the prediction that individuals with autism, who by definition are deficient in social functioning, will be insensitive to the emotional effects of music (specifically in Levitin 2006, p. 253, though similar views are expressed in Huron 2001; Peretz 2001). For short, we will refer to this claim as the autism music-difference hypothesis (AMDH).

To date, little has been done to test the AMDH empirically. Most of the experimental research into autism and music has focused on children with the condition, and has found that the ability to detect basic emotions in music is either spared (Heaton et al. 1999), or at worst, mediated by such factors as verbal mental age rather than diagnosis (Heaton et al. 2008). However, given that musical tastes are known to develop rapidly during childhood and adolescence in typical populations (North et al. 2000, 2004), and that developmental trajectories are affected by autism, it may be unsafe to generalize even these limited experimental findings to adults with ASC. Furthermore, an ability to *identify* expressive emotion in music does not necessarily mean that the children were *responding* to the music emotionally: they may simply have learned an association between particular patterns of music and (to them) arbitrary verbal labels.

Excluding studies of children, as well as individual case histories and savant studies of which there have also been a substantial number, to date there are three peer-reviewed papers reporting empirical data clearly relevant to the AMDH. Mottron et al. (2000) tested local and global processing using a musical contour paradigm; Bhatara et al. (2009) used silent and orchestrated versions of a common social attribution task (animated triangles: Heider and Simmel 1944), and Allen et al. (2009) investigated the experiences of music in adults with ASC in a qualitative study. None of these showed any clear pattern of deficits in the ASC group; however, participants in Allen et al. (2009), when freely describing their affective responses to music, tended to use terms which lacked external reference: rather, they employed words which described states of internal arousal, such as calmness and exhilaration (Allen et al. 2009, p. 35). This was different from responses by TD individuals, who (in, e.g., Zentner et al. 2008) have been found to use terms with external reference to describe their responses to music, such as nostalgia, awe, wonder, tenderness and sadness.

This limited evidence suggested that both physiological and verbal methods were needed to explore possible differences between an ASC and matched control group. However, the reliability of verbal self-report measures depends on a certain level of both verbal and emotional intelligence from participants. Lack of fluency in discussing one's emotions is known as alexithymia, literally "without words for emotions". In type II alexithymia, the range of emotions experienced (i.e., the "affective dimension" of emotion) is normal, but the ability to access the language needed to verbalize them (the "cognitive dimension" of emotional experience) is impaired (Vorst and Bermond 2001). As noted above, alexithymia appears to be highly comorbid with autism, and it is type II, not type I, alexithymia that is found to be associated with the condition (Hill et al. 2004).

We adopted a self-report scale, the Bermond Vorst Alexithymia Questionnaire (BVAQ-B: Vorst and Bermond 2001), as our measure of alexithymia. This is a five-factor measure of alexithymia, which has the advantage over the other commonly used measure, the Toronto Alexithymia Scale (TAS-20: Bagby et al. 1994), that the factor structure distinguishes between type I and type II alexithymia.

Key evidence for the relevance of alexithymia in autism was provided in a neuroimaging study by Bird et al. (2010). Measurements of type II alexithymia were taken using the TAS-20, and brain responses in ASC and control groups were compared in a paradigm evoking empathic responsiveness (observation of pain in a friend or partner). As expected, the ASC group showed reduced brain activation in the region of interest (left anterior insula) compared with controls, but the group difference disappeared when the brain responses were analyzed using ANCOVA with alexithymia as the covariate. The results were interpreted as showing that the effect of group membership on task performance was mediated by degree of alexithymia: in the authors' words "it is not autism per se, but high levels of alexithymia (in both individuals with and without an autism spectrum condition diagnosis) that are predictive of reduced empathic brain responses" (p. 1522).

The analysis in Bird et al. was mathematically equivalent to the mediation analysis methodology set out in the highly-cited paper by Baron and Kenny (1986). There, the authors set out three conditions for a variable M to mediate the effect of an IV, X, on a DV, Y. The authors argued that if these conditions apply, M can be interpreted as mediating the effect of X on Y, in other words, that the mechanism through which X affected Y is indirect, not direct, and functions via its effect on M. We adopt this method in the present paper to test one of our experimental hypotheses.

Underlying the mediation analysis of this study is a two stage model of the induction of musical emotions. According to this model, which is a standard one in music psychology though not as yet fully proven, basic properties of the emotional content of music such as valence are extracted from the sounds at an earlier stage, and the perceptual output is then relayed to more frontal areas for more sophisticated processing of its emotional significance and connotation (e.g., Juslin and Sloboda 2010, p. 113). In other words, the first stage in responding to music consists of low-level emotional response, sometimes modelled in a two-dimensional valency/arousal space (e.g., Kim and Andre 2008), in which the response typically includes components of physiological arousal. The second stage comprises the process of interpreting this arousal in more complex emotional terms at a higher cognitive level. The second stage involves a conscious awareness of the induced emotions, including, usually, the ability to identify them by name.

The aim of our experimental design was to test the hypothesis that our autism and control groups differed at one, both, or neither of these emotional processing stages. The input to the first stage consists of the auditory stimuli. These are processed, produce a low-level physiological response representing the outcome of the first stage, and a verbal response, which is the outcome of the complete process, i.e., of stages one and two together. Experiment 1 measures the overall output of the two stages, and looks for a group difference in overall verbal responsiveness. Experiment 2 focuses specifically on the first stage, in which a physiological response is induced, and examines whether the groups differ at this stage. A negative result would indicate that any group difference must be happening at the second stage, and the mediation analysis is designed to investigate whether any such second stage difference can be ascribed to the action of a specific covariate, in this case, levels of type II alexithymia.

The experimental hypotheses were firstly, a hypothesis of similarity: that at a physiological level, responses to music should be the same in ASC and control groups. The second hypothesis, a hypothesis of difference, was that at a verbal level, the descriptions of emotional response to music in the ASC group would be reduced or impoverished relative to the TD group. However, given the findings of Bird et al. (2010), we might expect any difference in verbal responsiveness to be mediated, at least partially, by the probable higher levels of type II alexithymia in the autism group. We also hypothesised that the emotion words chosen by the autism group would tend to reflect a bias towards more generalised mood and arousal terms, rather than those suggestive of more complex emotions.

General Method Section

Participants

Participants comprised an ASC group and a typically developing (TD) control group. The ASC sample consisted of a total of 23 high-functioning adults (18 men and 5 women) with diagnoses on the autism spectrum: all diagnoses had been made by professional clinicians following DSM criteria (American Psychiatric Association 2000). The majority of participants had already taken part in previous studies conducted at Goldsmiths, while others were recruited through the UK's National Autistic Society. The control group consisted of 24 adults (18 men and 6 women), none of whom had received a diagnosis on the autism spectrum at any point. The control participants were recruited through academic and community contexts in and around the College campus. In all cases it was made clear when seeking participants that no prior musical knowledge or expertise was required.

