Evaluating Patterns of Spared and Enhanced Processing within the Music Domain in Autism Spectrum Disorders

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ABSTRACT

Autism spectrum disorder (ASD) is a developmental disorder characterized by deficits in communication and social functioning, and restricted and repetitive behaviours. Apart from these deficits, individuals with ASD demonstrate an uneven cognitive profile which includes sparing and enhancements. Research on musical savants, many of whom have ASD or autistic-like traits, as well as past research examining pitch and tonality in individuals with ASD has shown that music is likely to be at least spared in individuals with ASD. The purpose of this thesis is to demonstrate that music is one of these cognitive strengths for individuals with ASD. The first study presented here addresses the question of timbre cognition, and demonstrates that individuals with ASD have enhanced discrimination of timbres relative to controls. The second and third studies address rhythm reproduction and cognition, showing an enhancement and a sparing, respectively, relative to controls once levels of motor dysfunction are controlled for. The fourth study replicates earlier findings about the ability of individuals with ASD to process tonality, and using a temporal manipulation demonstrates that individuals with autism are as good at processing tonality as their matched controls when the tempo is slow, medium and fast, although both groups show a decrease in accuracy at slower tempi. The fifth study examines implicit learning for both pseudo-linguistic stimuli and musical stimuli. In this experiment the control group was unable to succeed on the task, while the ASD group surprisingly succeeded both with pseudo-linguistic and musical stimuli. These results are discussed within the context of modern theories of cognition in ASD. The results of every experiment in this study encourage the conclusion that there is a

pattern of spared and enhanced cognition for musical materials apparent in this sample of individuals with ASD. There were no deficits found on any task relative to a control sample. This is a burgeoning field with exciting prospects for future work into the *abilities* of those with ASD.

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Acknowledgments

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Dedication

This thesis is dedicated to my wife, Mirelle Renalda King.
For all you are to me, I am thankful to God.

It doesn't seem to "call" her. She doesn't "get" music, she said – doesn't see what it is "about." One might suppose that Temple [Grandin] is simply not "musical," despite her absolute pitch and her ear.

-Oliver Sacks
An Anthropologist on Mars

I. General Introduction

Autism is primarily a disorder of socialisation and communication. DSM-IV-TR diagnostic criteria outline three main elements of behaviour defining autism: Qualitative impairments in social interaction; qualitative impairments in communication; and restrictive, repetitive and stereotyped behaviours (APA, 2000). A diagnosis of autism cannot be made without significant deficits in all of these areas. However, there is a spectrum of pervasive developmental disorders (PDD), of which five are described in the DSM-IV-TR, and of which autism is only one. Asperger's Syndrome (AS) is a generally (though not always) milder form of PDD in which the child develops language and communication normally, but demonstrates the impairments in social interaction, and restrictive, repetitive and stereotyped behaviours seen in individuals with autism. AS is not ordinarily associated with mental retardation. There is controversy about whether AS does or should exist as a separate category to high functioning autism (Simpson, 2004; Volkmar & Klin, 2001) and it remains to be seen whether AS will be included as a separate diagnostic group in DSM-V. Pervasive developmental disorder not otherwise specified (PDD-NOS) is another disorder on the spectrum, which is diagnosed when (for whatever reason) a child does not meet diagnostic criteria for another PDD, but there is an overwhelming and clinically significant impairment in the development of reciprocal interaction. These three disorders, Autism, AS and PDD-NOS, are the three PDDs that fall under the umbrella term "Autism Spectrum Disorder (ASD)" as it is used in this thesis. The other two PDDs include Rett's Syndrome which affects almost exclusively girls as it is linked to abnormalities in the X-chromosome, and Childhood Disintegrative Disorder (CDD) which is associated with a regression of development at between two and ten years of age which results in symptoms of PDD. These latter two PDDs are not included in the term ASD as it is used here.

The diagnostic criteria for ASDs are very specific, however, individuals with autism manifest a more far-reaching web of abilities and deficits than are diagnostically required. One extremely interesting characteristic of individuals with ASDs it that many develop skills that stand in contrast to their disabilities in social and communicative domains. Savant syndrome is closely associated with autism (Rimland, 1978; Hill, 1974) but even amongst individuals that do not meet criteria for savant skills (Treffert 1989), abilities within specific domains are sometimes surprisingly good. This thesis will extend previous literature showing that this is the case for music.

In this chapter, a general introduction to three main theoretical models of autism (Theory of Mind, Weak Central Coherence, and Enhanced Perceptual Functioning) are described, followed by a summary of past and current research into musical abilities in autism inlcluding work with musical savants, absolute pitch, and emotion processing and music. A discussion of Jackendoff and Lerdahl's (2006) structure of music is ensued by a cursory evaluation of the concept of musicality as it pertains to ASD. These sections are provided in order to create a context in which questions more specific to this thesis can be explored. However, detailed discussion of each area of music to be treated in this thesis (timbre, rhythm, tempo/metre, learning), as well as specific hypotheses relating to these areas, are largely reserved for the dedicated chapter. Thus while a description of Mottron and Burack's (2001) theory of Enhanced Perceptual Functioning is described in this introduction, it is looked at in more detail in the chapter pertaining to timbre processing, where it serves as the basis for the hypothesis in that experiment.

This more general introduction is intended to allow the reader to familiarize him or herself with the wider issues whose weight will bear upon the experimental chapters to ensue. Issues more specific than these will be dealt with in due course.

Theoretical models of Autism

Theory of Mind

The most influential theory of autism is the Theory of Mind deficit hypothesis (Baron-Cohen, Leslie, & Frith, 1985). By the age of around four, a typically developing child is able to make conjectures about mental states, and is able to understand, for example, that someone else's (erroneous) representation of reality may not be the same as their own. Before this watershed age, children demonstrate egocentricity; their own view of the world is the only view. There are precursors to Theory of Mind (ToM) in the young infant, such as joint attention (Charman, Baron-Cohen, Swettenham, Baird, Cox & Drew, 2000), proto-declarative pointing (Camaioni, Perucchini, Bellagamba & Colonnesi, 2004), and followed eye-gaze (Eskritt & Lee, 2007), but this new development of mentalizing allows the child to theorize about the goals, emotions and beliefs of other people. It facilitates the emergence of the child as a truly social being. In children with autism, this ToM apparently fails to emerge on time, or emerges atypically. The link between ToM and the symptoms of autism was first made by Baron-Cohen and his colleagues in the late 1980's. This was the first time that a cognitive mechanism was proposed which incorporated the larger symptomatology of autism (Tager-Flusberg, 2007).

The main problem at the time was the failure of autistic participants on a false-belief task that has become known as the Sally-Anne task (See Perner, Frith, Leslie & Leekam, 1989). In this task, a puppet show is enacted for participants. Sally puts her marble into her basket, then leaves the room. Anne then hides the marble in her box. The child is then asked where Sally will look for her marble when she comes back into the room. The child with a ToM will respond that Sally will look for her marble where she left it (and still thinks it is) – in her basket. Those without a ToM, it is argued, will answer that Sally will look for her marble *where it is*, despite the fact that Sally had no way of knowing where Anne had moved it to; this participant will figure that since he/she knows where the marble is, so should Sally.

Baron-Cohen and colleagues found that participants with autism behave like the latter individuals with no theory of mind – even participants much older than four years of age. They argue that this deficit can account for the social and communication impairments seen in autism; if a child has no idea what is going on inside the mind of another, how can the child hope to relate?

While this hypothesis can account for the social and communication impairments of autism, some scepticism has met its attempts to explain the whole symptomatology of the disorder. For example, social and communication impairments are not the only diagnostic criteria; restrictive and repetitive behaviours are an important part of the diagnosis of autism, especially in early life. It is these symptoms which often emerge first and prompt a diagnosis of autism (although it should be mentioned that these symptoms, too, can be indicative of other disorders). Secondly, the ToM hypothesis of autism cannot explain those areas of preserved or enhanced functioning such as visuospatial tasks, or music. Furthermore, there is increasing evidence that these difficulties are characteristic to a many other disorders, including schizophrenia (Uhlhaas, Phillips, Schenkel & Silverstein, 2006), Williams Syndrome (Sullivan & Tager-Flusberg, 1999), and Fragile X (Cornish, Burack, Rahman, Munir, Russo, & Grant, 2005). Finally, it is unclear how much the social and communicative difficulties of the type that are measured by the ToM tasks impacts upon non-social domains; some researchers speculate that reduced engagement in social activity leaves time for special skills (Fauville, 1936; Treffert, 1988), but this hypothesis is difficult to test empirically and the question remains open.

Influential theories of non-social cognition in autism include the WCC and EPF theories. A major strength of these theories is they have the potential to explain some aspects of special skills.

Weak Central Coherence (WCC).

The theory of Weak Central Coherence (Frith & Happe 1994) was developed in response to clinical descriptions suggesting that autistic people couldn't "see the wood for the trees" and observations of performance on psychometric IQ subtests. In a review of studies using the Weschler tests of intelligence with autistic participants Happé (1994) noted that peak performance was frequently observed on the Block Design task.

The Block Design task requires the participant to use a set of blocks that have sides that are white, red, or half white half red, to create increasingly more challenging patterns. Participants are timed, and then compared to a normative sample. Cognitively, the task requires a grasp of both global elements (the overall pattern) and, possibly more importantly local elements (relationships between individual blocks). People with autism are generally faster and more successful at the Block Design task than are typically developing people (Dawson, Soulières, Gernsbacher, Morton & Mottron, 2007; Mitchell & Ropar, 2004).

WCC proposes that people with ASD are high achievers on the Block Design task because of their enhanced ability to process the local level of stimuli and their relative disregard for the global level. Typically developing individuals generally have an opposite bias; they favour the global level of stimuli, and are thwarted on the Block Design task because they have difficulty seeing the relationships between individual blocks and how they come together to make the whole.

In an important early study Shah and Frith (1993), the Block Design task was presented to participants with ASD, those with mild mental retardation, and typically developing individuals, but with several manipulations. The first two – rotation, and the continence of obliques – encouraged no group differences, but the third manipulation – segmentation – produced a startling result. Particicpants with autism were better able than both groups of controls on the "unsegmented" condition. That is, when the target was not split up, block-by-block for participants to see which block went where, when the effect was instead a gestalt, participants with autism were better able to ignore the gestalt and segment the target for themselves. This finding, where coherence of the gestalt of the target is weakened in individuals with autism, supports WCC theory.

However, a more recent study conducted by Caron, Mottron, Berthiaume and Dawson, (2006) where a modified block design task (again, at various levels of cohesiveness) was presented to individuals with autism who have a visuospatial peak, and typically developing controls who also have a visuospatial peak, as well as individuals with autism, and typically developing controls, who do not have a visuospatial peak. Results showed that not all individuals with autism show peak performance on the block design; only a subgroup of individuals with concomitant locally oriented bias, displayed a peak, although all individuals with autism did show enhanced perception. López, Leekam and Arts (2008) also provide evidence that there may be subgroups in autism with regards to the central coherence profile. These conflicting findings promotes the Enhanced Perceptual Hypothesis of Mottron and Burack (2001) that will be discussed later.

Another psychometric task that illustrates the case of WCC is the Embedded Figures task. In this task, participants are shown a picture, and asked to find a simple geometric figure that is embedded in that picture, as quickly as possible. Typically developing participants generally process the picture as a whole and have difficulty disembedding the geometric figure from its global surroundings. People with autism score quite well on this task, and WCC theory argues that this is because they see this local geometric figure (and indeed, all the other local aspects of the picture) first, and best, and that their processing of the entire global picture is weak. Thus Weak Central

Coherence theory argues that people with ASD have a weakened ability to create a coherent central or global "picture" of the stimuli that they perceive.

In a second early experiment Shah and Frith (1983) presented the embedded figures task to children with autism and a mental-age matched control group, and a chronological-age matched control group, and found that children with autism were more competent at the task than would be predicted from their mental age, and commensurate with chronological-age matched control children. Shah and Frith (1983) identified embedded figures as an "islet of ability" since autistic children showed performance above their typical (mental age expected) performance. Shah and Frith (1983) showed that when children with and without autism were asked to execute a visual search for a simple figure that was hidden or embedded within a larger coherent picture, children with autism were much faster and more accurate than children without autism. The reasons for this are subject to interpretation, however the prevailing interpretation states that the children with autism were not "distracted" by the global picture, that is, they were not constrained to process the picture at the expense of its constituent parts. They were more naturally and quickly able to process the individual parts that make up the picture. This interpretation is linked to the Weak Central Coherence hypothesis of autism, which has most successfully been applied to the visuo-spatial processing literature. It has also, however, been likened to the superior performance of men on these tasks, and has even been used to support the "Extreme Male Brain" (Baron-Cohen, 1999) theory of autism. These data should be interpreted with caution, however, as Brian and Bryson (1996) failed to replicate enhancement on the embedded figures task

In 1999 Happé changed the emphasis of the WCC away from a global deficit model to discuss a local bias across domains. In this paper, three major modifications were made to the WCC account. Firstly, rather than focusing on the inability to extract global meaning from stimuli, Happé's new account of WCC places this as a more secondary outcome, choosing to concentrate more on the possibly enhanced abilities, for example enhanced visuospatial processing or music processing. Second, as an answer to several studies not finding a global deficit (Wang, Mottron, Peng, Berthiaume & Dawson, 2007; Mottron, Burack, Iarocci, Belleville & Enns, 2003; Mottron, Peretz & Ménard, 2000; Mottron, Burack, Stauder & Robaey, 1999), Happé suggested that the local processing bias is not an absolute, but a tendency towards the local processing style. This tendency shows up in many tasks, but in those tasks which explicitly challenge the participant to use global processing, the tendency can be overridden. Third, rather than envisioning WCC as explaining deficits in social cognition and communication, Happé proposed that WCC may only be one aspect of the cognition of individuals with ASD that exists alongside other cognitive mechanisms or biases.

