DURMS
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The Relationship between Subclinical Autism and Absolute Pitch in Musicians and Non-Musicians

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ABSTRACT

This study integrates and develops research on absolute pitch (AP) and autism by extending theories of cognitive flexibility to non-musicians and the subclinical autistic population of young adults. Quantifying subclinical autism with the Autism-spectrum Quotient (AQ), and testing Western university students from a variety of musical backgrounds, the hypotheses were that, in this sample, AP ability would positively correlate with level of subclinical autism (AQ score); musicality would positively correlate with AP ability; and musicality would positively correlate with AQ score. AQ subscales most closely related to AP and musicality were anticipated to be imagination and attention switching. The hypotheses were partially supported by the results: the 3 aforementioned variables correlated as expected, but attention to detail and attention switching AQ subscales were found to most closely relate to AP group differences, and social skills and attention to detail most closely to musicality group differences. These results are explored in context of previous research, and proximate mechanisms are suggested regarding cognitive processing styles, concluding that young adults with a high level of subclinical autism, high musicality, and high AP ability, tend to have a local cognitive processing bias, but not at the expense of global processing. Finally, this study suggests that AP is likely affected by both genetic and environmental factors, but that partial AP is impacted more solidly by musical training.

1. INTRODUCTION

Autism is commonly defined as a developmental disorder characterised by a triad of impairments: socialization; communication; and cognitive and behavioural flexibility, including imagination (Boucher, 2009; Cashin & Barker, 2009; Happé, 1994). This definition is complex, however, as certain impairments are also assets (Frith and Happé, 1994), as has been suggested following the discovery of savant skills, 'skills that stand in stark contrast to…[an] overall handicap' (Snyder, 2006, p. 1399), possessed by many autistic people (Happé, 1994). Further complicating the definition of autism is the spectrum, previously defined as a continuum (Wing & Gould, 1979), of autistic traits found in the neurotypical population (Boucher, 2009). The Autism-spectrum Quotient (AQ) has been developed as a self-screening method for 'measuring the degree to which an adult with normal intelligence has the traits associated with the autistic spectrum' (Baron-Cohen, & Wheelwright, 2001, p. 5). The level of subclinical autism calculated by the AQ is based on the following subscales: social skills, attention switching, attention to detail, communication, and imagination.

Absolute pitch (AP) is the ability to produce or identify specific tones without reference to an external pitch (Baggaley, 1974). An estimated 0.01% of people have this ability (Takeuchi & Hulse, 1993). Levitin (1994) investigated this scarcity and developed a two-component theory of AP. He differentiated pitch memory from labelling, stating that whilst it is rare to possess both abilities, it is more common to possess one, accounting for partial AP possession.

Whilst Levitin's (1994) study was enlightening regarding the rarity of AP, it did not investigate the links between AP and autism. As mentioned above, autistic people have often been found to possess savant skills, and AP is one of these (Heaton, 2003; Snyder, 2006). Heaton, Hermelin, & Pring, (1998) found that musically naïve autistic children showed superior AP ability to mental-aged match controls, but whilst this study was useful for investigating non-musicians, it did not consider partial AP or subclinical autism. Brown et al. (2003) studied subclinical autism and its relation to AP but did not consider non-musicians or partial AP. They concluded that musicians with AP have more autistic traits than those without, and that the biggest group differences between AP possessors (APs) and controls were related to social skills and communication autistic traits. Dohn, Garza-Villareal, Heaton, & Vuust (2012) studied the relationship between subclinical autism, using the AQ, and AP in both musicians and non-musicians, but did not test for AP in non-musicians. Interestingly, Dohn et al. found the biggest group differences between APs and non-APs to be related to imagination and attention switching AQ subscales. Such divergent results expose the conflicting theories about cognitive mechanisms that underlie AP (of which will be unpacked in this report's discussion), whilst also suggesting a need for further research regarding the relationship between AP and the AQ.

Gaps in this field of research, therefore, include studies that assess the relationship between subclinical autism and AP (including its partial form) in both musicians and non-musicians. By aiming to fill this gap, and looking closely at AQ subscales, this study hopes to contribute to wider debates surrounding AP, and whether it is genetic, a learnt ability linked to musical training,[1] or a mixture of both (Chin, 2003).[2] This contribution should also be aided by the study of young adults in a field that often only looks at children in a 'critical age period' of 4-8 years (Takeuchi & Hulse, 1993).

This study hypothesises that: In young adults, AP ability will positively correlate with level of subclinical autism (AQ

[1] It is estimated that 15% of musicians are APs (Baharloo et al., 1998).

[2] Note that whilst it is important to understand this debate in order to contribute to it, this investigation will not be a full elucidation of such discussions.

score); musicality will positively correlate with AP ability; and musicality will also positively correlate with AQ score, justified by the anticipated relationship between the 2 formerly predicted correlations, and Chin's (2003) suggestions that both genetics and environmental factors affect AP possession.

AQ subscales most closely related to AP ability and musicality are anticipated to be imagination and attention switching, as was suggested by Dohn et al. (2012), who published their study after consideration of both Brown et al.'s (2003) and Chin's (2003) important contributions to this domain of literature. Whilst the relationship between AQ subscales and musicality has not previously been assessed, I anticipate that it will be similar to that between the AQ and AP, due to the predicted relations between the 3 variables, as previously stated.

2. METHOD

Design. Independent variables were AP ability and musicality of participants (both continuous), and the dependent variable was their AQ scores. All participants completed all tasks but were later split into groups for between-participants analyses.