All participants were required to have normal hearing and to be fluent in English. The groups were matched on the factors considered most likely to affect the results: age, language ability, and gender. With respect to age, the means for the control and autism groups were 32.5 (s.d. 13.7 years) and 36.9 (12.3) respectively, $t(45) = 1.15$, n.s. They were also matched on a basic measure of receptive language, an advanced version of the BPVS (British Picture Vocabulary Scale, Dunn et al. 1997), to ensure that apparent differences in emotional/verbal responsiveness were not caused by poor grasp of language. There was a slightly higher, but non-significant mean verbal vocabulary score in the ASC compared with the TD group (mean raw scores were 154.7 vs. 150: $t(45) = .133$, n.s.). The small difference in gender balance between groups was not significant (Fisher's Exact Test: $p = .533$, n.s.). The groups did not differ significantly on the measure of type I alexithymia provided by factors 2 and 4 of the BVAQ ($p = .085$, n.s.). The design of the experiment was approved by the Goldsmiths Department of Psychology's Ethics Committee, and all participants gave written informed consent.

Materials

Prior to all the experimental sessions described below, participants completed the BVAQ-B. Participants also filled in the 50-item Autism-Spectrum Quotient (AQ: Baron-Cohen et al. 2001), as a gross check against inclusion of autistic individuals in the control group. All sound stimuli were delivered via Sennheiser HD 201 high fidelity headphones, from Windows Media Audio files stored on computer. The 12 musical stimuli used in this study were taken from a set piloted in the sound laboratory at McGill University, Montreal (Quintin et al. 2011), as reliably representing the basic emotions of "happy", "sad" and "scary". These comprise the three most universally recognised musical emotions (Fritz et al. 2009). For this reason, and also because it seemed less likely to provoke an emotion response, Quintin et al.'s "peaceful" category was not used. The music items were edited to be identical in both duration (30 s) and average (root mean square, r.m.s.) power.

Experiment 1: Verbal Responsiveness to Musical Items

Method

Materials

The twelve music items were divided randomly into two groups of six, whilst ensuring that the three basic emotions were equally represented in each group. When listening to the first group of six, participants were presented with a checklist of words relating to emotions, feelings and sensations, reproduced at Appendix 1. The checklist was compiled from data obtained in a pilot experiment, in which non-autistic participants freely assigned words to the music stimuli describing their emotion responses to them, and the 14 most popular choices overall were taken. To this list was added the 14 descriptors used by participants in Allen et al. (2009), to reduce possible bias against the ASC group by using words covering simpler mood state descriptions such as "calmness" and "excitement".

For the second set of six music items, the output of the pilot experiment with TD individuals described above was used as follows. The most common descriptors for each music item were grouped into "word bundles" of four to six words (see Appendix 2). The association between each word bundle and the associated item of music was then validated by further testing which showed that for each musical item, the nominated bundle was consistently the most likely to be chosen for that item. As a test item in Experiment 1, participants in the main study listened to the six music items in randomized order and were tasked with choosing, for each item, that word bundle which they thought a typical group of people would have used to describe the music. In asking participants to estimate the associations made by other people, this test therefore had some similarities to the popular TV show "Family Fortunes", in which family teams are asked to guess the results of surveys, e.g., "we asked 100 people to name something you would take on holiday", with the difference that the options were strictly limited in our task. This test was introduced as a precaution to take into account the possible objection that any reduction in verbal responsiveness observed on the part of the autism group in the first task might be due to a tendency to be more precise and focused in their responses, thus leading them to choose fewer words as a consequence not of a reduction in verbal responsiveness to the emotions in the music, but as a result of the use of sharper criteria to decide whether a particular emotion word was appropriate, or possibly, an inability to generalize across categories. Such a reduced ability for generalization has indeed been suggested as a characteristic of the autism population as a whole (Plaisted 2001, though see also McGregor and Bean 2012; Soulieres et al. 2011). Poor performance by the autism group in this test would have tended to confirm this explanation.

Design

This was a group difference design, with the total number of words checked in the list ("Wordcount") as the DV, intended as a measure of verbal responsiveness to the musical items as a whole. The "Family Fortunes" part of the test was scored by counting the number of associations between music items and word bundles that were identical to those in the pilot group.

Procedure

The participants were read the instructions given in the first part of Appendix 3 and then given the word list in Appendix 1. The tunes chosen for this part of the experiment were then played in a randomized order to the participant, through the Sennheiser earphones. Participants responded by ticking the appropriate emotion words in the checklist during the course of listening to the music and, if they wished, after it was over. Participants were allowed as much time as they wished to tick the boxes for the word lists for the successive tunes. When participants indicated that they had completed the task for each tune, the next one was played. The "Family Fortunes" task always followed the Wordlist task.

Results

The profile below (Fig. 1) shows the average number of times that each word was chosen by participants in the two

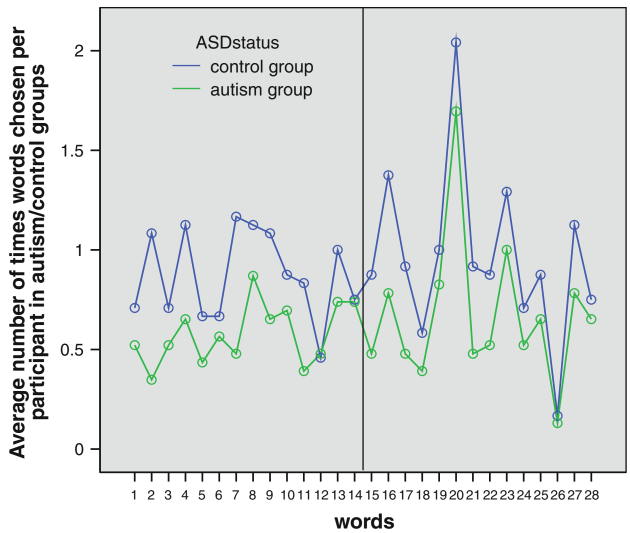

Fig. 1 Mean number of times each word was chosen by individuals, broken down into mean values for members of the control and autism groups

Table 1 Average combined frequency of four most popular words in each emotion category, by experimental group

	ASC group	Controls
Happy	0.69565217	1.041667
Sad	0.77173913	1.09375
Scary	0.91304348	1.354167

groups. The word order has been changed from that given in the list in Appendix 1, with the first 14 words being the words that had been used by the autism group in the previous study (Allen et al. 2009). There appears, visually, to be no difference between the two sets of words. This was confirmed statistically, where there was no tendency for the autism group to choose these words rather than the second group of 14; if anything there was a suggestion of a slight trend in the opposite direction: $t(23) = -1.48$, n.s.