In the most recent account of WCC, Happé and Frith (2006) confirm their assertion that the issue is not so much a deficit in global processing, but a bias towards local processing, and go further, even suggesting that not all, but a subtype, of individuals with autism evidence weak central coherence (Plaisted, 2000). They then suggest that, as a bias account rather than a deficit account, WCC is now amenable to the idea of a continuum approach, where individuals with autism (and their relatives with related genotypes and phenotypes) are generally placed at the extreme end of the continuum. This further implies that there is a wider autism phenotype that is shared by close genetic relatives of those with ASD. Happé and Frith continue by fitting WCC in with the other accounts of ASD symptomatology such as the Theory of Mind and Executive Dysfunction hypotheses, and attempt to reconcile WCC with competing theories such as Mottron and Burack's (2001) Enhanced Perceptual Functioning hypothesis. Within the confines of this new construct, local bias leads to conceptual integration impairments in tasks where the bias is not challenged. Unlike earlier incarnations of WCC, this new model suggests that, in general, individuals with ASD are more likely to have a local bias, and when this bias is allowed to dominate (for example, on tasks which encourage, or even do not discourage, local processing, like the Block Design or EFT).

Finally, Happé and Frith (2006) propose possible mechanisms by which Central Coherence might operate in autism. Computational models have been tested as explanatory models of CC operation, such as McClelland's (2001) proposal that hyperspecificity of representations might limit generalization of learning. O'Loughlin and Thagard (2000) suggested a connectionist model in which an increase in inhibitory impulses is seen against a decrease in the excitatory impulses.. This model leads to an overall disconnection of distal brain regions resulting in reduction in global brain functioning (and reduction of global perceptions) but preservation of lower-level proximal connections (and preservation of local perceptions). As the weakness of the WCC account of autism has long been a lack of specificity of mechanism, these attempts at computational modeling are well overdue. Neural modeling has also been proposed, one set of theories proposing specific pathways in the brain accounting for research findings, while the other discusses diffuse changes in neuronal connectivity (Frith & Happé, 2006). Frith and Happé discusses the finer points of these different neural models in their (2006) review.

WCC theory was originally based on findings from visual tasks, but soon researchers expanded its application to musical tasks (see, for example, Heaton et al., 2007; Heaton et al., 2008; Heaton 2003, 2005; Foxton et al. 2003; Mottron, Peretz & Menard, 2000; Heaton, Hermelin & Pring, 1998; Heaton, Pring & Hermelin, 1999). The local features of music were individual pitches or intervals, whilst global features were on the order of chords to intervals to melodies. At the local level, evidence showed that individuals with autism both with and without savant syndrome have outstanding pitch processing capabilities (Heaton, Pring & Hermelin, 1999; Heaton, 2003; Heaton, 2005; Heaton Hermelin & Pring, 1998; Heaton et al., 2008; Mottron, Peretz, Belleville & Rouleau, 1999). However, in the musical domain, individuals with autism did not seem to have a global deficit. In nearly all cases, the performance of people with autism on tests of global processing in music was preserved: as good as that of typically developing controls. It should be noted that there is some question about both the terms 'local' and 'global' as they apply to musical stimuli. Traditionally, the distinction has been made due to level of complexity. Pitches and intervals are local when viewed against the backdrop of global chords, contours or melodies. But it is becoming clear that a more formalized definition of precisely what comprises local or global processing within the musical domain is required. As Heaton (2005) notes, 'global' and 'local' are difficult to operationalize, and tend to be defined differently by each researcher. Nevertheless, the levels-of-complexity classification system has thus far been useful in research, and taken together the findings from the studies into music cognition in autism have shown enhanced sensitivity to pitch information, enhanced pitch memory and typical performance on tasks where stimuli is more complex (global).

In this set of experiments, WCC theory is directly relevant to the design and results of one experiment, the Chord Priming and Tempo Task, described in chapter five. In this experiment, stimuli were created in order to effect decreasing levels of coherence, with harmonized tunes playing which were either globally and locally related to the final chord, related globally but not locally to the final chord, related locally but not globally to the final chord, or neither globally nor locally related to the final chord. The participant is asked to make a judgment about how "good" the tune sounds, and training biases the participant towards more global (or "centrally coherent") tunes. If participants with ASD are more local processors, then they should describe the locally-coherent items as "good" while the tunes that are not locally-coherent will be described as "bad".

WCC is also brought to the discussions in the Timbre experiment (chapter 3) and the rhythm experiment (chapter 2).

Enhanced Perceptual Function (EPF)

It was from this observation, as well as the observation of an autistic savant draughtsman, that Mottron and Burack (2001) articulated the Enhanced Perceptual Function (EPF) account of ASD. EPF posits that it is a primary superiority in perceptual analysis that underlies the special abilities of people with autism. The local bias is still accounted for – detailed processing at the level of perception accounts for that – but the global deficit is discarded (Mottron, Dawson, Soulières, Hubert & Burack, 2006). EPF theory argues that people with autism can use a global strategy, but are not obliged to when such a strategy would be detrimental to performance. Similarly, ASD participants are not obliged to stick with a rigid local strategy that is only useful in a certain type of task; they are afforded the same flexibility, but greater sensitivity, than their typically developing controls.

EPF theory was originally formulated from observations from both visual and auditory domains that individuals with autism performed superiorly on domain-specific low-level tasks in laboratory situations, and daily importance of perception in the lives of individuals with autism (Mottron, Dawson, Soulieres, Hubert & Burack, 2006). These abilities were grouped under the term "perception", but in the style of 1990's neuropsychological literature, the umbrella term "perception" is extended to cover are range of cognitive as well as perceptual skills. This EPF encompasses the notion that detection, matching, reproduction, memory, and categorization will also be enhanced (Mottron et al., 2006). Thus, whilst absolute pitch ability and hyperlexia rely on post-perceptual processes they are nevertheless explained by the EPF model.

EPF can be applied to the musical domain in the case of QC, the savant musician (Mottron, Peretz, Belleville, & Rouleau, 1999). QC had no difficulties processing global aspects of music, but with her absolute pitch showed exceptional processing of more local (perceptual) features of music.

In their (2000) study, Mottron, Peretz and Menard demonstrated in non-savant adults with autism that there was no global deficit in processing musical materials. They did, however, demonstrate a local bias in music perception. Thus when typical controls failed to notice Gestalt maintaining changes made to melodies the autistic participants readily distinguished these changes. In a case study, Heaton, Pring and Hermelin (1999) also observed enhanced discrimination of Gestalt maintaining changes in a musically untrained adolescent with autism. However, when this study was replicated with a group of children with autism, they failed to notice Gestalt maintaining changes in stimuli and performed much like controls (Heaton, 2005). In the study carried out by Foxton et al (2003) a contour task was also included, and in line with findings by Heaton (2005) enhanced discrimination of Gestalt maintaining changes was not observed in the autism group. It should be noted, however, that whilst Heaton, Pring and Hermelin (1999) investigated children with autism, Foxton et al. (2003) worked with adults with autism.

This evidence all points towards the enhanced perceptual functioning model of autism described by Burack and Mottron (2001) and revised by Mottron, Dawson, Soulieres, Hubert and Burack (2006). Furthermore, recent evidence from non-musical domains of auditory processing clearly show that enhanced perception of pitch in auditory stimuli is not confined to music, although it is most clearly manifested in the musical domain.

The results of the timbre experiment described in chapter three are explained in terms of EPF theory. Discussion surrounds the processing of timbre as a function of enhanced perception.

As mentioned, both of these perceptual-cognitive accounts of autism (WCC and EPF) are relevant to this investigation, and will provide a framework for theoretical discussion or research findings presented in the thesis. However, a limitation of these theories is that they are unable to account for many cognitive mechanisms underpinning music cognition. For example, implicit memory, timing, and perception of tempo and rhythm are important for musical cognition but cannot be well situated within these theories.

Music and ASD

In 1943 When Kanner first named and identified early infantile autism, he described a surprising musical memory in the children he had studied. Of one, he noted that the child could discriminate eighteen symphonies by ear, by the time he was eighteen months old (Kanner, 1943). Several of the children seemed preoccupied by music, a finding that has stood the test of time. In experimental studies, children with autism differ from typically developing children in preferentially orient to music over linguistic auditory stimuli (Blackstock 1978; Lepisto et al. 2006; Kellerman, Fan & Gorman, 2005; Dawson et al., 1998). Indeed, many individuals with autism evidence a liking for, and ability or even talent for playing, music (Treffert, 1989)

This section of the chapter is dedicated to a formal review of the literature relating to musical cognition in individuals with ASD. These studies can be largely grouped into three categories: early findings from studies into musical savants, experiments on pitch perception and experiments on the cognitive processing of melody and musical structure.

Early Findings from Studies into Musical Savants

The most striking link between musical ability and ASD comes from a special category of individuals with ASD – *idiots savants*. The population of individuals with Savant Syndrome – as it is more fashionably called – is not composed exclusively of individuals with ASD. There is a whole subgroup of Savants who show a different triad of impairments: congenital blindness, intellectual disability and language disability (Pring & Tadic, 2005). Hermelin (2001) points out that “many savant musicians are congenitally blind, autistic or both” (2001, p. 156). Indeed, there does seem to be some sort of relationship between blindness and musical prodigy. This is not an uncommon story. Treffert (1989) points out that there is seemingly a “triad of impairments” linking blindness, mental retardation and exceptional musical ability. In these cases, the blindness is significantly and notably caused by retrolental fibroplasias, which is a loss of vision having to do almost exclusively with excess oxygen administered to prematurely born babies. Treffert refers us to cases of no fewer than 7 blind, and 7 sighted musical savants, all of whom show signs of what Treffert calls “autism as a symptom”. Treffert takes pains to differentiate between “autism as an illness”, what he defines as Early Infantile Autism and notes, as we have already, that the incidence of savant syndrome is already increased amongst this population, and his “autism as a symptom” which he believes is better seen as the broader phenotype of autistic behaviours and mannerisms (what might now be called ASD). It can be argued that all cases of musical savant syndrome are associated with “autism as a symptom”, and thus that it is the autism, and not the blindness, that is crucial in this triad of impairments. However, in these individuals, it is arguable whether it is possible to diagnose autism. Further, there are cases of savants who have other intellectual impairments (i.e. Treffert, 2006).

Idiots savants are individuals with intellectual impairment who show dramatically contrasting outstanding abilities. Early reports were anecdotal, describing individuals with apparent profound mental retardation doing spectacular and amazing feats. For example, the case of “blind negro Tom” first reported on by Mr. Long Grabs, a correspondent from the Fayetteville Observer (May 19, 1862). “Blind negro Tom” was an amazing sight for all those for whom he performed. As Grabs relates, “he resembles any ordinary negro boy 13 years old and is perfectly blind and an idiot in everything but music, language, imitation and perhaps memory…[he] learns airs and tunes from hearing them sung, and can play any piece on first trial as well as the most accomplished performer…” (Grabs, 1862) French physician Edouard Seguin (1866) also described Tom in his book, *Idiocy and Its Treatment by the Psychological Method*. It is he who describes Tom’s stereotypic behaviours that, as Oliver Sacks points out (1995), are more characteristic of autism. Because these stories were anecdotal, however, it is difficult now to determine either the characteristics of the individuals or the extent of the skills that they possessed. However, many of these early cases describe features that could be indicative of current criteria for autism or a related spectrum disorder.

Whilst the term *idiot savant* implies that these individuals demonstrate extreme intellectual impairment, Young (1995), in the largest savant group study to date, found that the majority of savants tested showed intellectual impairment at only mild or borderline levels. There are also several case reports of individuals considered to be savants despite average or even above average intellectual functioning (Heavey, Pring & Hermelin, 1999) and this is the case for at least one musical savant (Young & Nettlebeck, 1995). Given this more recent evidence about the characteristics of *idiots savants,* Heaton and Wallace (2004) have proposed that deficits in adaptive behaviour or 'everyday intelligence' be contrasted with the special skill in question.