Participants. 32 UK university students from Western backgrounds took part (15 males and 17 females, mean age = 20.2 years, range = 19-22). All participants were unpaid volunteers, recruited through social media, who were first given an information sheet, before giving signed consent.

Studying only university students accounted for intellectual similarity, without requiring additional tests that could have resulted in fatigue before primary tests. Baron-Cohen et al. (2001) found that science students scored higher than others on the AQ, and that males scored higher than females. This study, therefore, recruited students from a range of degree subjects (17 arts and 15 sciences), and a mix of genders, to study a range of the autism spectrum, whilst also investigating Baron-Cohen et al.'s (2001) findings as auxiliary studies.

A range of musical abilities were studied because Chin (2003, p. 165) stated that to uncover information about genetics and AP's cognitive mechanisms, researchers 'need to stop assuming that there is no way to test for AP in people with no music training'.

A Western, educated, industrialized, rich and democratic sample was intentionally used, despite potentially being perceived as problematically narrow (Henrich, Heine, & Norenzayan, 2010; Savage, Brown, Sakai, and Currie. 2015), because a higher prevalence of AP has been reported among East Asian populations (Gregersen, Kowalsky, Kohn, & Marvin, 1999), and this could have over-complicated results.

No volunteers were excluded, and none are known to have serious hearing or vision impairments.

Materials and stimuli. All materials and stimuli used were either inspired by previous experimental studies or justified by the pilot experiment. A general information questionnaire (Appendix 1) was used to obtain demographic information about participants' age, gender, degree subject, and genetic relations to those known to have AP and/or be diagnosed with autism.

A condensed version of the Goldsmith's Musical Sophistication Index (Gold-MSI) questionnaire was used to assess musicality (Appendix 2). Whilst this questionnaire is less objective than the Musical Ear Test used in Dohn et al.'s study (2012), it could not easily interfere with the Pitch Identification Test (PIT) due to it being a written measure.

The AQ was used to measure subclinical autism (Appendix 3), as was used by Dohn et al. (2012). This is a more objective method than using qualitative data from interviews, as Brown et al. (2003) did. The AQ questionnaire comprises 50 questions, each requiring participants to choose how much they agree with a statement. 10 questions assess each of the 5 autistic traits (social skills, attention switching, attention to detail, communication, and imagination).

A PIT was used, inspired by Heaton et al.'s (1998) study, to measure AP ability. It assessed pitch reception rather than production, for production is a rarer ability (Mottron, Peretz, Belleville, & Rouleau, 1999; Takeuchi & Hulse, 1993). This test could be taken by musicians and non-musicians alike, and comprised 3 parts: familiarization, distraction, and examination. Familiarization involved participants learning to associate 4 different sine tones with 4 different, randomly assigned visual icons. Sine tones were used because timbre has been found to be related to AP possession in some individuals, and pianists have been found to identify piano pitches more readily than other instruments (Chin, 2003). The 4 sine tones chosen were C_4 (261.63Hz), E_4 (329.628Hz), G_4 (391.995Hz), and B_4 (493.88Hz), corresponding to 4 black shapes, as in Figure 1. Rationale for these tones is that the 4-semitone interval between each is small enough to be difficult to remember (Heaton, Pring, & Hermelin, 2001), but not too small that recognition is impossible (Levitin, 1994).[3] The distraction period involved participants watching a 2.5-minute extract of the Queen's Christmas Speech (2018).[4]

C_4 E_4 G_4 B_4

Figure 1. Icons and their associated sine tones used in the main experiment

The pilot experiment was a between-participants design that aided the decision to use the black shape icons and the Queen's speech distraction video in the main experiment's PIT. 20 UK university students (8 males and 12 females, mean age = 19.9 years, range = 18-21), of whom were not part of the main experiment, took part. All participants were unpaid volunteers, recruited through social media, who were first given an information sheet, before giving signed consent. They were asked verbally their age and gender, whether they

[3] AP was tested via individual abstract tones, rather than melodic contours, because Heaton et al. (2001) found discrepancies due to developmental differences in adults when processing different-length stimuli, and additional variables such as the implication-realization theory could affect the study if contours were used (Narmour, 2015).

[4] Participants watched from 1:08-3:38.

knew if they had AP, and whether they were musically trained (classified as achieving performance grade 5 or above, for simplicity). None were known to be true AP possessors, and there were 6 musicians and 14 non-musicians. The participants then completed the PIT (see *Procedure*) using different conditions (icons and distraction techniques), depending on their randomly assigned groups. Sets of icons used can be seen in Figure 2, and the assignment of groups to conditions, and their PIT scores are shown in Appendices 4.1 and 4.2. Following the PIT, participants were asked how they associated the tones with the icons, if they used a conscious method, and how well distracted they felt they were (see Appendix 4.3). Cartoon vehicles and animal icons were discounted for sound-association reasons. Coloured shapes were discounted for synaesthesia complications, as was highlighted by one participant and supported by related literature that states '[autistic savant] skills are accompanied…a high incidence of…AP and synaesthesia' (Snyder, 2006, p. 1399). An Obama speech (2017) distraction was discounted due to clear pitch emphases of audience cheers, and an experimenter-read extract (Appendix 4.4) was discounted for poor consistency across tests.

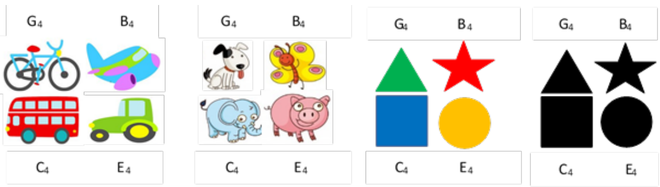

Figure 2. Icons and their associated sine tones used in the pilot experiment

Procedure. The main and pilot experiments took place in a small, quiet room in Butler College, Durham. Each participant completed all activities with only the experimenter present, and tasks were completed in the order explained in the *Materials and stimuli* section of this report.