The most popular words chosen in each emotion category were as follows: for the happy category: serene, calm, relaxed, soothed; for the sad category: thoughtful, wistful, peaceful, longing; and for the scary category: dramatic, magical, tense, escaping.

Combining these words by category, the average number of times they were used, broken down between autism and control groups, are shown in Table 1.

There was a difference in the Wordcount variable in favour of the control group, with a mean of 25.7 (SD = 7.1) words checked compared with 17.6 (SD = 9.1) for the autism group. An independent samples t test showed that this difference was significant, $t(45) = 2.46$, $p < .05$.

In a mediation analysis, it was found that Wordcount, group membership and type II alexithymia (as measured by combining the relevant BVAQ-B factors) were all significantly correlated: for Wordcount and Group, $r = -.345$, $p < .05$; for Wordcount and Type II alexithymia, $r = -.373$, $p < .05$, and for alexithymia and Group, $r = .356$, $p < .05$ (the control and autism groups were coded as 0 and 1 respectively, so a negative correlation between group and a variable signifies that the autism group scored lower than the control group, and vice versa).

We entered the alexithymia variable as an IV together with group membership in a multiple regression of the Wordcount variable on these two IVs. Examination of the plot of standardized residuals using Tukey's boxplots showed the presence of three outliers in the solution (all in the control group). When these were removed, the forced entry analysis showed that group membership became non-significant as a predictor of Wordcount, while type II alexithymia variable showed a clearly significant result, as shown in Table 2.

When the correlation of Wordcount with type II alexithymia was investigated within the control group, excluding the autism participants, it was observed to be significantly negative: $r = -.435$, $p < .05$. The correlation within the autism group was also negative, but did not reach significance.

The scores on the "Family Fortunes" part of the experiment were as follows: the means for the autism and control groups were 3.9 (1.8) and 3.3 (1.3), respectively, though the slightly superior performance by the autism group was not significant ($t(45) = 1.23$, n.s.).

Discussion

Experiment 1 rests on the assumption that the DV is a reasonable operationalization of the construct "verbal emotional responsiveness to music". This assumption may be questioned, but in the absence of any other well-validated instrument for measuring this construct, it was necessary to construct one for the purposes of the experiment. The consistency in the reduced frequency of naming of words by the ASC group revealed in Fig. 1 gives some support to the notion that the set of words does seem to be revealing a general group difference, rather than something specific to the particular words that happened to be chosen. The group difference in the Wordcount DV was consistent with the prediction that the autism group would show reduced levels of verbal emotional responsiveness to the music items. This was predictable both on the basis of the higher expected levels of alexithymia in the autism group (leading to lower levels of verbal emotional fluency in general), and in accordance with the conclusion of Huron, Levitin and Peretz cited above that emotional responsiveness to music would be lacking in the autism group.

Table 2 Regression of wordcount on group and type II alexithymia

Coefficients[a]						
Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	34.468	5.452		6.322	.000
	Group	−2.062	2.663	−.117	−.774	.443
	Type_II_alexithymia	−.464	.190	−.368	−2.443	.019

[a] Dependent variable: wordcount

The lack of any tendency in the ASC group to use internally rather than externally focused words was unexpected, but may be the result of the circumstances of this experiment, which differed from those in Allen et al. (2009). In the present instance, participants were encouraged to study the word list carefully, and it acted therefore as a strong cue. There have been indications that performance biases observed in individuals with autism may disappear when appropriate contextual information is provided (Hala et al. 2007).

The lack of any group difference on the "Family Fortunes" task suggests that the autism group is as capable as controls of linking emotion words to musical categories when cued to do so. Were there any tendency to interpret emotion words in a narrower or more focused way, we would expect to see either an inability to match musical items to word bundles at all, or a tendency to do so at random.

The bivariate correlations between group, alexithymia and Wordcount, and the regression results, show that Baron and Kenny's criteria were satisfied, and suggest that the type II alexithymia variable does indeed mediate the effects of autism on verbal responsiveness to music. The fact that the group effect is no longer significant when the mediator variable is introduced into the regression analysis, in fact has two implications. One is that there is nothing peculiar to autism that causes the lower Wordcount score: it seems to be part of a wider effect of type II alexithymia on Wordcount, a fact which is supported by the analysis of the control group, showing that even within this group type II alexithymia and Wordcount are negatively correlated. The second implication is that if type II alexithymia, in the form of inability to identify one's own emotions, accounts fully for the shortfall in Wordcount score in the autism group, this suggests that there is no other mechanism required to explain the shortfall: in other words, it suggests that the basic physiological-level emotional response to the music is intact. This conclusion is, however, only conjectural pending direct evidence that the physiological responses are similar in the two groups, and it is the aim of the following experiment to provide this.

Experiment 2: GSR Responses to Music

Materials

In addition to the twelve musical items described above, which were used both in the behavioural (Wordcount/Family Fortunes) and in the GSR parts of the experiment, for this experiment an additional six tracks of environmental noise were chosen as control stimuli, selected from CDs published by the BBC sound library on the basis that they were free of any sudden or potentially unpleasant sounds. These stimuli represented such sounds as running water and a bicycle on gravel; they were matched with the music stimuli (and one another) in duration and r.m.s. power. GSR measurement was carried out using a pair of BioLogic disposable snap electrodes (P/N 101603), connected to the palmar surfaces of the first and third fingers of the left hand. This is a standard position for this measurement (see for example iWorx 2011, p. 181). The electrodes were connected via a voltage inducer and current measuring apparatus to a computer program recording resistivity measurements in kilohms at a rate of 2 Hz throughout the experiment (equipment and program designed by the second author).

Design

This was a group difference design, with the group as the IV (independent variable) and GSR response as the DV (dependent variable). The DV measured the effect of musical stimuli on participants, as compared with a baseline level determined by periods of silence between the music extracts. For reasons explained below, environmental noise stimuli were used as a separate control condition. The GSR responses to the effects of these noise stimuli were measured in exactly the same manner as for the music. The order of presentation of the blocks of stimuli (sound followed by music, vs. music followed by sound) was randomized for participants. Within each music and sound block, the order of presentation of the individual music and sound items was pseudo-randomized.