The so-called Savant Syndrome affects more than just those with ASD, but whilst the estimated prevalence of Savant Syndrome in the entire population is approximately 0.06%, its prevalence in the ASD population is estimated at 9.8% (Rimland, 1978), although this estimate may be exaggerated (Heaton & Wallace, 2003). In his landmark study, Rimland (1978) identified 5400 children with autism in forty countries. Using questionnaires administered to parents and professionals caring for these children, 531 were identified as savants (yielding the estimated 9.8%). Rimland further reports that the most common savant abilities were memory and music. Hill (1977) on the other hand identified individuals with all types of mental retardation and investigated the incidence of savant syndrome amongst this significantly more heterogeneous group. Of 90,000 residents of homes for the mentally retarded investigated, only fifty-four were identified as savants. This places the incidence of savant syndrome at 0.06% for the entire population of individuals with some form of mental retardation;

significantly lower than the incidence of savant syndrome in individuals with autism. This indicates that savant syndrome is seen within the autistic syndrome much more often than it is present in individuals who have another learning or developmental disability.

Miller (1998) suggested that Savant Syndrome be diagnosed within a 'discrepancy-based model' that pits the different domains of an individual's abilities against one another, searching for a 'peak' performance in one discreet area. Treffert (1989) further proposed that there should be a division within the diagnosis of Savant Syndrome such that the magnitude of the discrepancy and its status relative to age-appropriate norms be considered. Taking these factors into account, Treffert (1989) proposed the concepts of the Splinter Skill, Talented Savant, and Prodigious Savant.

Splinter Skills may result from the uneven cognitive profile in autism. Recall the visuospatial peak discussed by Shah and Frith (1983, 1993) and evidenced by individuals with autism in the block design and embedded figures tasks. This strength in visuospatial functioning stands stark against the weaknesses in some language tasks. It is these peaks and troughs of scoring on standard IQ batteries that may underlie Splinter Skills. As defined by Treffert (1989), Splinter Skills are abilities that stand out against the overall functioning of an individual. Thus, a lower-functioning individual with autism who manifests mental retardation and poor language skills, but a visuospatial peak, may be said to have a Splinter Skill of visuospatial functioning. A second category of splinter skills appears to be related to restricted and circumscribed interests. Thus a child with autism may exhibit an encyclopedic knowledge of planets or dinosaurs whilst obtaining average scores on formal memory tests. It is individuals with this type of ability that makes up the bulk of people with Savant Syndrome.

According to Treffert's criteria, Talented Savants present with an ability of a higher caliber than a Splinter Skill. The ability of the Talented Savant is differentiated from a Splinter Skill in that a Talent cannot be attributed to uneven cognitive profile, but rather to developed ability in one (or more) areas. The Prodigious Savant has an ability that would still be considered outstanding if the individual did not have intellectual or social disability. Young (1995) suggests that savant status be reserved for Talented and Prodigious Savants as their abilities are developed beyond expected functioning.

Savants tend overwhelmingly to show abilities in one of five areas, including calendar calculation, memory, music, art or arithmetic skills (Hill, 1974). However, there have been savants reported in many more diverse areas of expertise from mechanical (Brink, 1980; Hoffman & Reeves, 1979; Tredgold, 1952) to savants with linguistic skills (Dowker, Hermelin & Pring, 1996). Despite this seemingly incoherent mass of abilities, many observers have noted that prodigious memory, and rote memory at that, seems to be common to all savants. Calendar calculators have historically been said to simply have a memorized calendar at their disposal (Hermelin, 2001). However, this idea that memory is the foundation of all savant skills does not hold up to the experimental evidence. Savants are manifestly flexible in the way that they process domain-specific information. Calendar calculators actually calculate the dates in question based on knowledge of the cycles of the calendar (Cowan, O'Connor & Samella, 2001; Heavey, Pring & Hermelin, 1999; Nettelbeck & Young, 1996; Anderson, O'Connor & Hermelin, 1998; O'Connor & Hermelin, 1992). In fact, comparisons of savants with typically developing individuals who are talented in the same area have often suggested that some similar mechanisms are responsible for the abilities in both groups (Heaton & Wallace, 2003). For example, ability to learn and use implicitly learned patterns or artificial grammars has been shown to be intact in people with autism (Klinger, Lee, Bush, Klinger & Crump, 2001) which would be essential for either those with autism or their typically developing peers to learn the rules of the calendar, rules of musical grammar, and linguistic grammar. Thus it is clear that savants do not rely on memory alone to produce their outstanding abilities, but rather that they are able to manipulate and represent highly organized and domain-specific information.

One such specific domain is music, which has been much studied in the savant population. In fact, Rimland and Hill (1984) suggested that music is the most prevalent savant ability being reported in 52% of their autistic-type savants.

Miller (1989) devoted an entire book to the description of one young savant's talents and limitations. Eddie is described as having perfect pitch, and excellent short-term memory for musical material. Repeating Charness, Clifton and MacDonald's (1988) test of J.L.'s memory for complex chords, Miller (1989) measured Eddie's chord span, and demonstrated the same capacity limitation in his 5-year-old savant that Charness found in the much older savant J.L.. Both savants were highly sensitive to chord sequence structure (conventionality, and relatedness between chords). However, Eddie also showed an effect on his performance by the length of the chord sequences. On melody span, Eddie showed a 5-note span which may be due, in part, to his age. Eddie is talented with regard to use of musical idioms; he can improvise within a style, indicating prodigious long-term musical memory but also a creativity, which Miller (1989, p. 181) highlights. Eddie, like most savants, remains reasonably incapable of talking about his love of music. His poor communication skills are reported to improve during music lessons (when he is focused and "present" in the conversation), but about music, he has little to say. This could relate to autistic features present in many savants (Miller, 1989 p. 190), since inherent in autism is a deficit in communication that impacts on language skills (American Psychological Association, 1994).

Whilst there is much to learn about musical savants certain characteristics appear to be universal in this group. For example, Absolute Pitch, excellent memory for musical material, at least some improvisational skill and ability to work within an appropriate musical idiom, and either autism, or characteristics associated with ASD (Hermelin, O'Connor & Treffert, 1989; Rimland & Fein, 1988; Heaton, Pring & Hermelin, 1999; Heaton, Hermelin & Pring, 1998; Young & Nettelbeck, 1995; Hermelin, O'Connor, Lee & Treffert, 1989; Treffert 1989).

Sloboda, Hermelin and O'Connor (1985) studied NP, a musical savant with autism and low IQ, attempting to compare his abilities with those of a prodigy of high IQ. The hypothesis was that either the savant abilities of NP would manifest themselves in a unique way, given his intellectual impairment, or that his savant abilities simply are the same as expert abilities. That is, that general intellectual functioning does not affect expert performance on musical tasks. NP was faced with learning Grieg's OP. 47 no. 3, a conventional piece in the diatonic scale, and Bartok's Mikrokosmos, a short atonal piece based on the whole-tone scale. The findings showed that NP was able to learn the tonal Grieg piece, and in fact when he made mistakes on this piece, they were "structure preserving" mistakes. However, NP could not learn Bartok's atonal piece; there was no structure for him to assimilate, and as such he continuously swapped atonal note for atonal note. Thus, Sloboda, Hermelin and O'Connor conclude, "the data suggest strongly that the ability is structurally based, and so akin to the ability of high IQ prodigies." (1985, p. 165).

Young and Nettelbeck (1995) repeated the experiment of Sloboda, Hermelin and O'Connor (1985) with another musical savant (TR). They sought to compare TR's musical abilities not with some external measure, but with his own general level of intellectual functioning. They showed that TR and his family had high abilities in memory and general intellectual functioning, but that TR alone shows expertise in music, thus superior memory and intellect are not sufficient for musical expertise. TR correctly reproduced the Grieg piece in identical conditions to Sloboda, Hermelin and O'Connor (1985), and was also able to use his expertise to learn the Bartok piece, albeit with more difficulty. However, this makes sense in light of the fact that TR was far more familiar with the whole-tone scale and its conventions than was NP.

These two studies, taken together, demonstrate important facets of savant skill. Firstly, although memory is an important feature of savant ability, simple memorization is not its defining characteristic. Several authors have implicated "rote" memory in savant performance (Bolte & Poustka, 2004; Spitz, 1994; Hermelin & O'Connor, 1986; Anastasi & Levee, 1961) and these experimental studies reveal a more complex picture in which experiential factors are implicated. Savant information processing, for example memory, is influenced by their contextual knowledge (i.e. rules of harmony, diatonic or whole-tone scale etc.). In addition, in line with studies on expertise (e.g. Charness, 1991), the skill of musical savants is learned largely incidentally, through implicit learning. Precocious or savant ability cannot be accounted for by practice alone, although practice facilitates that acquisition of musical understanding and undoubtedly contributes to the level of performance achieved by savant individuals.

In her work Bright Splinters of the Mind (2001), Hermelin describes an experiment (from Hermelin, O'Connor & Lee, 1987) into the improvisational powers of savants. Five savants (three with autism, two with autistic-like features) and five musically talented 13-year-old children with typical development, were asked to participate in five different improvisational tasks. These tasks included a continuation of a partly-heard piece, invention of a musical tune, improvisation of an accompaniment for a heard melody, invention of a tune and its accompaniment, and improvisation with jazz musicians. The control participants scored quite poorly on these tasks, but the savants scored very highly when they agreed to participate. This experiment shows that, contrary to original assumptions, savants can improvise and create musically.

Together, these two studies indicate that savant ability is not simply a talent for reproducing by rote what was once heard, but rather that, in keeping with the assertion that savants learn the musical context of the pieces they play, savants can also improvise within that musical context. That is, savants can generate new material that neither they, nor anyone else has yet heard.

Not all savants are autistic; there are known cases of savants with other disorders such as cerebral palsy (Treffert, 1989). But, as Heaton and Wallace (2004) point out, these savants share autistic traits such as detail-processing style and obsessionality, which may be linked to the development of the savant syndrome in any individual, autistic or not. In fact, even for those savants in whom autism cannot be diagnosed (for example, the blind) due to ADOS (Lord, et al, 1989) and ADI-R (Lord, Rutter & Le Couteur, 1994) requirements (i.e. joint attention, for which vision is necessary), some autistic traits are found (Heaton & Wallace, 2004). Indeed, many of the *idiots savants* described in earlier literature as non-autistic may, now with the new criteria in the DSM-IV-TR, fit the criteria for autism or an autism spectrum disorder more closely.

These findings from the savant literature are provocative, but to what extent can we generalize from savants to non-savant individuals with autism? This is a matter of debate, but one can be sure that the musical skills that savants evidence are at least informative in the study of non-savant individuals (Mottron, Peretz & Menard, 2000) as work from Heaton and her colleagues demonstrates (Heaton, 2003; Heaton, 2004; Heaton, Hermelin & Pring, 1998; Heaton, Pring and Hermelin, 1999). Of particular interest is work linking universally observed absolute pitch ability in savants and enhanced pitch memory and discrimination in non-savant individuals with autism.

Furthermore, the non-savant splinter skill category is of great relevance to this question. Individuals with Splinter Skills most often evidence an uneven profile of cognitive encompassing strengths and weakness across cognitive domains. This is also characteristic of autism. Those with Splinter Skills are judged to be much better at their Skill than they should be given the development level of their other abilities. If skills are good when considered intrapersonally but not interpersonally; for example when compared with skills of cognitively unimpaired typical children, these may be conceptualized as "spared" skills. It is therefore acknowledged that the disability does not impair all areas of functioning. Given the wealth of research that is currently probing the relative sparing of specific abilites in people with ASD, it is essential that we begin to think about these little islands of ability as key clues to the cognitive functioning of people with autism. An alternative way of thinking about abilities in autism, best exemplified by the work of Dawson, Soulières, Gernsbacher, Morton & Mottron (2007) is that many aspects of intelligence are spared and that autism represents a different type of human development.

Pitch Perception in Autism

One such islet of ability concerns the processing of pitch. All musical savants reported possess absolute pitch (AP, Miller, 1989; Heaton 2003). AP is, however, only rarely found in the rest of the population (being found in only 1 in 10,000 individuals; Takeuchi & Hulse, 1993), including in professional musicians, wherein a recent study found only 4 out of 625 music students (0.64%) met stringent criteria for AP (Baharloo, Service, Risch, Gitschier & Frejmer, 2000). This finding contrasts one modern theory of AP – that of

Levitin and Rogers (2004) – which states that everyone, to a certain extent, possesses AP. They point out that when non-AP possessors are asked to name a pitch, the modal response is to give the correct pitch. Further, when individuals are asked to sing a song in the same key that it is sung in popular music, most participants sing on or about the correct key, indicating some memory for absolute pitches. However, Zatorre (2003) outlines genetic and neurobiological factors which correlate with AP ability, indicating that the brains and genes of individuals with AP are different than those individuals without.