The GMSI questionnaire answers gave a continuum of results between 2 and 5.85 (it is possible to score between 1 and 7, higher scores are most musical), meaning that a median split could be used to assign participants into groups of high or low musicality for analysis.

For each question on the AQ questionnaire, points were scored 'if the respondent record[ed] the abnormal or autistic-like behaviour either mildly or strongly' (Wakabayashi, Baron-Cohen, Wheelwright, & Tojo., 2006, p. 264). Methodology for marking the questionnaire can be found in Appendix 3.2.

In the PIT, the 4 sine tones were played to participants for 2.5 seconds, at 3-second intervals, as in Brown et al.'s (2003) study, in a randomised order over 48 trials (12 times for each tone). During this time, the experimenter pointed to, and spoke the name of, the icons which were on pieces of paper on the table in front of the participant. Tones were played on Audacity, through laptop speakers at a constant volume that was consistent across participants. During the distraction period, participants were asked to mouth the word 'pat' repeatedly, as an articulatory suppression task to inhibit memory performance as they watched the Queen's speech. The examination period of the PIT required participants to identify 16 tones as either one of the 4 icon-associated tones, or 'other' (tones within 2 semitones of icon-associated tones). Marks were given for correct answers only, and a percentage score was calculated for AP ability, which allowed the assignation of High AP and Low AP groups to be formed from a median split method (separately from the musicality groups).

Finally, all participants were given a verbal debrief.

3. RESULTS

Before stating the main results, it should be noted that only 3 participants were closely genetically related to people diagnosed with autism, and only 2 (separate to the aforementioned 3) to known APs. Such values are small enough to discount any major genetic interferences that may have skewed results.

Correlations. 3 positive correlations were found: 1) between AP ability and AQ score ($r = .04$); 2) between musicality and AP ability ($r = .64$); and 3) between musicality and AQ score ($r = .39$). All 3 correlations were statistically significant (see Table 1). The correlation between musicality and AP ability was notably larger than that between AP ability and AQ score. Figure 3 shows a visual representation of the 3 correlations together. There are 30 points on the graph despite there being 32 participants, because 2 participants both had an AQ of 12 and scored 87.5% in the PIT test (one grouped as Low Musicality, and one high, hence the point is coloured both red and green). A different 2 participants both had an AQ of 17, scored 100% in the PIT test, and were in the High Musicality group. Except for one, all participants had an AQ score of lower than 32, which is considered to be the criteria clinical autism diagnosis (Baron-Cohen et al., 2001).

Table 1. Descriptive and Inferential Statistics for Correlations between all Variables

Variables correlated	Correlation (r)	t-value	df	p-value
AP-AQ	.39	2.29	30.00	.03
Musicality-AP	.64	4.53	30.00	< .001
Musicality-AQ	.39	2.34	30.00	.03

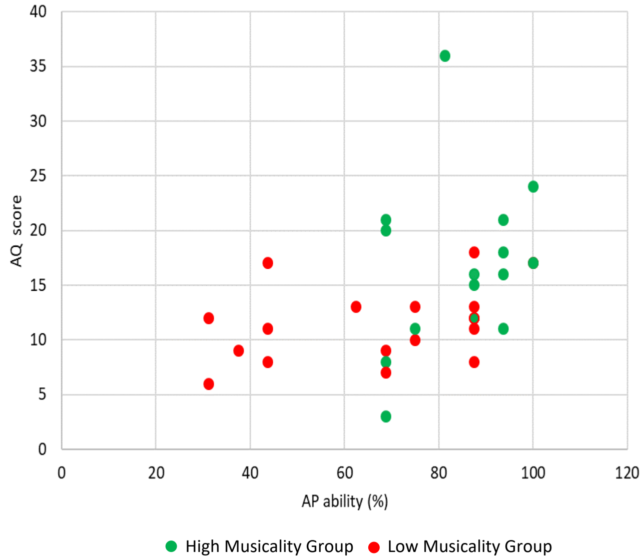

Figure 3. A graph to show the correlation between AP ability and AQ score of university students (Musicality groups are colour coded to give a visual representation of how 3 variables relate)

AQ Subscales. Descriptive and inferential statistics for the AQ subscale scores of the 2 AP groups are shown in Table 2, and of the 2 musicality groups in Table 3. Attention switching and attention to detail were the AQ subscales with the strongest relationship to AP group differences (differences in mean scores between groups = 1.50 and 1.75, respectively), and both group differences related to these traits were statistically significant (p = .01 for both). Social skills and attention to detail were the AQ subscales with the strongest relationship to musicality group differences (differences in mean scores between groups = 1.50 and 2.00, respectively), and again these group differences were both statistically significant (ps < .05). Other autistic traits did not show statistical significance in their relationships to group differences in either AP or musicality. Visual representations of these results are shown in Figure 4 (AP groups analysis) and Figure 5 (musicality groups analysis), with error bars showing standard deviations. Standard deviation values were similar in the 2 AP groups for each AQ subscale, and also in the 2 musicality groups for each AQ subscale, meaning that the results should be reliable.