Procedure

It should be noted that in the actual testing, the GSR procedure was always carried out first, and the behavioural experiment (Experiment 1) second for all participants. The experiments are described in reverse order because the principal results are contained in the behavioural study, and the GSR data serve mainly to support and help interpret these results.

Testing took place in a quiet environment within Goldsmiths, University of London. The first step was to establish a comfortable sound level for the individual participant. The participant listened to one of the music tracks on the headphones, with volume at a low level, and the volume was adjusted by the experimenter until the participant indicated that he/she was comfortable with it. This was necessary to avoid participant discomfort, since hyperacusis (extreme sensitivity to sound) has been found to occur more frequently in autism (Khalfa et al. 2004). The protocol involved a series of exposures to 30 s of sound stimulus alternated with 30 s of silence. Before playing the stimuli and recording the GSR readings, participants were told that during the procedure they should attempt to focus on the music (or sound) that was being presented, and to make their mind a blank during the periods of silence. Participants were asked to move physically as little as possible during this phase to avoid artifactual GSR responses. It was suggested that they shut their eyes during the duration of the GSR experiment: most participants complied.

Data Analysis

A standard method of obtaining GSR data, as in the present study, uses direct current measurements. Unfortunately, as pointed out by Schaefer and Boucsein (2000), this method has disadvantages, among them a tendency to electrode and skin polarization, and other sources of noise. We have observed in addition that increasing levels of relaxation of participants during the testing also lead to artefacts if standard methods such as finding average GSR levels were used. The solution recommended by Schaefer and Boucsein (2000), involving the use of alternating current and phase angle measurements, was not available for the current study. To overcome some of these problems, we applied an idea from an existing method commonly used to analyze sequential data in physics and econometrics, the so-called break of slope or break-in-slope (BIS) analysis (see e.g., Main et al. 1999; Harvey et al. 2009). These cited applications are somewhat technical, but the essential idea that we have taken over from BIS analysis is that the magnitude of an effect applied at a particular point in a sequence of data points can be estimated by measuring the slopes of the data points prior to stimulus onset, and posterior to stimulus onset, and taking their difference as a valid estimate of effect magnitude.

Details of the actual calculation are given in Appendix 4, but in brief, on the grounds that the change of slope between periods of listening to music and periods of silence was likely to be most apparent early in the transition from silence to music, and from music to silence, the change of slope in the GSR trace was measured by comparing GSR readings 5 s before, during, and 5 s after the changeover.

While this paradigm might be expected to provide a valid measure of the physiological effects of listening to music as compared with the silent condition, it might be argued that the observed effect was due solely to low-level activation of the auditory system. To rule out the possibility that it was merely acoustic stimulation of a certain decibel level that is responsible for any observed effects, it was necessary to carry out parallel measurements with sounds that matched the music stimuli in intensity and duration but lacked the characteristic qualities of melody and rhythm that define music. This has been done in other studies by the use of white noise as a control stimulus (Carlson et al. 1997), or using both white noise and pure tones as comparison stimuli (Lutkenhoner et al. 2006). Given that 30 s of either white noise or pure sine tones might be found irritating and give rise to spurious GSR responses for that reason, for the comparison condition we chose six environmental sounds from BBC sound archives matched for r.m.s. sound levels to the musical extracts.

For each stimulus type (music and environmental noise) the median of all such derivatives was taken as a measure of the effect of the sound stimulus. This provided two figures for each participant, representing the effect on them of music versus silence, and of noise versus silence. Comparison of these two measures, using repeated measures or other analyses, would enable the testing of possible effects generated by other variables, as detailed below.

In addition, we used a short music experience questionnaire based on that used in Allen et al. (2009) to provide an approximate measure of the extent to which participants had been exposed to music during their lives, including both the extent of their musical education and their current self-chosen exposure to music (both listening and playing). A recent paper (Dellacherie et al. 2010) has shown that level of musical education can have a significant effect on physiological responses to music. As in that paper, we encoded participants as HE (high experience/education) and LE (low experience/education), and included this variable in the analysis of the GSR results.

Results

The break-in-slope measures of GSR response to music were found to be non-normally distributed within the two groups, with significant positive skewness in both: skewness = 1.23 (s.d., 0.472) in the control group, and 2.09 (0.49) in the autism group. A similar result was found in group responses to the environmental noise stimuli. High values of kurtosis were also observed. A standard method for tackling this situation is transformation using logarithms (Howell 2012, p. 347). This reduced both skewness and kurtosis for both measures and both groups to within acceptable limits, and the log-transformed variables were henceforward used to represent the GSR effects of music, and of noise, respectively.

In order to determine the effect of music on GSR response not attributable merely to response to sound, we carried out a mixed repeated measures ANOVA with GSR response (music, noise) as the repeated measures variable, and group as the between subjects variable. There was a significant effect of the RM factor and a significant effect of group, but no RM factor by group interaction:

Factor effect: $F(1, 40) = 15.0$, $p < .001$. Overall mean of GSR response to music $= -0.206$, mean of GSR response to noise $= -0.730$, difference $= +0.524$.

Group effect: $F(1, 40) = 5.39$, $p < .05$. Overall response of control group to music and noise combined $= -0.125$, response of autism grou $p = -0.812$, difference $= +0.687$.

Factor by group effect: $F(1, 40) = .224$, n.s.

The next analysis incorporated the dichotomous musical education variable. The groups did not differ significantly on the proportions of LE (low education) versus HE (high education) individuals: $p = .253$, n.s. (Fisher's exact test).

In order to investigate the possibility suggested by Dellacherie et al. (2010) of an interaction between musical education and physiological responsiveness, it was necessary to create a variable which specifically measures responsiveness to music as such. The basic repeated measures model (see e.g., Howell 2012, p. 460, model I) assumes that treatment effects can be estimated in the case of a two-level RM variable by taking the difference between the two levels. We therefore took the difference between the GSR responses to music, and to noise, as a measure of the physiological response to music per se.

We called this variable obtained by subtracting the GSR noise variable from the GSR music variable, Response. The two groups differed by a small amount in their means for the Response variable: control mean = 0.588 (0.665), autism group mean = .460 (1.08), but the difference was not significant, $t(40) = .639$, n.s. An ANCOVA with Wordcount as DV and musicality and Response as IV and covariate respectively gave non-significant effects for both musicality ($F(1, 39) = 1.98$, n.s.), and Response ($F(1, 39) = 0.723$, n.s.). However, using a custom model incorporating the possibility of a musicality by responsiveness interaction yielded a significant interaction ($F(1, 38) = 6.63$, $p < .05$), though main effects remained non-significant.

The interaction effect can be illustrated by creating a dichotomous variable from a median split of the Response variable and showing the interaction with musicality as illustrated in Fig. 2.