In 1998, Heaton, Hermelin and Pring showed that children with autism have superior pitch discrimination abilities relative to typically developing controls, and in 2003 and 2008, Heaton showed that children with autism have an enhanced long-term memory for pitch, and that they are able to use it to label pitches, effectively indicating that AP is more likely to emerge in individuals with autism. It has been suggested that this propensity for AP may contribute to the reason that individuals with autism are over-represented in the savant population (Hermelin, 2001). Whilst it does not appear that AP is advantageous for typical musicians, Miller (1998) has argued that it may be advantageous where there are intellectual impairments. However, it may be that AP is more common in groups of individuals whose early developmental trajectories are atypical. For example. AP has been described in Williams syndrome (Lenhoff, Perales & Hickok, 2001) and congenitally blind children who are not savants (Gaab, Schulze, Ozdemir & Schlaug, 2006).

Several studies have noted that those with autism have a particular strength with regards to pitch discrimination and memory (Applebaum, Egel, Koegel & Imhof, 1979; Heaton, 2003; Heaton, 2004; Heaton, Hermelin & Pring, 1998; Heaton, Pring and Hermelin, 1999; Heaton, Cummins, Williams, Happe, 2008; Bonnel, Mottron, Peretz, Trudell, Gallun & Bonnel, 2003; Mottron, Peretz & Menard, 2000).

Both WCC and EPF theories of autism (discussed above) predict the enhancement of discriminative abilities within local domains and has been proposed to account for pitch. Unlike EPF theory, WCC theory especially predicts that the global processing essential for music comprehension and reproduction would be impaired in autism. However, research into perception of melodic contour and chord sequences have indicated that this impairment, characteristic within the visual domain (Plaisted, O'Riordan, & Baron-Cohen, 1998a; Plaisted, O'Riordan, & Baron-Cohen, 1998b; Happe & Frith, 2006) does not in fact appear in the musical domain, where people with autism perform typically or even, as EPF theory predicts, demonstrate enhanced perception (Foxton et al. 2003; Heaton, 2003; Mottron et al. 2003; Mottron, Peretz & Menard, 2000; Heaton, Pring & Hermelin, 1999).

In her (2003) study, Heaton investigated whether non-savant, musically untrained children with autism were better able to identify and discriminate between pitches than would typically developing matched controls. In the first experiment, she taught the children to identify the pitches by associating each pitch with the picture of an animal, thus reducing the linguistic load of the task on the children. Once the children had been familiarized to the test stimuli, they were tested with the same four pictures and same four pitches to see whether they were able to identify the pitches without a reference pitch, and remember this information. The children with a diagnosis of autism were better able to identify and remember the pitches, and associate them with their identifier, the animal, than were the children with typical development.

In the second experiment (Heaton, 2003), three of the tones were played together, creating a chord that left only one familiarized tone out, and the children were asked to "disembed" the notes in the chord so that they could analyze which note was missing in the chord. Children with autism were significantly better than their typically developing matched controls at performing this disembedding task.

The third experiment (Heaton 2003) was designed to test whether children with autism still succumb to gestalt, chord information even if they are not pre-trained to do this. This time, Heaton (2003) did not familiarize participants with absolute reference tones, but instead the chords, and the target tones, were taken from 12 major and 12 minor keys. Participants were asked to indicate whether the target tone was contained within the tonic triad reference chord. In this experiment, participants with autism were not found to perform better than their typically developing matched controls. This finding indicates that the chord disembedding superiority demonstrated in experiment two is highly dependent on the type of experimental paradigm used, and whether it predisposes participants to disembed or not. In this experiment three, Heaton (2003) showed that when tones are not pre-exposed and retrieval labels are not provided the children with autism succumbed to the Gestalt of the chords just as much as did the typically developing matched controls.

This series of experiments demonstrates that individuals with autism definitely show superior tone discrimination and memory, but that a local bias does not impair music processing. Replication by Altgassen, Kliegel and Williams (2005) indicates that this is a robust effect.

In her (2004) study, Heaton tested the hypotheses that children with autism would be better able to judge musical intervals that varied over pitch distance, and that this would allow them to process novel melodies in terms of these pitch intervals rather than more generally through contour, as typically developing controls tend to do (Liegeois-Chauvel, Peretz, Babaie, Laguitton & Chauvel, 1998; Peretz & Morais, 1987; Peretz, Morais & Bertelson, 1987; Peretz, 1990; Peretz & Babaie, 1992; Edworthy, 1985; Dowling, 1978). Heaton's first hypothesis was borne out: the children with autism were better able to judge the pitch directions of small intervals (1- 4 semitones) than were the typically developing controls. On medium and large intervals (5 – 12 semitones) there was no difference. The children with typical development clearly showed significantly worse performance on the small-intervals condition while the children with autism clearly showed no differences between their judgment of the small intervals over the large and medium. In the second part of her experiment, however, Heaton (2004) found no evidence that this enhanced interval discrimination ability as it interfered with the Gestalt representation of musical contour. Indeed their performance was indistinguishable from that of typical controls.

Heaton (2004) points out that the ASD group's success on the first experimental task is due to enhanced pitch discrimination, rather than pitch memory. In this experiment, the pitches were constantly changing, so that in each trial the participants did not have to remember any pitches, but rather to deal with a new pair of pitches each time. In the subsequent experiment, Heaton (2004) replicates an earlier effect of Foxton et al. (2003) that contrary to previous findings showing that autistic participants were able to detect Gestalt maintaining changes in melodies that went undetected by typical controls (Heaton et al. 1999; Mottron et al. 2000) children with autism do not adopt a local strategy when discriminating between two musical melodies. This finding is in line with earlier studies (Heaton 2003) showing that chords are perceived holistically unless the experimental paradigm predisposes a local processing strategy.

These are the most recent outputs of a body of research showing that pitch perception, discrimination, and memory are enhanced in autism without any apparent impairments in processing more global musical structures. With the capacity for pitch perception accounted for in individuals with autism, we now move to another area of music perception that theorists have proposed might be impaired: emotional processing of music.

Emotional Processing of Music

Heaton, Hermelin and Pring (1999) began studying emotional processing of music in children with autism, with a simple paradigm designed to look at perception of musical mode (major or minor) as indicative of emotion. Commonly, music in the minor mode of Western Tonal music is seen to evoke sadness, while music in the major mode is seen to evoke happiness (Heaton, Hermelin & Pring, 1999). This is the case even for musically naïve listeners (Heinlein, 1928) and has been observed in infants as young as three years (Kastner & Crowder, 1990). However, difficulties in understanding emotional expressions on faces and in voices have been widely reported in autism (e.g. Wang, Lee, Sigman & Dapretto, 2007; Golan, Baron-Cohen, Hill & Golan, 2006) and this led researchers to question whether individuals with with autism would appreciate emotion in music.

In the study by Heaton et al. (1999), children with autism and age and IQ matched typical controls were presented with two schematic pictures and corresponding labels, one of a happy and the other of a sad face, and first asked all participants to identify each. They then played novel four-bar melodies which were presented in all major and minor mode tunes as well as in harmonized major and minor mode versions. They found that complexity of stimulus did make a difference; harmonized versions of the melodies were more often correctly categorized than simple tunes. Surprisingly, however, there was no difference between participants with autism and their controls on the accuracy of their melody categorization.

Heaton, Allen, Williams, Cummins and Happé (2008) extended these earlier findings by presenting children with autism, Down syndrome and typical development with extracts of "real" music drawn from the classical orchestral repertoire. In a "feeling state" condition musical extracts were matched with pictures depicting fear, anger, loving, triumph and contemplation, and in a movement conditions the extracts were matched with pictures depicting running, walking, jumping and gliding. The data from the typical children showed superior identification of feeling state in comparison with movement extracts and this ability increased with age until ten years, at which point identification did not differ from that of musically naïve adults. When a regression analysis was carried out on the data from the clinical groups (Autism, Down syndrome) it was observed that verbal mental age, but not diagnosis was a significant factor in determining levels of performance.

Indeed children with autism whose IQ scores were in the normal range showed levels of identification that did not differ from those of the typically developing children.

The most recent study probing emotional understanding of music in individuals with autism spectrum disorders was carried out by Allen, Hill and Heaton (in press). This qualitative study probed the personal experiences of music in twelve adults with high functioning autism. Participants were first asked to fill out a closed-question questionnaire about early musical experience, and were then engaged in a semi-structured interview about their experiences as listeners of music. Interviews were recorded and then analyzed using qualitative methods designed to draw out the themes and analyze the content of each participant's narrative with respect to those of the other participants' narratives.

The results of this study are quite surprising. A sub-group of participants (classified as the "classical" group) reported liking of music from an early age, and engagement with (and in a few cases, playing of) classical music. The other sub-group reported that their interest in music came about only in their adolescence when they "discovered" popular music. Both groups of participants most often (and most notably) reported listening to music for its "mood-altering" properties, including the "buzz" and "relaxation." Participants also reported listening to music for its aesthetic effect, and for its "therapeutic" properties, as well as to build a sense of belonging.

These results are surprising for the depth and importance of emotion in the autistic experience of music. Since Sack's first described Temple Grandin's belief that music is "just pretty" is was assumed that music listening was motivated by an enjoyment of musical structure. The cool rationality of music, perhaps exemplified in much of Bach's work, "should" be most salient to these "un-emotional" systematizers (in the Baron-Cohen, Knickmeyer & Belmonte (2005) sense). However, the study by Allen, Hill and Heaton (in press) shows that this is clearly not the case and that people with autism, like typically developing people, listen to music for a broad range of reasons, including emotional ones. These three studies are the only ones to probe the effect of autism on the emotional experience of listening to music. The findings are striking in showing that a diagnosis of autism did not correlate with or cause deficits in processing emotion in music, and yet deficits in processing emotion in social situations are one of the diagnostic criteria for autism. This seminal work has shown that, as far as our limited ability to track and measure emotion goes, there are no deficits in emotional processing of musical material in autism. Indeed clinical reports, for example by Kanner (1943), have suggested that some children with this disorder show an intense pre-occupation with music, and it is difficult to understand how this could be the case for stimuli without affective value.

However, despite the studies reviewed above, it is the case that many crucial questions about musical processing in autism have yet to be addressed. For example implicit learning, perception of timbre, tempo and rhythm have yet to be addressed. Researchers have investigated implicit learning in autism, but these studies have focused exclusively on language learning and have yet to address the question of music learning. Theoretical accounts, already outlined, are of relevance to studies investigating perceptual processes implicated in music cognition. This relevant literature and the theoretical accounts from which the various hypotheses for the studies are drawn will be reviewed at the beginning of the experimental chapters.

A Theoretical Structure

Along the lines of Jackendoff and Lerdahl (2006), music can be divided into two structures: musical surface and musical structure. Musical surface includes pitch, timbre, tempo, intensity and duration; all of those aspects of sound which comprise a sequence of notes. Musical structure, however, is made up of two independently acting hierarchical organizations: rhythm and pitch. Rhythm can be further subdivided into grouping and metre. All of these components combine to create our perception of each musical piece we hear. It is notable that pitch is included under both the musical surface and musical structure categories, and yet rhythm is included only once. What is necessary to consider is that duration and tempo make up the surface of what may be called the "rhythm" of a sequence of notes – the sequence of notes in time. However, rhythm itself is a theoretical structure which underlies the duration and tempo, thus making it a musical structure. Pitch, on the other hand, is both the name for the note that we hear on the surface, and it is the name for the construct (A#, 330 Hz., do re mi, tonic triad) that one refers to.

Jackendoff and Lerdahl (2006) begin their paper with five fundamental questions about music. They note that these are the same as the five fundamental questions asked about language. While they acknowledge that the answers are quite different between language and music, one answer that they propose to remain the same regards the capacity for music. Following the Chomskian notion of an in-born capacity for language (more specifically, for grammar), Jackendoff and Lerdahl propose that there is also an in-born capacity for music (one is left to wonder, however, at further specifics). It is this capacity (in-born or not) for music, arguably prerequisite even in those with neurodevelopmental disorders, that will be probed in this thesis.

Despite Jackendoff and Lerdahl's (2006) reticence on the nature of this in-born capacity for music, their division of music into two main domains has some support in the neurobiological literature. Firstly, dissociations between language, music, and other non-musical but familiar sounds have been demonstrated in patients with selective brain lesions or congenital defects (Peretz et al., 1994; Griffiths et al., 1997; Piccirilli, Sciarma & Luzzi, 2000; Peretz et al., 2002; Godefroy et al., 1995; Mendez, 2001; Takahashi et al., 1992) These dissociations demonstrate that music itself is a specific "module" in the human brain, that is, it is not simply a function of other, more general cognitive abilities. Further, the "music module" can be dissociated into two distinct modules: that for pitch information, and that for temporal information (see, for example, the model of Peretz and Coltheart, 2003). For example, preserved understanding of rhythm, but impaired tonal processing was found in one patient with a lesion of the superior temporal gyrus (Piccirilli, Sciarma & Luzzi, 2000; see also Hyde & Peretz, 2004). Thus it is clear that there is a neurobiological backdrop to modern theorizing about the modularity of music (Peretz, 2006). It should be noted that not all investigators interpret the evidence in this way, citing the theoretical account of Pinker (1997) or the fact that the double dissociations seen here can be simulated by networks that do not have a dedicated music module (for a complete discussion, see Peretz, 2006).