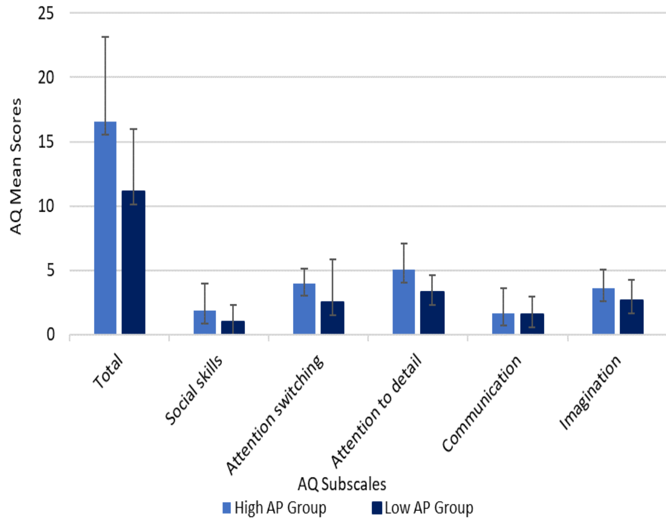

Figure 4. Group differences between High AP and Low AP ability relating to AQ subscales

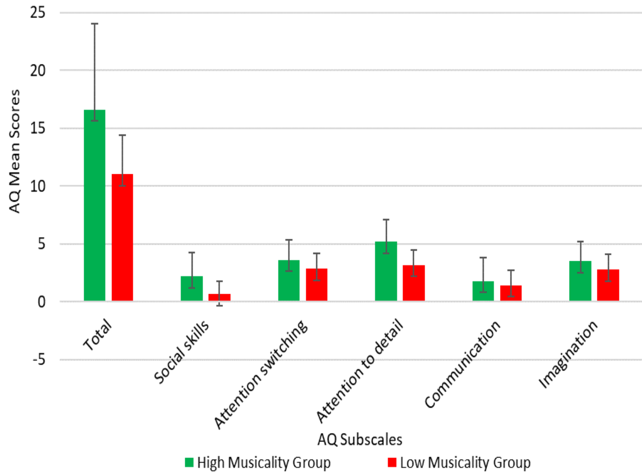

Figure 5. Group differences between High Musicality and Low Musicality relating to AQ subscales

Table 2. Descriptive and Inferential Statistics for the AQ Subscale Scores of Low AP and High AP Groups

AQ subscale	M Low AP group	SD Low AP group	M High AP group	SD High AP group	Diff. mean scores between groups	t-value	df	p-value
Total	11.13	4.88	16.56	6.58	5.43	2.65	27.67	.01
Social skills	1.00	1.34	1.88	2.07	.88	1.42	26.05	.17
Attention switching	2.50	3.36	4.00	1.14	1.50	3.05	29.96	.01
Attention to detail	3.31	1.30	5.06	2.05	1.75	2.88	25.42	.01
Communication	1.56	1.41	1.69	1.92	.13	0.21	27.54	.84
Imagination	2.69	1.58	3.63	1.41	.94	1.77	29.61	.09

Table 3. Descriptive and Inferential Statistics for the AQ Subscale Scores of Low Musicality and High Musicality Groups

AQ subscale	M Low Musicality group	SD Low Musicality group	M High Musicality group	SD High Musicality group	Diff. in mean scores between groups	t-value	df	p-value
Total	11.06	3.34	16.63	7.44	5.57	2.73	20.80	.01
Social skills	.69	1.08	2.19	2.04	1.50	2.60	22.77	.02
Attention switching	2.88	1.31	3.63	1.75	0.75	1.37	27.82	.18
Attention to detail	3.19	1.28	5.19	1.94	2.00	3.45	25.94	.002
Communication	1.44	1.26	1.81	2.01	0.37	0.63	25.27	0.53
Imagination	2.81	1.33	3.50	1.71	0.69	1.27	28.24	0.22

Auxiliary Investigations. Motivated by the benefits of a varied sample, this study investigated the relationship between gender and AQ scores, and between degree subject studied and AQ scores, in addition to the primary inquiries surrounding the hypotheses. It was found, within this sample, that neither gender nor degree subject had a statistically significant relationship with AQ scores (see Tables 4 and 5).

Table 4. Descriptive and Inferential Statistics to Show the Relationship between Gender and AQ Score

	M females	M males	Diff. mean scores between genders	t-value	df	p-value
Total AQ score	15.44	11.79	3.65	1.75	29.44	.09

Table 5. Descriptive and Inferential Statistics to Show the Relationship between Degree Subject Studied and AQ Score

	M arts students	M science students	Diff. mean scores between degree subjects studied	t-value	df	p-value
Total AQ score	13.82	13.87	.05	-.02	24.01	.99

4. DISCUSSION

This study's hypotheses were partially supported by the results. All 3 variables correlated with one another, as predicted: AP ability positively correlated with AQ score, musicality positively correlated with AP ability, and musicality positively correlated with AQ score. The correlation between musicality and AP ability was notably larger than that between AP ability and AQ score, suggesting that partial AP could be more of a learnt ability than a genetic one.

It was anticipated that AQ subscales most closely related to both AP ability and musicality would be imagination and attention switching. Results of this study found attention switching and attention to detail to be the autistic traits with the strongest relationship to AP group differences, partially supporting the hypothesis, and Dohn et al. (2012). Social skills and attention to detail were the AQ subscales with the strongest relationship to musicality group differences. This finding, again, partially supports the hypothesis, for whilst significant group differences in musicality were not found to relate to the subscales predicted, attention to detail was significantly related to group differences in both AP ability and musicality, and it was hypothesised that the relationship between AQ subscales and musicality would be similar to that between AQ subscales and AP ability.