In order to incorporate the other variables into the model, we carried out an ANCOVA with Wordcount as the DV. As the main effects of music and GSR Response were known to be non-significant, we created a custom model with the interaction effect and the group variable as factors, and type II alexithymia as covariate. When applied to the whole sample the group variable was non-significant: $F(1, 36) = 3.87$, n.s. Type II alexithymia was significant ($F(1, 36) = 4.96$, $p < .05$) as was the interaction term ($F(3, 36) = 4.26$, $p < .05$).

The significance of the music education by GSR response term in the ANCOVA suggested the incorporation of an interaction term using the greater power and flexibility of the multiple regression method. It is known that the use of an interaction in ANOVA or ANCOVA corresponds to a moderation analysis in multiple regression (details are given in e.g., Howell 2012, pp. 551–556). The terms for group and type II alexithymia were incorporated in the first step of a hierarchical regression, and the

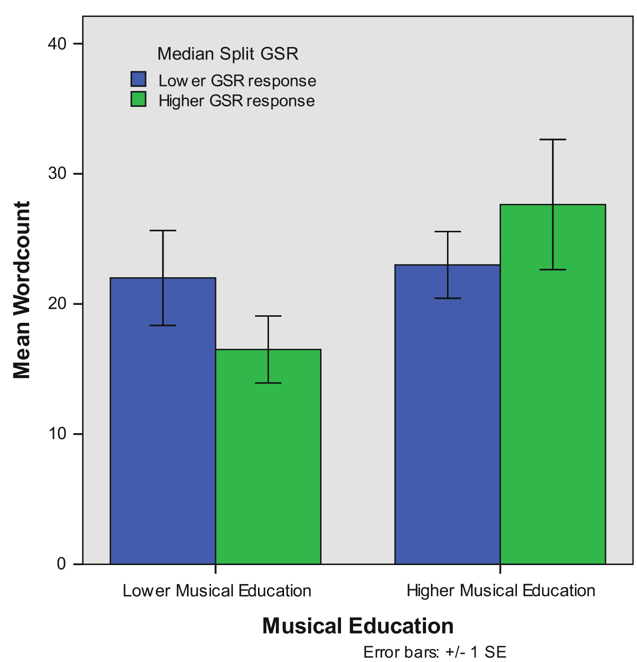

Fig. 2 Interaction effect of musical education level with level of GSR response

interaction variable as the IV in the second step of the regression. A significance test was made on the change of effect (adjusted R-squared) in step 2.

The regression model using group and type II alexithymia together predicted 15 % of variance in the Wordcount variable measured as adjusted R-squared: $F(2, 44) = 5.18$, $p < .05$. The model incorporating the interaction term as well accounted for 22.8 % of variance in the dependent variable, and the addition of the new term gave rise to a significant increase in R-squared: $F(1, 38) = 4.35$, $p < .05$. In this model, the type II alexithymia variable showed a clearly significant effect: the regression coefficient was significantly non-zero ($t = -2.197$, $p < .05$) and the group variable showed a non-significant effect ($t = -1.037$, $p = .306$, n.s.)

To investigate whether there was any effect of the mood of the music (happy, sad, scary) on response, with or without a group interaction, we examined the three response variables obtained by confining attention to the GSR responses on happy, sad and scary music. All group effects were non-significant: the maximum difference was for scary music, where the control group mean (0.474) exceeded the autism group mean (0.225), $t(40) = 0.817$, n.s.

However, taken over the groups as a whole, the mood of the music did have an effect. Repeated measures ANOVA on the repeated measures variable, happy, sad, scary, with group as the between subjects variable, gave means for these three responses as 0.834, 0.333 and 0.350, respectively. Bonferroni-adjusted post hoc tests showed that the happy response was greater than that to sad music ($p < .01$) and scary music ($p < .001$) but there was no difference between reactions to these latter two types of music.

We also carried out a conventional analysis of the GSR data by taking average GSR readings for participants during the playing of the music, and during the intervals of silence. Both variables were found to be highly positively skewed, and as above, we carried out a logarithmic transformation to render them acceptably close to the normal distribution. The difference between these transformed variables was taken, as a measure of the effect of the music versus silence condition (no correction was made in this case for sensitivity to noise per se). The control group scored a higher average on this variable (0.595) compared with the autism group (0.373) but the difference was not significant, $t(44) = 1.8$, n.s.

Discussion

The results indicated that there was no sign of any reduced responsiveness to the musical stimuli, at this physiological level, in the ASC group compared with the control group. The comparatively large standard deviations suggest that within-group variability is much larger than any effect of autism, if it exists.

The analysis of the dichotomous musical education variable showed that the effect of the GSR Response variable varies with level of education. In the LE (low education) participants, the effect of higher GSR response appeared to be to reduce verbal responsiveness to the music. The reason for this is not clear, though it is possible that in the LE participants, a higher GSR response might reflect higher arousal due to dislike of the music. A participant disliking the music would be unlikely to report a variety of verbal responses to it (other than, possibly, dislike). In the HE group, to which the types of classical or semi-classical music comprising most of the stimuli would have been familiar, higher arousal might reflect higher interest and engagement with the music as a whole, so greater verbal responsiveness to it would be expected.

The multiple regression results showed that the addition of the interaction term to the analysis not only improved the power of the model, but also helped to highlight the mediation role of the type II alexithymia variable, which showed an enhanced effect, and further reduced the significance of the autism/control group variable.

The relevance of Experiment 2 to the basic hypothesis, that alexithymia mediates the effect of autism on verbal responsiveness to music, is that it rules out one obvious objection to the interpretation of Experiment 1, namely that the group difference in alexithymia is confounded with some other variable which is actually responsible for the difference in Wordcount. If, for example, the autism group was immune to the basic emotional appeal to music and exhibited a reduced physiological reaction to it, then we need look no further for an explanation of the reduction in verbal emotional responsiveness in the autism group. The fact that the autism and control groups did not differ in their responses to music, makes this possibility less plausible.

General Discussion

One of our hypotheses, that the autism group would show a greater tendency to choose internally focused (calmness, exhilaration) rather than externally focused emotion words was not supported.