Nonetheless, proceeding with the conviction that the evidence does weigh in on the side of modularity of music, what does this “music” ability entail? We have already regarded some theories which subdivide music into tonal and metric components. In the ASD population, the tonal components have been so extensively studied (Applebaum, Egel, Koegel & Imhof, 1979; Heaton, 2003; Heaton, 2004; Heaton, Hermelin & Pring, 1998; Heaton, Pring and Hermelin, 1999; Bonnel, Mottron, Peretz, Trudell, Gallun & Bonnel, 2003; Mottron, Peretz & Menard, 2000; Mottron, Peretz, Belleville & Rouleau, 1999). However, the metric components – specifically rhythm – have been little investigated in the ASD population. Thus it is clear that some attempt should be made to document the rhythmic abilities of this population. The other aspects of Jackendoff and Lerdahl’s (2006) model of music, the surface structures, are the next logical step. Timbre, tempo, intensity and duration might be proposed areas of further study.

In this case, certain limitations of testing constrained what was examined. Timbre, tempo and duration will all be examined in future chapters (Timbre, Chapter 3; Tempo, Chapter 5; Duration (as in rhythm), Chapter 4). However, intensity is a psychophysical perception which can be subjectively altered by environmental factors. For example, in an echoic room, a tone may sound subjectively louder than in a sound-attenuated room. Similarly, where there is ambient noise, a tone may sound subjectively softer than in a quiet room. Due to these limitations, testing of intensity would best take place in a sound-attenuated room with carefully controlled stimuli. For this study, it was decided that the children would be easiest to work with if they were seen in their own environments, at school, at a time that was convenient for them, thus the decision to postpone the study of intensity was made.

Developmentally, these plans for a study of musical ability in participants with ASD are sound. Putting aside, for the moment, discussion of pitch, rhythm is perceived by infants, albeit at a simpler level than adult listeners (Bergeson & Trehub, 2006; Hannon & Trehub, 2005; Trehub & Thorpe, 1989). Similarly, timbre is successfully recognized by infants as young as seven months (Trehub, Endman, Thorpe, 1990) along with tempo (Trainor, Wu & Tsang, 2004).

Some interesting abilities are discussed in the developmental literature surrounding structures which are not specifically accounted for in Jackendoff and Lerdahl's (2006) model of music. Specifically, understanding of tonal context and implicit learning for musical materials have been demonstrated in infants, implying that there is an innate precursor to these learned behaviours (Trehub, Schellenberg & Kamenetsky, 1999; Trainor & Trehub, 1994; Trainor & Trehub, 1993; Trainor & Trehub, 1992; Saffran, Johnson, Aslin, Newport, 1999). The understanding of tonal context is somewhat related to the musical culture in which one finds oneself, but work with infants has shown that the knowledge of relationships between sounds is influenced by inherited, biological faculties. Implicit learning is the putative mechanism by which one absorbs the musical "grammar". Thus while tonality and musical grammar are culture-specific and must be learned by the infant, implicit learning is the mechanism by which this happens. Both aspects of musical functioning are essential for development of a musical ability, and thus were also included in this survey of musical ability.

With the exception of one study investigating local and global processing using a chord priming task (Heaton, Williams, Cummins & Happé, 2007) little is know about how autistic people process musical structure. This abiity will be examined in chapter 5 of this manuscript.

Similarly, only one study has probed perception of rhythm in autism, as this study specifically focused on rhythmic patterning in speech (Järvinen-Pasley, Pasley & Heaton, 2008). Thus very little is known about rhythm, the second aspect of musical structure. The cognitive underpinnings of rhythm, as defined by Jackendoff and Lerdahl (2006), however, have been examined. Jackendoff and Lerdahl (2006) argue that rhythm can be divided into two separate structures: grouping structures and metrical structures. Grouping structures are constituted by domain general gestalt principles. These have been extensively studied in autism, in vision and audition using the global/local paradigms described above. Whilst the findings from these studies have produced mixed results no studies attempting to operationalise Gestalt principles in musical stimuli have observed deficits in autism (Heaton, 2003; Mottron et al. 2003; Mottron, Peretz & Menard, 2000; Heaton, Pring & Hermelin, 1999; Heaton, Williams, Cummins & Happé, 2007).

Metrical structures, the second part of the rhythmic organization, are realized by the metrical grid which aligns itself by beats to the musical surface (Jackendoff & Lerdahl, 2006). The grid is itself in a hierarchical design whereby there are sequences of strong and weak beats of varying intensities. This question of metre in individuals with autism has been little regarded, although co-occuring dyspraxia noted in some studies (Dziuk, Larson, Apostu, Mahone, Denckla & Mostofsky, 2007) might predict difficulties here. Thaut (1988) studied the ability of autistic children to produce an improvised 16-note musical melody on the xylophone, compared with younger typically developing children and older adults with mental retardation. He found that the performance of the children with autism was roughly commensurate with that of typically developing children and that children with autism scored especially well on measures of rhythm on this task. Apart from this study, however, none have looked at metrical or rhythmic ability in individuals with autism.

Finally, Jackendoff and Lerdahl (2006) argue that the emotional, or affective role of music is one of its most important. They note the validity, but also problematic nature, of defining the affective tone of the piece by its mode and pitch usage. This is what Heaton, Hermelin and Pring (1999) did when they studied affect and modal processing in children with autism. However, the increased complexity called for by Jackendoff and Lerdahl (2006) was addressed to some extent in the study carried out by Heaton et al. (2007). Here the number of adjectives potentially describing the music was increased and reliance on mode as a determinant factor in determining musical meaning was reduced. Both studies found that individuals with autism are not impaired on tasks requiring them to label music with emotional or affective terms.

There are other aspects of musical processing that could have been examined in this study. Musical production ability is an obvious marker of musical development, especially in Western Tonal music. However, with the notable exception of rhythm clapping, it was not thought prudent (logistically or for the comfort of participants) to undertake the examination of production ability with these populations. More expert functions such as reading musical notation or identifying musical idioms was not within the ability level of these participants. Further exploration of explicit musical memory in the ASD population in general, as well as that of savants in particular, is of considerable importance, but it (like emotion processing) was eschewed in favour of examining more fundamental aspects of music.

The subjects that do form a part of this study of musical abilities in individuals with ASD are those perceptual aspects of music ("musical surface") and fundamental aspects of music ("music structure"), with the exception of pitch (which has been widely studied in the ASD population). In addition, two more, higher-level musical abilities were examined in this study, namely local/global understandings of tonal context, and implicit learning for musical structure. The first, understanding of the tonal context, was chosen specifically for its relationship to two hypotheses of general cognitive processing in ASD, the Weak Central Coherence (WCC) theory (Happé & Frith, 2006), and the Enhanced Perceptual Functioning (EPF) theory (Mottron & Burack, 2001). This experiment, which is presented in chapter 5, incorporates into itself a test of temporal processing. The second of these two higher-order musical processes is implicit learning, which was chosen for its fundamentally important relationship to a normal developmental trajectory. If implicit learning for music were found to be impaired, one would not be surprised to also find other impairments in musical processing.

Musicality

Autism is most often regarded as a syndrome of deficits; however research has shown that, in every aspect of musical functioning thus far examined, individuals with autism show performance at least commensurate, if not exceeding that of typically developing matched controls. The question is then raised; do individuals with autism have all of the functioning capability necessary to develop musicality?

In her (2003) paper, Trehub asserts "In the absence of disability, commonplace musical competence (such as recognizing and producing tunes) is acquired effortlessly, as is conventional linguistic competence" (p. 669). Trehub continues to argue that this commonplace musical competence, this "musicality," develops naturally in the typically developing infant and child, and right into adulthood. She points out that it is not human perceptual skills that have reserved music for the enjoyment of human beings but that the social aspect of music, is the reason that humans alone enjoy music as a part of our culture. Given Trehub's insistence that language should be acquired as effortlessly as music (but only in the absence of disability) and that the social aspects of music are some of the most important, it does not seem likely that children with autism would develop musical knowledge and skills effortlessly. The fact is that people with autism do not develop language effortlessly, and the social processing that should make music so important is likely to be difficult for people with this disorder of social communication.

However, empirical data from savants with autism shows that at least some individuals with this disorder develop very high levels of musical skill. Allen, Hill and Heaton, (in press) also noted that several of their adults participants with autism cited of the feeling of belonging to something social, something communal as motivations for listening to music.

It is also the case that some music theorists (e.g. Patel, 2007) are moving away from the notion that music serves primarily social functions to a view that we listen to music because it exerts transformative effects on our sense of self. This move towards conceptualising the drive to listen to music in intrapersonal rather than interpersonal terms enables us to ask better questions about the musical experiences of people with autism who are clearly motivated to listen to music.

While the pitch elements of Lerdahl and Jackendoff have been explored extensively in ASD research, the remaining musical traits required for the development of musicality have been little examined. A few reports have looked briefly at particular individuals' abilities to play their instrument within the specified rhythm, (O'Connell, 1974; Thaut, 1988), but no systematic investigations of rhythm, tempo, or timbre have been undertaken.

There are various reasons to believe that these other aspects of musical functioning may not be spared or enhanced as is pitch. Both prevailing perceptual-cognitive theories of autism, WCC (Frith & Happé, 1994) and EPF (Mottron & Burack, 2001), would predict a mixed pattern of deficit and sparing across the musical domain. WCC (Happé, 1999) with local bias at verbal semantic levels, if generalizing to music, might predict deficits in processing sequences of auditory stimuli.

The "deficit in social clock timing", a hypothesis of autism as a deficit in timing (Wimpory, Nash & Nicholas, 2002) would also predict poorer performance on rhythm and tempo tasks. A newer hypothesis about spectro-temporal complexity (Samson, Mottron, Jemel, Belin & Ciocca, 2006) predicts that individuals with autism should have difficulty processing timbre as it is a spectro-temporally complex facet of auditory information. Deficits in pitch would not be predicted by either of these theories. In the case of pitch, this is because it is not a spectro-temporally complex stimulus, and also does not have a significant temporal component. Thus, while some of the only data available (the pitch data) demonstrates preserved or enhanced ability, it cannot be hypothesized that this will be the case for other musical components to be probed.

A Way Forward

The main goal of this thesis is to examine various hypotheses relating to musical deficits and sparing in autism. Research has shown that individuals with autism fulfill the melodic and tonal requirements of musicality (Heaton 2006; Heaton 2005; Altgassen, Kliegel & Williams, 2005; Heaton, 2003), however the timbral, rhythmic, temporal, metric and learning portions of the requirements for musicality remain unexplored. Thus these questions will be probed in a group of five experiments to be carried out with school aged children with autism spectrum disorders, and mental- and chronological-age matched control children. The characteristics of these participants, and an initial exploration of their background characteristics, are described in chapter two.

In chapter three the perception and processing of timbre will be probed. The literature review introducing this chapter will focus on the mechanics and characteristics of timbre in music, and will highlight the role of EPF theory in evaluating the musical performance of individuals with ASD. The hypothesis is motivated by the EPF theory and states that individuals with autism will be superior to controls in processing this complex acoustic property. However, Samson et al have predicted deficits in processing stimuli with high spectro-temporal complexity and this is presented as an alternative and opposing hypothesis.

Two aspects of rhythmic processing are explored in the fourth chapter. This chapter is introduced with a more detailed discussion of the literature pertaining to rhythmic abilities in ASD and other developmental disorders. It continues with a description of the two experimental tasks presented in the current experiment. Firstly the rhythm reproduction task tested participants' ability to recognize and reproduce rhythms in a call-and-response format. In this experiment, considerations of possible motor impairments in the clinical sample were taken into account, as this may cause participants with autism difficulty completing this task. The second rhythm experiment described here removed considerations of motor problems as far as possible, presenting a pure rhythm recognition experiment. Both experiments are discussed in light of the impact of motor control problems and social timing deficits.

In chapter five, an experiment examining understanding of tonal centre is presented. This is a replication of previous work by Heaton, Williams, Cummins and Happé (2007) with an important manipulation: processing of global and local perception in music is tested at different tempi. Further discussion of WCC theory is made with respect to this task, and Speed-of-processing deficits are introduced as a potential explanation in discussion of these results.

Finally, in the sixth chapter, an experiment examining implicit learning for music and pseudolinguistic stimuli is presented. In chapter five evidence is presented that participants with ASD are indeed able to acquire implicit information about music – in that case, tonal information. However, this experiment asks whether children with ASD can quickly and accurately learn grammatical information in musical and linguistic modalities, and whether this pattern of learning may explain why these children attend preferentially to musical rather than linguistic stimuli. After a cursory introduction to artificial grammar learning paradigms and their associated issues, These results are discussed with reference to the modularity (or lack thereof) of language and music in the brain.