Proximate mechanism. The 3 correlations, and the unexpected strength of the relationship between attention to detail and AP ability and musicality, will now be analysed in the context of related literature. Unanticipated results may be accounted for by the 'uncertainty surrounding the neural mechanisms that may underlie AP' (Zatorre, Perry, Beckett, Westbury, & Evans 1998, p. 3172). There are many theories about AP and its relationship to autism, but there remains to be agreement amongst many, as will be explored here. Whilst theories about partial AP and subclinical autism in musicians and non-musicians are lacking, Gokcen, Frederickson, & Petrides,. (2016, p. 2072) state that 'individuals with elevated levels of autism-like traits experience a…similar pattern of social and executive function difficulties to those diagnosed with autism', so such studies will be assessed in attempt to rationalise this study's results. The difference between high subclinical autism and diagnosed autism may remain accountable for some discrepancies, however.

Executive dysfunction theory is a key account of autism, referring to a lack of cognitive flexibility. It often relates to AP studies due to its helpfulness in explaining uneven intelligence profiles (Dohn et al., 2012; Frith and Happé, 1994; Heaton et al., 1998). Dohn et al. (2012) highlighted that 'difficulties in attention switching are associated with poor cognitive flexibility…and may be associated with an analytical cognitive style', and therefore it is logical to suggest that the results of this study may support the executive dysfunction theory.

Part of the executive dysfunction theory is the weak central coherence theory, which supports that the cognitive style of those with autism favours local processing at the expense of global processing (Happé, 1999; Heaton, 2003). Whether a local processing cognitive style, also referred to as an analytical or field independent cognitive style (Chin, 2003), is necessary for the possession of AP is debated. Heaton et al. (1998) and Brown et al. (2003) support that it is necessary, but Schlemmer failed to find evidence for a higher field independence among APs compared to non-APs (2009), and Dohn et al. (2012) stated that 'it does not appear that local processing style is a necessary precursor for AP in individuals with autism', because AP group differences were not closely related to attention to detail in their study. Such divergences may be accounted for by experimental differences (Frith and Happé, 1994; Heaton, 2003), but given that both AP and musicality group differences were closely related to attention to detail in the results of this study, it is reasonable to suggest that a local processing cognitive style is a necessary precursor for high partial AP ability, and is often found in those who are both musically trained and score highly on the AQ.

Whether the honing of local processing occurs at the expense of global processing is also a prevalent debate related to autism and AP studies. Stoesz, Jakobson, Kilgour, & Lewycky. (2007) assert that musical training lessens global bias, because there are structural differences in processing regions of the brain that have been found to relate to when a musician began training. Mottron et al. (1999), however, believe that simple deficit mechanisms, used to explain links between autism and AP, are inadequate for studying musicians, because musical training involves relative pitch recognition, a skill that relies on global processing. Such complications may account for the differences in AQ subscales that were related to AP ability group differences and musicality group differences in this study, such as the lack of poor attention switching found in those in the high musicality group. This supports that whilst a local processing bias may exist in individuals displaying many autistic traits, it is unlikely that, for musicians, it is accounted for by a deficit in global processing (Mottron, Peretz, & Menard, 2000).

The close relationship between autism-like social skills and group differences in musicality cannot be explained by the weak central coherence theory, and may require further analysis of the theory of mind account of autism that makes predictions about impairments in socialization, imagination, and communication (Cashin and Barker, 2009; Frith and Happé, 1994), but does not closely relate to debates about local and global cognitive processing.

Suggestions for future research. Suggested mechanisms that could explain this study's results are merely speculative, due to the lack of physiological exploration, and variable manipulation used in this study. Pertinent physiological studies include Bianchi et al.'s (2017), that found that musicians with higher partial AP ability show more activity in the right auditory cortex of the brain, meaning greater involvement of the left hemisphere, an area of the brain which specializes in local processing (Stoesz et al., 2007). Brown et al. (2003), Chin (2003), and Zatorre et al. (1998) all refer to the idea that AP musicians show a different pattern of cerebral blood flow when listening to music than non-AP musicians do, indicating a leftward asymmetry of the planum temporale. This also corroborates ideas that local processing cognitive styles are advantageous. Zatorre et al. (1998) found that APs did not need to access working memory mechanisms to identify pitches, whereas non-APs did, showing that they were in fact using relative pitch ability to label tones. This was discovered by looking at activity in the right inferior frontal cortex of the brain, also though measuring cerebral blood flow, which was accessed in non-APs, but not APs. Without measuring cerebral blood flow during the PIT, the line between partial AP and relative pitch may have become blurred in my experiment, so I suggest that future replications of this study measure cerebral blood flow.

Other limitations of this study may have also affected the results. Using a sample of only 32 participants means that median splits used to create AP and musicality groups may not have been accurately representative. Future replications could use a larger sample size and create extreme quartile groups. Additionally, assuming intellectual balance, based on the simple criteria of attending university, was not as accurate as an intelligence quotient test would have been. The subjective, self-rating nature of the AQ questionnaire is not infallible, so a future study could use additional tests to measure each autistic trait alongside the AQ. Suggested tests are a 2-factor-imagination-scale to measure imagination (Thompson, 2008), the empathy quotient to measure socialization and communication (Baron-Cohen and Wheelwright, 2004), the Piagetian AB Task for attention switching (Piaget, 1954) , and the visual Block Design test for attention to detail (Wechsler, 1997).

The PIT distraction period may have needed to be longer, to ensure that partial AP ability was in fact partial AP ability and not relative pitch ability. Heaton et al. (1998) did a second PIT after a week's distraction, something that I recommend, considering that Levitin (1994) found that 'local information processing leads to stable long-term representations with a capacity for…pitch memory and pitch labelling'.