The Wordcount variable measures the outcome of a two stage process of music emotion processing, as discussed in the "Introduction". We have not, it is true, measured the responsiveness at stage two independently, but certain conclusions can be drawn on the basis of the data we have. The GSR analysis, measuring the outcome of the first stage, indicates that the groups do not differ in their basic physiological responses to music: the range of variation of response within groups is much larger than the between group difference. Although this does not prove the null hypothesis, given that such proof is never possible with null hypothesis significance testing (e.g., Howell 2012, p. 91), it does make it highly implausible that any such difference could have accounted for the overall group difference in stages one and two combined, which is exhibited in the significantly larger Wordcount mean for the control versus autism group. Even if a difference in basic physiological responsiveness existed, it would be hard to sustain any argument which proposed this as the explanation for the overall group difference in Wordcount, given the high level of variability within each group. Such variability would surely result in such a level of error in the final Wordcount variable that no group difference would be statistically apparent, which is not the case.

Our conclusion is that the group difference in Wordcount arises at the second stage of responsiveness to music, namely the stage at which higher-level cognitive processes lead to an attribution of a named emotion to the internal arousal generated by the music. If there is indeed no group difference at the first stage, the group difference observed in the overall process must arise at this second stage. The question then arises of what mechanism can explain it. There appears to be something intrinsic to autism which makes it hard to verbally describe what it feels like to experience the physiological arousal caused by the music. This, however, immediately suggests that we may be dealing with the phenomenon of alexithymia, or difficulty in verbalising emotions. It makes it highly plausible that the group difference based on classification by clinical condition is in fact mediated by the correlated difference in levels of alexithymia between the two groups.

While a statistical analysis alone cannot prove that the alexithymia factor is the causal one, we have given supporting evidence that other possible explanations are unlikely candidates to account for it. There were no significant differences in age, gender, or receptive vocabulary between the groups. The "Family Fortunes" task suggests that there was no difference in the autism group in their tendency to interpret emotion words compared with the control group. Furthermore, the variety of alexithymia found to mediate the effect was that of type II rather than type I. There are two arguments in favour of this conclusion. Firstly, the groups did not differ significantly in type I alexithymia; secondly, type I alexithymia, which involves a tendency to low emotional responsiveness, should have produced a lesser physiological reaction to the music in the autism compared with the control group, and this was not observed.

It is plausible to deduce, in conclusion, that the groups did not differ in their fundamental "visceral" physiological response to the music, but that the reduced ability of the autism group to verbalize their emotional responses accounted fully for the lower Wordcount score in that group. In sum, the two central experimental hypotheses were verified by the data. This conclusion, as well as the analysis used to reach it, is consistent with those used in Bird et al. (2010) to deduce that the group differences observed between ASC and TD groups in an empathy task could be accounted for by the comorbid type II alexithymia in the autism group.

In particular, we found no evidence for the AMDH from our results. To the extent that ASC and TD participants overlapped considerably in their GSR responses to music, there was some evidence against the AMDH, though a null result cannot be proved. However, the difference in verbal responsiveness suggests that caution needs to be exercised when using a self-report format to record responses when studying musically-evoked emotions in listeners, especially if clinical groups are involved. Studies relying solely on verbal report measures may conclude that participants are impaired in emotional responsiveness when in fact the deficit is due to participants' reduced ability to verbalize their emotions (i.e., type II alexithymia). The hypothesis that people with autism are emotionally unresponsive to music raises this issue in an acute form, given the high comorbidity of autism and alexithymia. These findings suggest that future studies of musical emotions using self-report measures to compare groups whose mean alexithymia scores may differ, should not be interpreted as proving the existence of group differences in emotional responsiveness unless the possible alexithymia confound has also been considered.

Our findings, in conjunction with those of Bird et al. (2010), may also suggest that alexithymia is not merely a fortuitous by-product of autism, but possibly a mediating factor for other aspects of the condition, in the social or communication domains.

Acknowledgments The research reported in this paper was conducted by the first author as part of a program of PhD study, and is largely based on material contained in his PhD thesis. This program of study was self-funded by the first author. The third author was the first author's PhD supervisor. The second author provided significant assistance with developing the equipment for carrying out the GSR experiments and the software for recording the results in a form available for subsequent analysis by the first author using standard statistical methods.

Appendix 1 Wordcount response sheet

Item no:	1	2	3	4	5	6
excited						
tranquil						
bright						
chilled out						
magical						
tense						
feel a buzz						
exhilarated						
happy						
thrilled						
relaxed						
serene						
sad						
peaceful						
dramatic						
pleasure						
soothed						
invigorated						
anxious						
escaping						
thoughtful						
cheerful						
longing						
scared						
wistful						
calm						
hopeful						
lively						

Appendix 2 Word bundles sheet

BUNDLE ONE	BUNDLE TWO	BUNDLE THREE
happy movement irritated joyful fun sunshine	relaxed peaceful melancholy calm sad	alert anticipation suspense, tension eager excitement sense of danger
BUNDLE FOUR	BUNDLE FIVE	BUNDLE SIX
threatened oppressed Scared confusion, bewildered slipping and falling	lively dancing energised upbeat adventurous exuberant	grief and despair intensity calmness, tranquility reflective, thoughtful loss

Appendix 3: Instructions to Participants

I am going to play you six items of music, and then ask you about your responses to them. To begin with, I would like you to take a few minutes to look at this list of words. If you come across a word which you don't understand, please ask me when you come to it and I will try and explain it.

Please now read the words to yourself, not aloud, and tell me when you have finished.

I will now play the music, one piece at a time. While I am playing the first piece, please look again at the words and decide if any of them describes the way the music makes you feel, or describes a thought that comes to you when listening, even if momentarily or fleetingly. If there are any words like this, please put a tick next to them in column 1, which is this one. You can do this either during the music or after it has finished. It is quite all right if you decide that none of the words applies, and in that case just leave the column blank and tell me when you are ready to move on to the next item of music.

Please note that I only want you to record the thoughts or feelings that the music evokes in you. I am not looking for a description of the music itself, but of what is going on in your mind in response to the music, using the words provided in the list. If you have a thought or feeling that is not on the list, please tell me what it is.

Now I will play you the next item, and I would like you to do the same in column 2. Please remember that the feeling should be one that you have yourself—it may be that this is not the feeling you see expressed by the music. If for example you think the music sounds sad, but you yourself feel pleasure and not sadness (perhaps because it has pleasant memories for you), you should mark 'pleasure' and not 'sad'.

Now please look at the following set of six "bundles" of words that might be used to describe music. I am going to play you six more items of music.

This experiment is different from the last one. The bundles represent typical words used by an earlier group of people to describe the way they felt about the different items of music. I would like you to use your judgement to decide which bundle you think was the one used by the group to describe that piece of music. The words in the bundle don't necessarily have to represent the way the music makes you feel, or a thought that the music evokes in you.

You do not have to choose different bundles for each item of music. It is fine if you want to choose the same one to describe two or more items.

Appendix 4: GSR Analysis

The program devised by the second author sampled GSR values and stored them on computer at the rate of 2 Hz.