All of these sparings and enhancements are then critically discussed in light of the prevailing model of brain dysfunction in ASD.

II. Participants

Abstract:

Two groups of children took part in this study; the first were children diagnosed with ASD recruited from two schools with specialist provision in England, the second were children with moderate learning disabilities recruited from schools with specialist provision for special educational needs (SEN) in England. While there were no statistical differences between the two groups of participants on matching criteria, the issues surrounding matching these two groups for comparison are addressed. The background data collected is described along with some interesting results: participants with ASD performed better than participants with MLD on the test of dexterity used in this study, the Pegboard; Block Design was unsurprisingly performed better by participants with ASD, but interestingly Pegboard performance was correlated with Block Design, presenting an interesting issue with using this task with a population that is known to suffer from dyspraxia; finally, the tests of language functioning showed disparate results, the TROG performance was not different between the ASD and MLD groups, but BPVS was unsurprisingly different with the ASD group showing a deficit relative to the MLD group.

ASD Participants

The children who participated in the studies were recruited from two schools with specialist provision for autism in England. In all, there were twenty-two individuals aged between twelve and sixteen years (mean age 13.86), all with a primary diagnosis of ASD as recorded on their statements of special educational needs. Three of these participants were female.

One of the schools provided mandatory music lessons, and the students at this school (n= 9) had experience playing tuned percussive instruments such as the xylophone for a period of one to three school years (mean = 1.25 years). The remainder of participants attended a school without specialist music provision and were less experienced musically.

Test results providing background date for the whole participant sample is shown in Table II:A.

Table II:A: Descriptive Statistics for ASD Participants

	N	Minimum	Maximum	Mean	Std. Deviation
BPVS	22	.00	130.00	56.59	37.06
TROG	22	0	18	11.64	4.88
Pegboard Dominant	22	14.69	27.15	20.56	3.03
Pegboard Nondominant	22	18.54	38.18	23.87	4.49
Block Design	22	15	69	44.50	15.40
Ravens	22	3	55	20.27	13.79

The British Picture Vocabulary Score - II (BPVS) (Dunn, Whetton & Burley, 1997) is a test of receptive vocabulary that demonstrates the verbal mental age of a participant. The test is a four-picture multiple-choice in response to a single descriptive word. The participant is required to choose the picture that most corresponds with the stimulus word. Normative scores by culture are available which indicate at what age a given participant is performing.

The Test for Reception of Grammar -2 (TROG-2) measures understanding of grammatical structures. Its structure is twenty grammatical constructs each tested four times using different test stimuli in a forced-choice format. Participants listen to a sentence (the grammar) and are asked to choose the picture that corresponds with that sentence. With each item, there are lexical and grammatical foils. The test is designed to test both normal development of grammatical understanding, and to test language disorders.

The Pegboard task (Henderson & Sugden, 1992) is a task measuring manual dexterity. The participant is required to place twelve pegs into the holes situated equidistant from one another on a board, using only one hand at a time. Scores are thus obtained for both the dominant (Pegboard Dominant) and non-dominant (Pegboard Nondominant) hands. Due to the reports of dyspraxia in autism (Dziuk, Larson, Apostu, Mahone, Denckla, Mostofsky, 2007) and the fact that experiment 2 (chapter 4) describes a rhythm experiment where participants are required to use their hands to make musical rhythm, it is prudent to include a screening test for fine motor impairment which may influence the participants' performance on this task.

The Block Design is a subtest of the Wechsler Intelligence Scale for Children (Wechsler, 1949). This test is designed to test performance IQ, using visuospatial puzzles to challenge a participant's ability to piece the segments together. This test was included here because of its now well-known association with autism (Shah and Frith,1993). Shah and Frith (1993) found that participants with autism perform better than typically developing participants on the block design task. Later, Caron, Mottron, Berthiaume, Dawson, and Brain (2006) have shown that it is perhaps only a subgroup of the autistic population that shows this extraordinary pattern of performance, but nonetheless some individuals with autism do show a strength on the block design task. When considering different cognitive theories of autism, it is important to consider performance on the block design task, since several theories have showcased this performance as evidence for (or against) their merits.

Raven's Progressive Matrices (RPM) (Raven, Court & Raven, 2003) is the test of non-verbal intelligence utilized in these experiments. RPM uses a six-to-eight picture multiple choice format in response to a pictorial exemplar. The task is a test of logic in which a series of pictures which are related by some logical operation is unfinished, and the participant must choose the picture that completes the logical progression. As a test of non-verbal intelligence, Raven's Progressive Matrices scores do not fall victim to the language delay and communication impairment found in autism as may tests of verbal intelligence.

Matching Issues

Matching, in the case of children with ASD, is a complex topic which has been little explored in the literature. Recently, however, the Journal of Autism and Developmental Disorders devoted an issue to the topic (JADD vol. 34 (1), 2004), and some interesting recommendations were made. Mottron (2004) finds that while the Weschler scales, BPVS and RPM are the measures that are most often used to match participants with pervasive developmental disorders to comparison participants, the BPVS and RPM lie on the peak of and uneven cognitive profile of autistic functioning. The result is that, while these three measures of IQ are highly correlated in the typically developing population, only the Wechsler can be said to give an accurate evaluation of IQ in participants with ASD. Dawson, Soulières, Gernsbacher and Mottron (2004) suggest that both RPM and BPVS may well overestimate the ability of the ASD group. Both studies (Mottron, 2004; Dawson, Soulières, Gernsbacher & Mottron, 2004) go on to recommend only Full-Scale IQ measures (FSIQ) from the Weschler group of tasks to be used to match ASD groups to control groups.

These authors claim that the RPM and BPVS *over*estimate ASD participants' intelligence with respect to control groups. Thus, matching the performance of ASD groups with controls on these variables provides an extremely stringent test of ASD performance.

In addition, since music is largely a non-verbal ability (Stoesz, Jakobson, Kilgour & Lewycky, 2007) the non-verbal test of IQ, the RPM, was used to match the ASD group to the MLD comparison group. RPM is a well established culture-fair test of fluid intelligence which is well-tolerated by children both with and without autism.

This philosophy of matching is in line with the view of other theorists featured in that issue of JADD. Burack, Iarocci, Flanagan & Bowler (2004) recommend that, while any attempt at matching is inherently difficult, that the best instances of matching strategies consider of the purpose and precise hypotheses being tested before choosing a comparison group. In this study, the specific aspect of functioning investigated is musical functioning, which in the domain of non-verbal intelligence, and thus the RPM was used thought to provide a good measure of matching between the ASD group and their comparison group.

Chronological age was the second factor used to match these groups. In many studies comparing children with and without autism children are matched on the basis of mental age. However, this often results in a CA discrepancy between groups (e.g. controls are younger) which means that listening experiences, important for musical learning, will differ between groups. As the ASD group was not intellectually high-functioning, the control group included individuals with moderate learning disability.

This study sought to investigate how the music perception skills in individuals with autism spectrum disorders compare to individuals with the same level of cognitive functioning, but without ASD. In the terms that Treffert (1989) would use, this study sought to investigate the “talent” of individuals with autism. In Treffert’s (1989) work, he outlines three categories of savant talent: Splinter Skills, Talent, and Prodigy. Splinter Skills are those skills which are apparent against a backdrop of disability; the peaks on an uneven cognitive profile. The Talented category refers to individuals whose ability is exceptional relative to other individuals with comparable intellectual ability. The Prodigious category is reserved for individuals whose ability is exceptional even compared to typically developing individuals. Whilst this rating scale was developed for use with those with Savant Syndrome, it clearly applies to all domains where ability can be compared between diagnostic groups.

Since few studies before have examined the areas of musical functioning that will be investigated in this work, it was found prudent to begin with a conservative goal. It has been established that some musical abilities exist as splinter skills for at least a subgroup of individuals with autism (e.g. Heaton, Pring & Hermelin, 1999), thus here it was asked whether musical ability exists also as a talent for non-savant individuals with autism, that is, compared to individuals with commensurate intellectual abilities and disabilities.

MLD Participants

The comparison participants with moderate learning difficulties (MLD) were recruited from three schools with specialist provision for special educational needs (SEN) in England. There were twenty-three participants in all, two of whom were female. They were aged between thirteen and sixteen years (mean age 14.22). Three of the participants had taken private music lessons, and all had some music instruction at their school. The mean length of music lessons for this group is 0.8 years. Participants were not matched for musical learning experience, however neither group had enjoyed very much musical learning; nearly all participants had only been exposed to music lessons at their school. There was no significant difference between the two groups (ASD and MLD) on receipt of musical tutelage (F=1.940, t=0.174).

Background data for the comparison participants is shown in Table II:B Some difficulties (e.g. dyspraxia) prevented some participants from completing the full battery of tests.

Table II:B: Descriptive Statistics for MLD Participants

	N	Minimum	Maximum	Mean	Std. Deviation
BPVS	20	30.00	132.00	99.30	25.28
TROG	18	1	20	14.22	5.03
Pegboard Dominant	19	17.12	38.87	24.37	6.32
Pegboard Nondominant	19	18.40	81.03	30.07	16.72
Block Design	15	2	47	22.13	12.99
Ravens	23	2	47	23.26	14.16

MLD participants scores on the matching variables (chronological age, and Ravens Matrices) did not differ from those of the participants with ASD (Age: F=1.247, p=0.270; RPM: F=0.513, p=0.478).

British Picture Vocabulary Scale

On the measure of receptive vocabulary (BPVS) the participants in the ASD group performed at significantly lower levels than the participants in the MLD group (F=18.646, p=0.0001). As it is a measure of verbal performance, however, this is not terribly surprising. Part of the diagnostic criteria for autism is the presence of a language delay and communication deficit. Participants with MLD have no such diagnostic requirement *a priori*. Thus while participants were expected to have comparable non-verbal IQ scores, it was expected that their verbal IQ scores would be significantly different in the direction that was observed.

TROG-2

In the context of this thesis TROG-2 was used as a measure of receptive grammar. As experiment 5 in chapter 6 tested implicit learning across speech and music domains, this test provided base line information about the extent that individual participants had acquired grammar. This data is important as some researchers have identified grammatical and syntactic difficulties in autism(Scarborough, Rescorla, Tager-Flusberg, Fowler, & Sudhalter, 1991; Minshew, Goldstein, & Siegel, 1995) while others report that grammar and vocabulary is unimpaired (Bartak, Rutter, & Cox, 1975; Pierce & Bartolucci, 1977; Tager-Flusberg, 1981). The comparison of TROG-2 scores revealed no significant difference between the ASD and MLD groups ($F=2.698$, $p=0.109$).

At first glance it is puzzling that there should be a difference between experimental groups on one verbal IQ task (BPVS), but no difference on another verbal task (TROG-2). However, the BPVS is an explicit test of vocabulary, while the TROG-2 is a test of receptive grammar. As discussed above, it is unclear wherein the language deficit in autism lies, whether with vocabulary or grammar or neither (or both). These results indicate that perhaps a deficit in vocabulary, but not in grammar, is present in this sample with ASD. However this result would have to be confirmed by careful manipulation and replication.

Pegboard

The Pegboard is a test that probes manual dexterity and is standardized and age normed, thus it can be determined whether participants were performing well for their age, or not.

Below, in Table II:C, the scores for both groups of participants can be seen to be significantly below chronological age. However, on the dominant hand, the pegboard performance of the MLD group was significantly lower than that of the ASD group (F=6.306, p=0.016). On the non-dominant hand the groups did not perform significantly differently (F=2.799, p=0.102).

Table II:C: Raw and standardized scores for pegboard performance

Participants	Age (mean)	Pegboard Score Dominant Hand	Pegboard Score Dominant Hand Standardized (years)	Pegboard Score Non-Dominant Hand	Pegboard Score Non-Dominant Hand Standardized (years)
ASD	13.86	20.57	7	23.87	8
MLD	14.22	24.37	6	30.07	3

It is unclear why this difference has emerged. It was expected that MLD control participants, having no *a priori* reason for a motor control deficit, would perform better than ASD participants. However, the difference between groups has emerged in the opposite direction, with ASD participants performing better (but still subnormal).

Block Design

The Block Design task is a subtest of the Weschler Intelligence Scale for Children III (WISC-III) which measures visuospatial and motor skills. In their seminal (1993) study, Shah and Frith reported the finding that many individuals with ASD are particularly skilled on the Block Design task. This was supported in a meta-analysis of Weschler profiles carried out by Happé (Happé, 1994). Shah and Frith (1993) interpreted their findings as autism-specific ability to disembed elements of Gestalt configurations. More recently, however, Caron, Mottron, Berthiaume, Dawson and Brain (2006) have shown that peak performance on the block design task is not universal in autism but rather is observed in a sub-group of individuals. One aspect of the block design task that is not always fully considered is that it has a motor component and poor scores on this test could reflect difficulties in manipulating the blocks rather than representing the holistic qualities of the stimuli. There is increasing evidence for dyspraxia in autism (Dziuk, Larson, Apostu, Mahone, Denckla, Mostofsky, 2007) that might well impair the gross and fine manipulation skills needed to manipulate the blocks. The task is timed with higher scores reflecting quicker task completion times.