Materials and stimuli used may have unintentionally influenced this study's results. Whilst the pilot test attempted to ensure choices were justified, the sample used was very small and statistical significance of its results were not calculated, and therefore justifications may not have been fully supported. O'Boyle and Tarte (1980, p. 535) examined the relationship between pure tone frequencies and geometric figures and found that 'round figures…generally received lower frequency assignments than other figures'. Whilst this factor could have only impacted 1 of 4 stimuli used, other similar factors may have been at play, so interviews following the PIT to uncover this are suggested if this studied is replicated.

5. CONCLUSION

This study has achieved its aims to develop previous research on AP and autism, by extending theories of cognitive flexibility to non-musicians, partial APs, and the subclinical autistic population of young adults. It was found that the level of subclinical autism in young adults positively correlated with both AP ability and musicality, and the latter 2 variables were also positively correlated. Attention to detail and attention switching AQ subscales were found to most closely relate to AP group differences, and social skills and attention to detail were most closely related to musicality group differences, rendering the hypotheses partially supported. Such results are likely due to the tendency for young adults with more autistic traits, higher musicality, and high AP ability to have a local cognitive processing bias. This study's findings, however, 'challenge the notion that [this] is accounted for by a deficit in global…processing' (Mottron et al., 2000: 1057), particularly in those with high musicality. This conclusion was reached following the necessary consideration of several mechanisms. Finally, regarding the genetics versus environmental debate, this study found that AP is likely affected by both genetic and environmental factors, due to the cognitive brain processes that may be affected by both autistic traits and musical training. A stronger correlation, however, was exposed between musicality and AP ability than between autistic traits and AP ability, suggesting that partial AP is impacted more solidly by environmental factors than genetics.

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APPENDICES

Appendix 1: General Information Questionnaire for Main Experiment Participants.

General Information Questionnaire

Participant Number: ________

Name: ______________________________

Age: ________

Degree Subject: ____________________

Gender (this question is optional): _______________

Do you possess absolute pitch ability? (please circle as appropriate): Yes | No

Is anyone in your immediate family, that you know of, diagnosed with clinical autism? (please circle as appropriate):
Yes | No

If you answered 'yes' to the above question, what relation is this person to you? _________________________

Does anyone in your immediate family, that you know of, possess absolute pitch ability? (please circle as appropriate):
Yes | No

If you answered 'yes' to the above question, what relation is this person to you? _________________________

Appendix 2: Condensed Goldsmith's Musical Sophistication Index Questionnaire.

(The Goldsmiths Musical Sophistication Index v1.0, 2012)

14 of 43 questions in the full questionnaire have been selected for use. This is to both prevent fatigue in participants and remove irrelevant questions to the type of musical ability needed to be assessed for this study.

1	2	3	4	5	6	7
Completely Disagree	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Completely Agree

Please circle the number that corresponds to the most appropriate category above for each question below:

I spend a lot of my free time doing music-related activities: 1 / 2 / 3 / 4 / 5 / 6 / 7

I usually know when I'm hearing a song for the first time: 1 / 2 / 3 / 4 / 5 / 6 / 7

If somebody starts singing a song I don't know, I can usually join in: 1 / 2 / 3 / 4 / 5 / 6 / 7

I can tell when people sing or play out of tune: 1 / 2 / 3 / 4 / 5 / 6 / 7

Pieces of music rarely evoke emotions for me: 1 / 2 / 3 / 4 / 5 / 6 / 7

I can sing or play music from memory: 1 / 2 / 3 / 4 / 5 / 6 / 7

I can compare and discuss differences between two performances or versions of the same piece of music: 1 / 2 / 3 / 4 / 5 / 6 / 7

I have never been complimented for my talents as a musical performer: 1 / 2 / 3 / 4 / 5 / 6 / 7

I would not consider myself a musician: 1 / 2 / 3 / 4 / 5 / 6 / 7

I engaged in regular, daily practice of a musical instrument (including voice) for 0 / 1 / 2 / 3 / 4-5 / 6-9 / 10 or more years.

At the peak of my interest, I practiced 0 / 0.5 / 1 / 1.5 / 2 / 3-4 / 5 or more hours per day on my primary instrument.

I have had formal training in music theory for 0 / 0.5 / 1 / 2 / 3 / 4-6 / 7 or more years.

I have had 0 / 0.5 / 1 / 2 / 3-5 / 6-9 / 10 or more years of formal training on a musical instrument (including voice) during my lifetime.

I can play 0 / 1 / 2 / 3 / 4 / 5 / 6 or more musical instruments.

Appendix 3: Autism-spectrum Quotient Information.

3.1: AQ questionnaire (as was given to participants).

PARTICIPANT NUMBER: ______ **Tick one response that best describes how strongly each item applies to you.**	**Definitely agree**	**Slightly agree**	**Slightly disagree**	**Definitely disagree**
1. I prefer to do things with others rather than on my own.				
2. I prefer to do things the same way over and over again.				
3. If I try to imagine something, I find it very easy to create a picture in my mind.				
4. I frequently get so strongly absorbed in one thing that I lose sight of other things.				
5. I often notice small sounds when others do not.				
6. I usually notice car number plates or similar strings of information.				
7. Other people frequently tell me that what I've said is impolite, even though I think it is polite.				
8. When I'm reading a story, I can easily imagine what the characters might look like.				
9. I am fascinated by dates.				
10. In a social group, I can easily keep track of several different people's conversations.				
11. I find social situations easy.				
12. I tend to notice details that others do not.				
13. I would rather go to a library than to a party.				
14. I find making up stories easy.				
15. I find myself drawn more strongly to people than to things.				
16. I tend to have very strong interests, which I get upset about if I can't pursue.				
17. I enjoy social chitchat.				
18. When I talk, it isn't always easy for others to get a word in edgewise.				
19. I am fascinated by numbers.				
20. When I'm reading a story, I find it difficult to work out the characters' intentions.				
21. I don't particularly enjoy reading fiction.				
22. I find it hard to make new friends.				
23. I notice patterns in things all the time.				
24. I would rather go to the theatre than to a museum.				