The program also recorded the exact time at which each GSR reading was taken, and also whether there was a sound stimulus being presented at that point (and if so it identified the code number of the stimulus) or whether there was silence at that point. A simple Windows Excel program was written to analyse the data for each individual. The program was applied separately to the data recording response to music, and to noise stimuli. The first step executed by the program was to locate each point at which there was a change of stimulus, i.e., where either the sound (music or environmental noise) ceased and a period of silence began, or vice versa (a "transition point"). For each transition point, the program also measured the GSR readings taken at two other points, located at 5 s before, and 5 s after the transition point (i.e., at ten sample readings before and after the transition point): the "bracket points" for that transition point. This period was found to give a measure of the short term trend of the readings that would be both large enough to minimise the distorting effects of random noise, and short enough to represent the trend prevailing over a short time period.

For each transition point, the program averaged the readings at the two corresponding bracket points, and subtracted them from the reading at the transition point. In order to give a result in kilohms per second, this result was divided by a scaling factor of 2.5 (for the reason, see below). The program then calculated the absolute value of the resulting number for each transition point, and finally, took the overall median of these absolute values. The median was adopted, since it this statistic is known to be less susceptible to the influence of possible artifacts or other causes of extreme values, than the use of a simple average. Algebraically, if the reading at the transition point at time t was R_t, where t is measured in seconds, then readings were taken at the bracket points corresponding to R_{t-5} and R_{t+5} and the quantity $|R_t - (R_{t-5} + R_{t+5})/2|$ was calculated for each value of t corresponding to a transition point, and then the effect size was finally calculated as effect size = median$\{|(R_t - (R_{t-5} + R_{t+5})/2)|/2.5\}$, taken over all t marking transition points. The units of GSR measurement were in kilohms, so the units of this effect size measure were in kilohms per second.

The rationale for this is that in the absence of any effect of sound versus silence, one would expect the slope of the trace line at the transition point to be continuous before, during and after the transition point. The most parsimonious hypothesis is that the change from music to silence or vice versa has a first order linear effect on the slope. It is easy to see that if R_t were a linear function of time t (i.e., if the transition had no effect), then $R_t - (R_{t-5} + R_{t+5})/2$ would be zero. In fact, if the trace of resistance against time is visualised as a graph with time as the x-axis and resistance as the y-axis, then $R_t - (R_{t-5} + R_{t+5})/2$ is the vertical distance between the point represented by coordinates (t, R_t), and the midpoint of the line joining the points (t − 5, R_{t-5}) and (t + 5, R_{t+5}). The estimate of rate of change of R with time during the period between the first bracket point and the transition point is $(R_t - R_{t-5})/5$, in units of kilohms per second. The rate of change of R in the second time period is $(R_{t+5} - R_t)/5$, in units of kilohms per second. The difference between these two, or $(2R_t - (R_{t-5} + R_{t+5}))/5$, is the difference in the slopes of the traces immediately before and after the transition point, and this was taken as the definition of the effect size of the sound/silence or silence/sound transition at that point.

References

Allen, R., & Heaton, P. (2010). Autism, music, and the therapeutic potential of music in alexithymia. *Music Perception, 27*(4), 251–261.

Allen, R., Hill, E., & Heaton, P. (2009). 'Hath charms to soothe…' An exploratory study of how high-functioning adults with ASD experience music. *Autism, 13*(1), 21–41.

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders* (4th Ed., text Revision. Ed.). Washington, DC: American Psychiatric Association.

Bagby, R. M., Parker, J. D. A., & Taylor, G. J. (1994). The 20-item Toronto-Alexithymia-Scale.1. Item selection and cross-validation of the factor structure. *Journal of Psychosomatic Research, 38*(1), 23–32.

Baron, R. M., & Kenny, D. A. (1986). The moderator mediator variable distinction in social psychological-research—Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology, 51*(6), 1173–1182.

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The Autism-spectrum quotient (AQ): Evidence from Asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders, 31*(1), 5–17.

Begeer, S., Koot, H. M., Rieffe, C., Terwogt, M. M., & Stegge, H. (2008). Emotional competence in children with autism: Diagnostic criteria and empirical evidence. *Developmental Review, 28*(3), 342–369.

Berthoz, S., & Hill, E. L. (2005). The validity of using self-reports to assess emotion regulation abilities in adults with autism spectrum disorder. *European Psychiatry, 20*(3), 291–298.

Bhatara, A. K., Quintin, E.-M., Heaton, P., Fombonne, E., & Levitin, D. J. (2009). The effect of music on social attribution in adolescents with autism spectrum disorders. *Child Neuropsychology, 15*(4), 375–396.

Bird, G., Silani, G., Brindley, R., White, S., Frith, U., & Singer, T. (2010). Empathic brain responses in insula are modulated by levels of alexithymia but not autism. *Brain, 133*, 1515–1525.

Blood, A. J., & Zatorre, R. J. (2001). Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *Proceedings of the National Academy of Sciences of the United States of America, 98*(20), 11818–11823.

Carlson, S., Rama, P., Artchakov, D., & Linnankoski, I. (1997). Effects of music and white noise on working memory performance in monkeys. *NeuroReport, 8*(13), 2853–2856.

Dellacherie, D., Roy, M., Hugueville, L., Peretz, I., & Samson, S. (2010). The effect of musical experience on emotional self-reports and psychophysiological responses to dissonance. *Psychophysiology, 48*(3), 337–349.

Dunn, L., Dunn, L., Whetton, C., & Burley, J. (1997). *British picture vocabulary scale*. London: NFER-Nelson.

Falkmer, M., Stuart, G. W., Danielsson, H., Bram, S., Lonebrink, M., & Falkmer, T. (2011). Visual acuity in adults with Asperger's syndrome: No evidence for "Eagle-Eyed" vision. *Biological Psychiatry, 70*(9), 812–816.

Fritz, T., Jentschke, S., Gosselin, N., Sammler, D., Peretz, I., Turner, R., et al. (2009). Universal recognition of three basic emotions in music. *Current Biology, 19*(7), 573–576.

Hala, S., Pexman, P. M., & Glenwright, M. (2007). Priming the meaning of homographs in typically developing children and children with autism. *Journal of Autism and Developmental Disorders, 37*(2), 329–340.

Harvey, D. I., Leybourne, S. J., & Taylor, A. M. R. (2009). Simple, robust, and powerful tests of the breaking trend hypothesis. *Econometric Theory, 25*(4), 995–1029.

Heaton, P. (2009). Speaking about music and the music of speech. *Brain, 132*(10), 2897–2899.