The data from the block design task was correlated with the data from the Pegboard task (described above) and the correlation was statistically significant for both the ASD group, (Dominant hand: r=-0.637, p=0.001; Non-dominant hand: r=-0.661, p=0.001) and the MLD group, (Dominant hand: r=-0.632, p=0.011; Non-dominant hand: r=-0.635, p=0.011). Thus it was the finding in this sample that motor skills affected performance on Block Design.

The Block Design task was included in this battery of background tasks because of its link to WCC theory, which was tested in one of the experiments in this study, but also because musicians have been shown to be advantaged in comparison with non-musicians on this test (Stoesz, Jakobson, Kilgour & Lewycky, 2007). This may be because non-expert listeners hear music with a global advantage (i.e. they do not segment well), however as expertise develops so do local music perception skills (i.e. expertise encourages segmentation).

III. Timbre Perception

Abstract:

Whilst several studies have investigated perception of pitch in ASD, no investigations into timbre perception have been carried out. Predictions based on the EPF and WCC theories would predict enhanced sensitivity to timbre, although, it has also been suggested that deficits in processing spectrally complex stimuli are characteristic in ASD, and this would predict poor discrimination of timbral features in music. The results from the experiment presented in this chapter, showed clearly enhanced sensitivity to timbre in ASD and supported current theoretical accounts of perceptual and cognitive style and biases in ASD.

Timbre is one of the fundamental constituents of music, and yet theorists have found it difficult to define. Tone quality and tone colour have variously been used to describe timbre, but both fail due to their pre-existing meanings in English usage. The American Standards Association defines timbre as "[...] that attribute of sensation in terms of which a listener can judge that two sounds having the same loudness and pitch are dissimilar... timbre depends primarily upon the spectrum of the stimulus, but it also depends upon the waveform, the sound pressure, the frequency location of the spectrum, and the temporal characteristics of the stimulus." (American Standards Association, 1960, p. 45) In other words, timbre is a multidimensional, spectrally and temporally complex characteristic of sound.

Timbre characterizes the identity of a sound source. It is more than just a component of music; perception of speech relies on timbre, as does perception of any ambient sound. It is timbre that allows us to discriminate between the sounds of two different instruments, or car engines, or vacuum cleaners, or lawnmowers. Timbre is an important feature of everything that we hear.

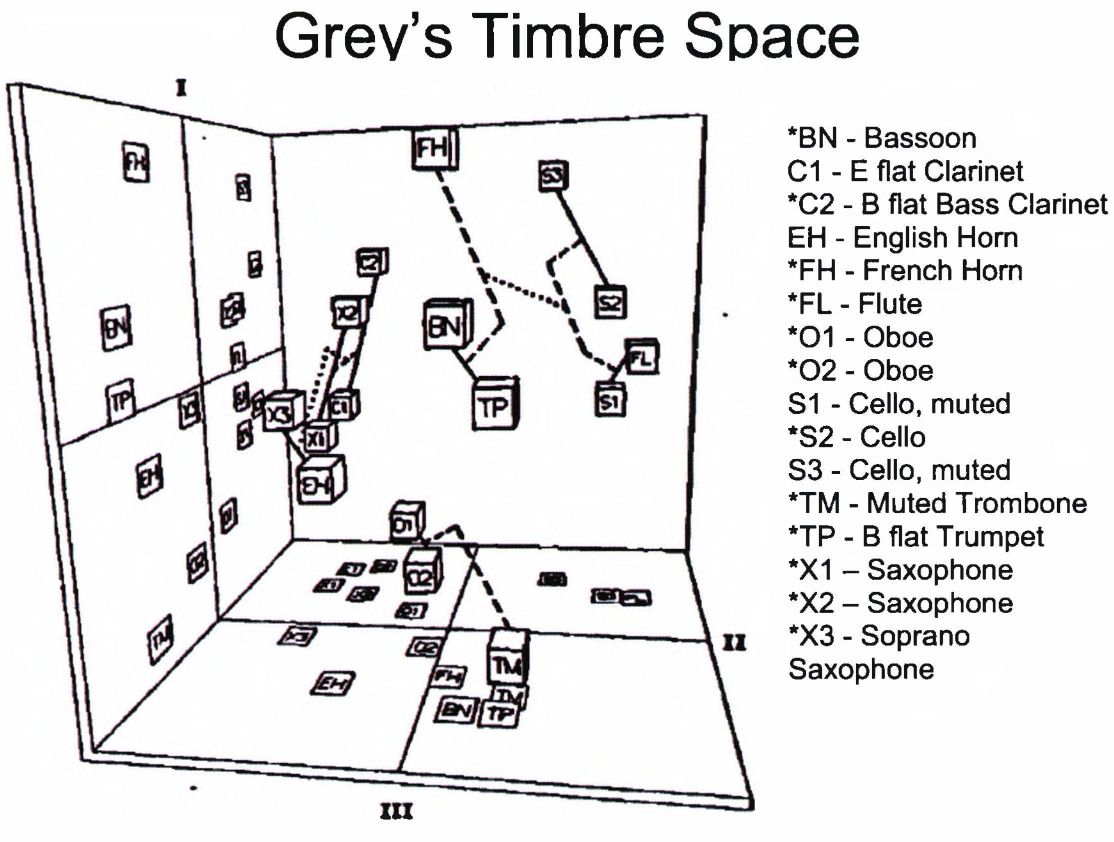
Pitch, like timbre, is one of the basic properties of sound and is processed at a relatively low level of functioning. However, neuropsychological studies have shown that pitch and timbre are processed differently in auditory sensory (echoic) memory (Krumhansl & Iverson, 1992; Semal & Demany, 1991; Háden, Stefanics, Vestergaard, Denham, Sziller, Winkler, 2009). In addition, the processing of timbre relies upon several acoustical dimensions, making it a multidimensional perceptual attribute, unlike pitch (which relies only on fundamental frequency) or loudness (which relies on intensity).

Research into the structure and perception of timbre has shown that timbre originally focused on one dimension of the sound, namely its spectral envelope. Helmholtz (1868) showed that the relative amplitudes of these spectral components of complex tones were indeed indicative of a dimension of sound. However, it has become clear that this definition of timbre is too narrow. For example, as Samson, Zatorre and Ramsay (1997) note, the changes in spectral envelope caused by a transistor radio do not necessarily alter the recognition of instruments played through it (Eagleson & Eagleson, 1947). Secondly, when the spectral envelope of an instrument is reversed – e.g. the piano note is played backwards – the actual spectra of the struck notes remain the same, and yet the timbre of the instrument in this reversed condition is impossible to determine (Berger, 1964). These results led Samson, Zatorre and Ramsay (1997) to conclude that musical timbre does not depend on a single physical dimension. Furthermore, they argue that timbre relies on a temporal dimension as well, as it has been shown that removal of part of the spectral envelope of an instrumental sound impairs recognition of the timbre of that instrument (Berger, 1964; Wedin & Goude, 1972). Thus they make the case that timbre, unlike pitch, has high spectro-temporal complexity.

Parallels have often been drawn between timbre and colour, and the analogy will be carried further here. Colour is itself a complex quality, comprised of three independent components: hue, saturation and brightness. Every colour, from black to white, has these three qualities in varying degrees, which is to say that the colour seen relies not only on one dimension, but on all three dimensions. Similarly, every timbre is comprised of independent components; spectral envelope might be one, temporal pattern another. What is certain is that like colour, timbre is a quality, and this quality is one of high complexity.

Given that the structure and functional characteristics of timbre, are relatively poorly understood, measuring timbre and comparing sound characteristics on differents instruments presents a significant challenge. It is clear that a violin shares more timbral similarity with a viola than it does with a trumpet, and research could not progress until this knowledge was translated into an experimental measure. Here, the technique of multidimensional scaling (Kruskal, 1964; Shepard, 1962) is of use. This technique takes an n-dimensional space in which it plots the dissimilarities between stimuli as the distance between each point in the space (Ramsay, 1982). And thus one achieves a spatial representation of the relationships between each stimulus in the set. With regards to timbre, Grey (1977) conducted a multidimensional scaling of the perception of several orchestral instruments, and created a timbral "space" in which the relationships between different instruments is clearly defined. (Figure III:1).

Figure III:1: Grey's Timbre Space



Using this Timbre Space, we can compare the perception of either closely related (within the same quadrant) or less related instruments' timbres.

Timbre perception has never been studied in ASD, although the clinical and anecdotal literatures abound with descriptions of individuals who show strong reactions to timbrally distinct auditory objects, like vacuum cleaners. The absence of any such studies is especially surprising given that both hyper- and hypo-sensitivities in all sensory modalities are in evidence in people with ASD (Tsatsanis, 2005). Although sensory abnormalities were included in the diagnostic criteria for autism in DSM-III (APA, 1987) they were excluded in DSM-1V (APA, 1994). However, Since publication of DSM-1V a wealth of studies has confirmed their prevalence in autism (Leekam, Nieto, Libby, Wing & Gould, 2007; Kern et al. 2006; Liss, Saulnier, Kinsbourne & Fein, 2006) and it may be that sensory abnormalities will be included in DSM-V.

Because they are both relatively low-level perceptual properties of sound, the research on pitch processing is most instructive regarding a hypothesis for timbre processing in ASD; the Enhanced Perceptual Functioning (EPF; Mottron & Burack, 2001) theory makes strong predictions. EPF claims that individuals with ASD have a processing enhancement such that the basic perceptual aspects of stimulus processing are finer-grained. This enhancement, it is argued, is what allows Absolute Pitch (AP) to develop so often in people with ASD, and also explains why individuals such as those in Heaton's (2003) study are better able to process and recall individual pitches, despite an absence of musical training and AP as typically defined. As timbre is a basic perceptual aspect of musical stimuli, EPF would also predict enhanced processing of timbre relative to controls. Based on EPF, it is thus hypothesized that the individuals with ASD will perform remarkably well on this task, relative to controls, and that differences will emerge either on both levels of relatedness, or with the most closely related timbres (as it was for pitch in Heaton, 2004).

The new elaboration of WCC theory (Happe & Frith, 2006) also comes to bear on this timbre discrimination task. The ability probed in this task is a (relatively) simple one that can be performed by attention to the presentation of two specific tones to the exclusion of all else; the extended melody may make it easier to discriminate timbre by giving a more protracted example, but the requirements of the task are much more *local*. The two notes in question do not even need to have the same fundamental frequency (or pitch), although this does aid discrimination. Instead, timbre is a property of the sound that is independent of pitch or intensity. It has been demonstrated that timbre is processed independently of melody in typically developing infants (Háden, Stefanics, Vestergaard, Denham, Sziller & Winkler, 2009) however it appears that they become more entwined with development (Halpern & Müllensiefen, 2008). It is unclear precisely what is involved in timbre discrimination in adult listeners since, unlike pitch discrimination which is directly (though not exclusively) related to the vibrations of the tympanic membrane, timbre incorporates many more top-down processes of expectation and inculturation. However, many similarities can be drawn between timbre perception and pitch perception, for example in much the same way as infants process timbre, it appears that infants are able to process pitches absolutely, but that this ability diminishes throughout development, as music begins to be processed more relatively (Saffran, 2003). Interestingly, individuals with ASD have been shown to maintain their in-born capacity for absolute pitch processing (Heaton, 2003), and it will be interesting to discover whether “absolute timbre” will follow suit, that is, whether timbre will be processed more finely in ASD participants than in control participants.

A final point with respect to EPF and WCC theories and this timbre task. If indeed timbre processing is an enhanced perceptual function, or a local task (depending on the theoretical account), then the performance on this task should correlate with performance on other tasks, such as the embedded figures task, or the block design task. For this reason, performance on the block design subtest of the Wechsler Intelligence Scale for Children, version III (WISC-III) was assessed, and performance on this task will be compared against performance on the timbre task in order to evaluate the possible compatibility of EPF or WCC theories.

However, EPF and WCC are not the only theories of autism that are relevant to this discussion of timbre. A recent hypothesis regarding the performance of people with ASD on auditory tasks calls these hypotheses into question. In their (2006) paper, Samson, Mottron, Jemel, Belin and Ciocca ask whether spectro-temporal complexity can explain the autistic pattern of performance on auditory tasks. They note that individuals with ASD present with both a hypo-reactivity to loud and/or verbal sounds, and with a hyper-reactivity to low-intensity sounds. They also note that individuals with ASD have enhanced discrimination abilities with regards to pitch, and indeed that they have finer discrimination abilities too. Based on a review of studies investigating the functional neuroanatomy of auditory perception in ASD, Samson et al. hypothesize that in ASD there is increased sensitivity for first-order (simple) auditory stimuli but inferior sensitivity for second- or third-order complex auditory stimuli.