25. It does not upset me if my daily routine is disturbed.				
26. I frequently find that I don't know how to keep a conversation going.				
27. I find it easy to "read between the lines" when someone is talking to me.				
28. I usually concentrate more on the whole picture, rather than on the small details.				
29. I am not very good at remembering phone numbers.				
30. I don't usually notice small changes in a situation or a person's appearance.				
31. I know how to tell if someone listening to me is getting bored.				
32. I find it easy to do more than one thing at once.				
33. When I talk on the phone, I'm not sure when it's my turn to speak.				
34. I enjoy doing things spontaneously.				
35. I am often the last to understand the point of a joke.				
36. I find it easy to work out what someone is thinking or feeling just by looking at their face.				
37. If there is an interruption, I can switch back to what I was doing very quickly.				
38. I am good at social chitchat.				
39. People often tell me that I keep going on and on about the same thing.				
40. When I was young, I used to enjoy playing games involving pretending with other children.				
41. I like to collect information about categories of things (e.g., types of cars, birds, trains, plants).				
42. I find it difficult to imagine what it would be like to be someone else.				
43. I like to carefully plan any activities I participate in.				
44. I enjoy social occasions.				
45. I find it difficult to work out people's intentions.				
46. New situations make me anxious.				
47. I enjoy meeting new people.				
48. I am a good diplomat.				
49. I am not very good at remembering people's date of birth.				
50. I find it very easy to play games with children that involve pretending.				

3.2: AQ scoring method (unknown to participants).

The AQ comprises 50 questions (or items) - 10 relating to each of the 5 autistic subscales, as follows:

Social skill: Items 1, 11, 13, 15, 22, 36, 44, 45, 47, 48.

Attention switching: Items 2, 4, 10, 16, 25, 32, 34, 37, 43, 46.

Attention to detail: Items 5, 6, 9, 12, 19, 23, 28, 29, 30, 49.

Communication: Items 7, 17, 18, 26, 27, 31, 33, 35, 38, 39.

Imagination: Items 3, 8, 14, 20, 21, 24, 40, 41, 42, 50.

One point is scored for each item that the participant ticks relating to the 'abnormal' or autistic-like behaviour either mildly or strongly. Abnormality is classified by 'poor social skill, poor communication skill, poor imagination, exceptional attention to detail, and poor attention-switching/strong focus of attention' (Wakabayashi et al. 2006).

Agreement with the following items meant that points were score for abnormality: 1, 2, 4, 5, 6, 7, 9, 12, 13, 16, 18, 19, 20, 21, 22, 23, 26, 33, 35, 39, 41, 42, 43, 45, 46.

Disagreement with the following items meant that points were score for abnormality: 3, 8, 10, 11, 14, 15, 17, 24, 25, 27, 28, 29, 30, 31, 32, 34, 36, 37, 38, 40, 44, 47, 48, 49, 50.

With some items relating to abnormality through agreement, and others through disagreement, biased responses are mostly mitigated.

Appendix 4: Pilot Experiment Details.

4.1: Assignment of groups to icons and distraction techniques.

Table 6. Participant Assignments to Groups in the Pilot Experiment[5]

Group Number	Total number of participants	Gender split (Male: Female)	Musicality split (Musician: Non-musician)
1	2	1:1	0:2
2	2	1:1	1:1
3	2	1:1	1:1
4	2	0:2	0:2
5	2	1:1	1:1
6	2	1:1	0:2
7	2	0:2	1:1
8	2	0:2	1:1
9	1	1:0	0:1
10	1	1:0	1:0
11	1	0:1	0:1
12	1	1:0	0:1

Table 7. Group Assignments to Conditions in the Pilot Experiment

Distraction techniques \ Icons	Black shapes	Coloured shapes	Cartoon vehicles	Cartoon animals
Barack Obama Speech[6]	1	2	3	4
Queen's Speech	5	6	7	8
Experimenter-read extract	9	10	11	12

4.2: PIT scores of groups.

Table 8. PIT Scores of Participants in Pilot Experiment Groups

Group Number	PIT scores (participant 1: participant 2 - where applicable)
1	81.25% : 43.75%
2	31.25% : 43.75%
3	62.5% : 43.75%
4	62.5% : 62.5%
5	81.25% : 75%

[5] Note that groups 9-12 are singular participants, rather than groups, because a limited number of students volunteered for the pilot experiment. They are still referred to as groups because 12 condition variations needed to be assessed, and called them groups keeps the assessment explanations consistent and clear.

[6] The video was watched from 0:11-2:43.

6	68.75% : 100%
7	100% : 62.5%
8	93.75% : 87.5%
9	75%
10	87.5%
11	93.75%
12	87.5%

As Table 8 shows, a range of AP abilities was evident in the sample of the pilot experiment. Participants in group 5, using the materials that were selected for the main experiment, both scored relatively high, but not getting 100%, suggesting that the difficulty of the distraction period and random allocation of the icons to tones was most suitable here.

4.3: Participants' conscious methods for associating icons with tones.