Heaton, P., Allen, R., Williams, K., Cummins, O., & Happe, F. (2008). Do social and cognitive deficits curtail musical understanding? Evidence from autism and Down syndrome. *British Journal of Developmental Psychology, 26*, 171–182.

Heaton, P., Hermelin, B., & Pring, L. (1999). Can children with autistic spectrum disorders perceive affect in music? An experimental investigation. *Psychological Medicine, 29*(6), 1405–1410.

Heider, F., & Simmel, M. (1944). An experimental study of apparent behavior. *The American Journal of Psychology, 57*(2), 243–259.

Hill, E., Berthoz, S., & Frith, U. (2004). Brief report: Cognitive processing of own emotions in individuals with autistic spectrum disorder and in their relatives. *Journal of Autism and Developmental Disorders, 34*(2), 229–235.

Howell, D. (2012). *Statistical methods for psychology* (8th Ed.). Belmont, CA: Wadsworth.

Huron, D. (2001). Is music an evolutionary adaptation? *Biological Foundations of Music, 930*, 43–61.

iWorx. (2011). *iWorx Psychophysiology Lab Manual*. Retrieved 20 March 2012, from http://www.iworx.com/LabExercises/lockedexercises/LockedGSRANL.pdf.

Juslin, P. N., & Sloboda, J. A. (2010). *Handbook of music and emotion: Theory, research, applications*. Oxford: Oxford University Press.

Juslin, P. N., & Vastfjall, D. (2008). Emotional responses to music: The need to consider underlying mechanisms. *Behavioral and Brain Sciences, 31*(5), 559–621.

Khalfa, S., Bruneau, N., Roge, B., Georgieff, N., Veuillet, E., Adrien, J. L., et al. (2004). Increased perception of loudness in autism. *Hearing Research, 198*(1–2), 87–92.

Khalfa, S., Isabelle, P., Jean-Pierre, B., & Manon, R. (2002). Event-related skin conductance responses to musical emotions in humans. *Neuroscience Letters, 328*(2), 145–149.

Kim, J., & Andre, E. (2008). Emotion recognition based on physiological changes in music listening. *IEEE Transactions on Pattern Analysis and Machine Intelligence, 30*(12), 2067–2083.

Koelsch, S. (2010). Towards a neural basis of music-evoked emotions. *Trends in Cognitive Sciences, 14*(3), 131–137.

Konecni, V. J. (2005). The aesthetic trinity: Awe, being moved, thrills. *Bulletin of Psychology and the Arts, 5*, 27–44.

Krumhansl, C. L. (1997). An exploratory study of musical emotions and psychophysiology. *Canadian Journal of Experimental Psychology-Revue Canadienne De Psychologie Experimentale, 51*(4), 336–353.

Levitin, D. (2006). *This is your brain on music*. New York: Dutton.

Lombardo, M. V., Barnes, J. L., Wheelwright, S. J., & Baron-Cohen, S. (2007). Self-referential cognition and empathy in Autism. *PLoS One, 2*(9), 11.

Lutkenhoner, B., Seither-Preisler, A., & Seither, S. (2006). Piano tones evoke stronger magnetic fields than pure tones or noise, both in musicians and non-musicians. *Neuroimage, 30*(3), 927–937.

Main, I. G., Leonard, T., Papasouliotis, O., Hatton, C. G., & Meredith, P. G. (1999). One slope or two? Detecting statistically significant breaks of slope in geophysical data, with application to fracture scaling relationships. *Geophysical Research Letters, 26*(18), 2801–2804.

McGregor, K. K., & Bean, A. (2012). How children with Autism extend new words. *Journal of Speech Language and Hearing Research, 55*(1), 70–83.

Mottron, L., & Burack, J. A. (2001). Enhanced perceptual functioning in the development of autism. In J. A. Burack, T. Charman, N. Yirmiya, & P. R. Zelazo (Eds.), *The development of autism: Perspectives from theory and research* (pp. 131–148). Mahwah, NJ: Lawrence Erlbaum Associates.

Mottron, L., Peretz, I., & Menard, E. (2000). Local and global processing of music in high-functioning persons with autism: Beyond central coherence? *Journal of Child Psychology and Psychiatry and Allied Disciplines, 41*(8), 1057–1065.

North, A. C., Hargreaves, D. J., & Hargreaves, J. J. (2004). Uses of music in everyday life. *Music Perception, 22*(1), 41–77.

North, A. C., Hargreaves, D. J., & O'Neill, S. A. (2000). The importance of music to adolescents. *British Journal of Educational Psychology, 70*, 255–272.

Peretz, I. (2001). Listen to the brain: A biological perspective on musical emotions. In P. Juslin & J. Sloboda (Eds.), *Music and emotion*. Oxford: Oxford University Press.

Plaisted, K. C. (2001). Reduced generalization in autism: An alternative to weak central coherence. In *Development of Autism: Perspectives from theory and research* (pp. 149–169). Mahwah: Lawrence Erlbaum Assoc Publ.

Quintin, E.-M., Bhatara, A., Poissant, H., Fombonne, E., & Levitin, D. J. (2011). Emotion perception in music in high-functioning adolescents with Autism spectrum disorders. *Journal of Autism and Developmental Disorders, 41*(9), 1240–1255.

Salimpoor, V. N., Benovoy, M., Larcher, K., Dagher, A., & Zatorre, R. J. (2011). Anatomically distinct dopamine release during anticipation and experience of peak emotion to music. *Nature Neuroscience, 14*, 257–262.

Salimpoor, V. N., Benovoy, M., Longo, G., Cooperstock, J. R., & Zatorre, R. J. (2009). The rewarding aspects of music listening are related to degree of emotional arousal. *PLoS One, 4*(10), e7487.

Schaefer, F., & Boucsein, W. (2000). Comparison of electrodermal constant voltage and constant current recording techniques using the phase angle between alternating voltage and current. *Psychophysiology, 37*(1), 85–91.

Soulieres, I., Mottron, L., Giguere, G., & Larochelle, S. (2011). Category induction in autism: Slower, perhaps different, but certainly possible. *Quarterly Journal of Experimental Psychology, 64*(2), 311–327.

Stewart, L. (2011). Characterizing congenital amusia. *Quarterly Journal of Experimental Psychology, 64*(4), 625–638.

Vorst, H. C. M., & Bermond, B. (2001). Validity and reliability of the Bermond-Vorst Alexithymia Questionnaire. *Personality and Individual Differences, 30*(3), 413–434.

Zentner, M., Grandjean, D., & Scherer, K. R. (2008). Emotions evoked by the sound of music: Characterization, classification, and measurement. *Emotion, 8*(4), 494–521.