Whilst the sample of this pilot experiment was very small, and the PIT score of 1 or 2 participants per condition will not have given a fully reliable account of which icons and distraction techniques are most suitable, verbal explanations for how participants associated tones with icons (if they used a conscious method) and how well distracted they felt they were, also influenced decisions regarding the main experiment's materials. Such verbal explanations have been simplified and are shown in Table 9.

Table 9. Verbal Feedback on Pilot Experiment Conditions

Participant number	Group number	Notable verbal feedback
1	1	No conscious methods for tone associations. Felt fairly distracted.
2	1	No conscious methods for tone associations. Felt confused in the distraction period due to intermittent audience cheers in the video sounding similar to the pitch of the sine tones.
3	2	Confused by the yellow shape not being the highest pitch, as always associates yellow with higher pitches.[7] Felt confused in the distraction period due to intermittent audience cheers in the video sounding similar to the pitch of the sine tones.
4	2	No conscious methods for tone associations. Felt fairly distracted.
5	3	No conscious methods for tone associations. Felt fairly distracted.
6	3	No conscious methods for tone associations. Felt very distracted.
7	4	No conscious methods for tone associations. Felt fairly distracted.
8	4	Associated the height that a butterfly flies at to the high tone associated with it. Felt very distracted.
9	5	No conscious methods for tone associations. Felt fairly distracted.
10	5	No conscious methods for tone associations. Felt fairly distracted.
11	6	No conscious methods for tone associations. Felt fairly distracted.
12	6	No conscious methods for tone associations. Did not feel very distracted at all.
13	7	Associated the height that an aeroplane flies at to the high tone associated with it. Felt fairly distracted.

[7] It would seem that this statement relates to theories of sound-colour and colour-sound synaesthesia and chromesthesia (de Thornley Head 2006; Goller et al. 2009), which could complicate and distract from the main study.

14	7	No conscious methods for tone associations. Felt very distracted.
15	8	Associated the large body of an elephant to a large instrumental body with a low tone. Felt fairly distracted.
16	8	No conscious methods for tone associations. Felt fairly distracted.
17	9	No conscious methods for tone associations. Felt very distracted.
18	10	No conscious methods for tone associations. Did not feel very distracted at all.
19	11	No conscious methods for tone associations. Did not feel very distracted at all.
20	12	No conscious methods for tone associations. Felt fairly distracted.

The conditions assigned to group 5 were chosen for the main experiment, for no conscious methods were used for tone association with black shapes, and participants both felt fairly distracted by the Queen's speech.

4.4: Extract read by experimenter for distraction as a pilot experiment condition.

This speech is taken from Fearless Motivation (2018). It takes roughly 2.5minutes to read through:

'It's easy to have FAITH everything is going to work out, when everything IS working out.
It's much harder to have faith when you are facing challenges in your life. But that is exactly when you need to apply your faith. Because faith is believing in the unseen. Faith is taking the first step. Faith is jumping in the deep end and KNOWING everything will be OK. It's easy to be positive when everything is working out… It's much harder, much, much harder when nothing is working out….But that's when we need it the most.

EVERYTHING IS WORTH THE PRIZE!
EVERYTHING IS WORTH THE FIGHT!

Everything worth the prize will require a real fight to achieve that prize. If you want the prize, you can't quit at half time. You can't quit mid-season. You must play the whole game. Pre-season, through the cold, through darkness, through the challenges, the opponents.You will be knocked down… but you MUST GET UP. KEEP FIGHTING. DIG DEEP and discover your true STRENGTH. Then you will win the real prize: CHARACTER. EXPANSION. YOU, rising to the next level.

IF I SURVIVE THE STORM, I CAN OUTDO THE NORM.
TO BREAKTHROUGH THE NORM, I MUST FIRST SURVIVE THE STORMS.
TO HAVE MORE THAN MOST – I MUST DO MORE THAN MOST. BELIEVE MORE THAN MOST. LEARN MORE THAN MOST. SACRIFICE MORE THAN MOST. BELIEVE MORE THAN MOST.

LONG TERM, I know what I need will come my way.
LONG TERM, I know if I keep at it I will be rewarded.
LONG TERM, I know consistency pays off.
LONG TERM I know all my actions, all my discipline all my integrity will pay off in a big way.

I HAVE FAITH everything will work out. IN THE END all will be fine… IF I KEEP WORKING. IF I KEEP LEARNING. IF I CONTINUE TO EVOLVE. IF I CONTINUE TO ADAPT. IF I LEARN NEW WAYS.

Set backs aren't always negative. Sometimes they are sent to guide us in a much bigger and better direction…But you can only see that if you show character in those hard times. If you remain open minded in the hard times. If you show strength through your struggles. Don't say "Why me". Ask: "How can I come out of this stronger? -What can I learn?" In the hard times we see who really has the character. In the hard times we see what people are really made of. What are you made of? What are you made of? CHARACTER. EXPANSION. GROWTH AND PRIDE! CHARACTER. EXPANSION. GROWTH AND PRIDE!

DIG DEEP! Find that strength that lives inside you. TRUST that if you keep doing your thing, you will be rewarded. It might not happen right away, it rarely does, but it will happen if you keep going. Don't allow regret to enter your life. Don't you dare look back on your life in 5 years and think "I could have done more, if only I stuck it out, I could have been in a much better position." No. Look back with pride. Look back and be able to say to yourself, "it wasn't easy, but I AM SO PROUD I stuck it out…because I got my rewards." Make sure your story is one of strength. Make sure your story is one of someone who refused to give up. Refused to settle. Refused to be normal.

Keep going. Your future self is begging you.'