Samson et al. (2006) define the difference between a simple and a complex stimulus to be one of a difference in spectro-temporal complexity. They give an example of a pure tone, which does not change over spectra (frequency, in this case) or over time (it will be the same stimulus at time b as it was at time a). Thus, it is a simple auditory stimulus. A harmonic sequence, however, contains several frequency components and may change over time, and would thus be a complex auditory stimulus.

Timbre is an auditory stimulus with high spectro-temporal complexity that changes over time (from the onset of an instrument playing, through the steady-state and finishing in the decay). These are, in fact, three dimensions to timbre that emerged from Grey's (1976) multidimensional scaling technique. The first relates to the actual spectrum of energy in the spectral envelope of the sound, the second relates to the low-amplitude but high-frequency aspects of the onset of the stimulus (the attack) and the third relates to the rise and decay times and how the amplitude of components of the spectra changes over time. As Samson, Zatorre and Ramsay (1997) point out, the first of these dimensions deals specifically (and explicitly) with the spectrum, whilst the other two dimensions deal more with temporal aspects of the stimulus.

The observation that timbre is a simple and fundamental aspect of music, but is also characterised by high spectro-temporal complexity, makes it difficult to generate clear hypotheses about timbre discrimination in ASD. In order to clarify this apparent paradox, Samson et al. (2006) suggest that the concept of spectral and temporal complexity is much like the concept of a global and a local aspect of music; they are relative. Thus whilst a tone with timbre has high spectro-temporal complexity with respect to a pure tone, when it is viewed with regards to a whole melody (with a very high spectral complexity, and very long temporal complexity), the timbre is a more basic aspect of that melody. Thus when considered in terms of tens of seconds, complexity over milliseconds is less pronounced.

Cognitive models of perception and cognition in ASD, namely WCC and EPF, both predict that children with ASD will show finer timbre discrimination abilities than their children without ASD who are age and intelligence group matched, however the newer spectro-temporal complexity model of ASD predicts the opposite. Thus hypotheses for this experiment are not clear.

Methods

Stimulus

Synthesized sounds of each of the sixteen instruments accounted for in Grey's (1977) study were sought, and ten were found (see Figure III:1, instruments marked with asterisk). These twelve synthesized instrumental timbres are from Finale Notepad for Windows 2006, composition software available for free download (http://www.finalemusic.com/notepad/).

Instruments were considered timbrally similar if they occupied space in the same quadrant, and dissimilar if they did not. From this, seven pairs of timbrally similar instruments and ten pairs of timbrally dissimilar instruments were constructed (see table III:A). With these pairings, thirty timbrally identical stimuli were made, and thirty timbrally non-identical stimuli were made, fifteen each of similar and dissimilar timbre pairings. The reason for this arrangement – thirty identical and thirty non-identical – is so that signal detection theory could be used to investigate the performance of participants on this task. All timbral pairings were thus presented at least once, but, because there were relatively few non-identical but similar pairings of instruments, it was inevitable that many were presented more than once to reach this number of stimuli. This number of stimuli was selected with two constraints in mind: the participants' attention span would not allow for the presentation of too many stimuli, while the statistical power required "enough" stimuli to be presented (especially considering that there were subgroups of interest within the non-identical stimuli). Pilot testing with some children with ASD indicated that the participants' attention could be captured for presentation of a maximum of about sixty trials, which would equate to thirty identical stimuli, and thirty non-identical stimuli which further subdivides into fifteen similar and fifteen dissimilar stimuli. "Enough" statistical power could not be estimated for this experiment, as no previous data on the topic exist. Thus, it was thought prudent to present the maximum number of stimuli that the participants could handle in order to increase the statistical power.

These stimuli were made specifically for this experiment for several reasons. First, the stimulus sets that have been used to investigate timbre processing in the recent literature use synthetic sounds that do not even approximate orchestral instruments (see, for example, Samson, Zatorre &

Ramsay, 1997). While this is a more pure test of timbre discrimination, for this initial investigation into the timbre processing abilities of quite young people with ASD, it was thought prudent to use stimuli for which the participants had at least some referent (familiarity). The idea of using recordings of actual instruments, which would lend the maximum amount of validity and familiarity to the stimuli, was considered. However, with live performances differences in timing, pitch and intensity could not be adequately controlled. Thus it was decided that artificial instrument timbres, such as those used, from Finale Notepad, were the most logical choice. The melodies played by these instruments were composed for this experiment simply out of convenience. Since the data set was to be new (using Finale Notepad instruments) there was no apparent reason to ask another researcher for his or her stimulus melodies.

Table III:A: Timbre similarity of instrument pairings

Timbrally Identical		Timbrally Similar		Timbrally Dissimilar	
Bb Bass Clarinet	Bb Bass Clarinet	Bassoon	Bb Trumpet	Bassoon	Tenor Saxophone
Bb Trumpet	Bb Trumpet	Bassoon	French Horn	Bb Bass Clarinet	Bb Trumpet
Bassoon	Bassoon	Bb Bass Clarinet	Saxophone	Bb Bass Clarinet	Bassoon
Cello	Cello	Flute	Cello	Bb Bass Clarinet	Trombone
Flute	Flute	French Horn	Bb Trumpet	Cello	Soprano Saxophone
French Horn	French Horn	Oboe	Trombone	Flute	Oboe
Muted Trombone	Muted Trombone	Saxophone	Soprano Saxophone	Flute	Soprano Saxophone
Oboe	Oboe			Horn	Trombone
Saxophone	Saxophone			Horn	Soprano Saxophone
Soprano Saxophone	Soprano Saxophone			Oboe	Bassoon

Stimuli thus consisted of ten novel melodies without accompaniment, each containing seven notes with the same time signature (4:4), the same moderate tempo (crotchet = 120). , and written in Concert Pitch. Melodies were assigned to timbre pairs at random and were each repeated six times throughout stimulus presentation. Within all timbre pairs, each member of the pair was played in the same melody. Each melody was separated from its partner by one bar of rests. The stimuli created for this experiment can be found in Appendix 1.

Stimuli were presented using the playback function in Finale Notepad, and were played in the original electronic timbre in which they were composed. Standard computer speakers attached to a PC laptop were used to present the melodies, and the volume was set to a level that was comfortable for the participant.

Presentation was as follows. Participants were told that they would hear a melody, followed by a pause, and then they would hear the same melody again. They were instructed to listen carefully so as to determine whether different instruments were playing the melody the two times they heard it, or whether the instrument was the same. The first complete stimulus was then played, which included the both members of a timbre pair, in tempo and following this presentation participants were asked whether the two instruments were the same, or different. Participants' responses were recorded by the experimenter after each presentation. If participants complained that both of the songs were the same, the direction to listen for the instruments playing the song was reiterated. Presentation continued until all sixty stimulus pairs were played, and the responses recorded.

Table III:B: Psychometric data for ASD and MLD participants

	Diagnosis	Number	Mean	Standard Error	F	p-value
Age (Years)	ASD	17	14.18	0.231	0.062	0.805
	MLD	15	14.27	0.284		
Raven's Raw Score	ASD	17	22.06	3.505	0.666	0.421
	MLD	15	26.33	3.914		
BPVS Scaled Score	ASD	17	70.00	6.908	8.175	0.008
	MLD	15	98.93	7.400		

Participants were three girls and fourteen boys between the ages of thirteen and sixteen (mean age=14.18) with a diagnosis of ASD, and two girls and fifteen boys between the ages of thirteen and sixteen (mean age 14.27) without a diagnosis of ASD, but with moderate learning difficulties (MLD). Children were recruited from local schools with a special provision for pupils with autism spectrum disorders (ASD) or MLD, or dedicated specialist high schools throughout England. All children consented freely to participate in this experiment, and written permission was obtained from legal guardians in compliance with the ethical review board requirements of Goldsmiths College.

There was no significant difference between the groups on measures of age (F=0.062, p=0.805), or non-verbal IQ (Raven's Standard Progressive Matrices) (F=0.666, p=0.421), however as expected, the ASD group scored significantly lower on the scaled scores measure of verbal IQ (VIQ), the British Picture Vocabulary Scale (BPVS) (F=8.175, p=0.008). Table III:B shows the statistics for this group of participants.

Results

An initial analysis of the data was carried out using signal detection (SDA; Green & Swets, 1966). The rationale for doing this was (a) whilst the ASD and control participants were carefully matched on age and non-verbal intelligence, verbal IQ scores were lower in the ASD group and this may have resulted in difficulties in understanding the task. (b) Control participants had moderate learning difficulties and may also have experienced difficulties in understanding the task (c) experiments that require dichotomous responses risk misinterpreting a response bias (yes/no) as a measure of sensitivity. D'prime statistics for sensitivity and response bias are shown in Table III:C below.

Table III:C: Signal Detection Analysis, Sensitivity and Response Bias

	Diagnosis	Mean	F-Value	p-value
d'	ASD	0.6450	5.938	0.021
	MLD	-0.7320		
c	ASD	-0.0276	0.102	0.752
	MLD	0.0313		

This analysis showed that the c statistic (indicating a response bias) was quite close to 0 (no bias) for both groups, who did not differ significantly from each other (ASD: t=-0.223, p=0.826; MLD: t=0.227, p=0.824, ns.). Comparison of the d' statistic (indicating sensitivity level) across groups, indicated increased sensitivity in the ASD in comparison to the MLD group.

For the main analysis, inspection of the data hinted that the assumption of normality may be violated in this dataset, and thus the one-sample Kolmogronov-Smirnov test was performed, which tests for normality in the sample. The results of this test can be seen below, in Table III:D.

Table III:D: One-Sample Kolmogorov-Smirnov Test

	Same	Unrelated	Related
N	32	32	32
Kolmogorov-Smirnov Z	1.486	1.306	1.370
Asymp. Sig. (2-tailed)	.024	.066	.047

These results indicated that, as suspected, the distribution of data for the present sample was significantly different from the normal distribution. Thus remaining analysis was undertaken using non-parametric tests, where appropriate.

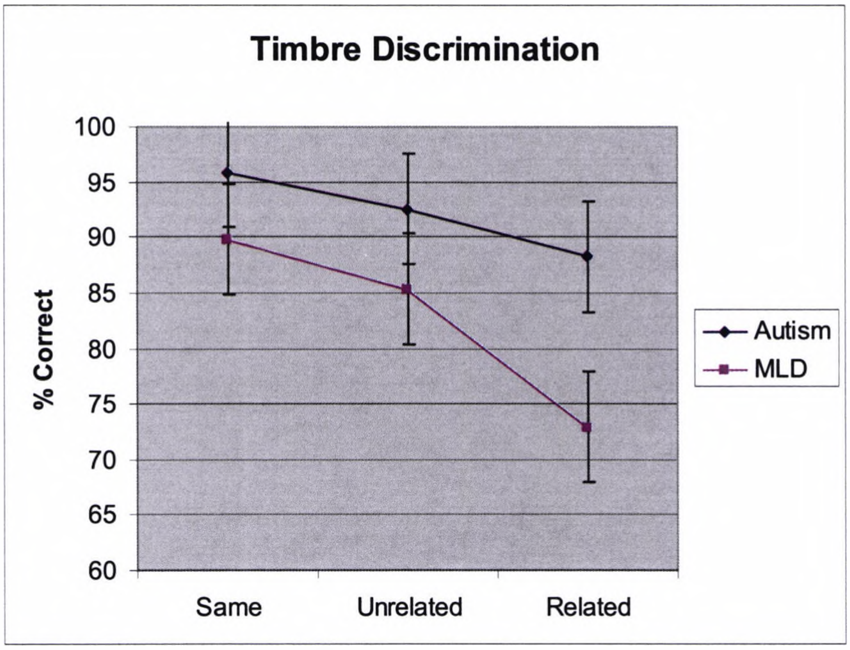
The first hypothesis tested, due to the predictions made by EPF theory and WCC theory, and the results with pitch obtained by Heaton (1997), is the *a priori* prediction that the ASD group would show enhanced perception of related timbre types. This is further pointed to by the signal detection analysis, which found that the ASD group were more sensitive to discrimination of the timbres. Therefore, proceeding from the recommendation of Wilkinson (1999), a planned, two-sample Kolmogorov-Smirnov test was undertaken where diagnosis (ASD or MLD) was the grouping variable and timbre pair type (same, related or unrelated) was the test variable. The results can be seen below, in Table III:E.

Table III:E: Two-sample Kolmogorov-Smirnov test for diagnosis by timbre pair type

	Same	**Unrelated**	**Related**
Kolmogorov-Smirnov Z	.886	.841	1.406
Asymp. Sig. (2-tailed)	.413	.479	.038

Here, there was a significant difference between diagnosis in terms of how well participants discriminated between timbres that were only slightly different, or related (K-S Z=1.406, sig=0.038). However, on pairs where timbres were the same or unrelated, no statistical difference was found (same K-S Z=0.886, sig=0.413; unrelated: K-S Z=0.841, sig=0.479). A graphical plot of these data show the direction of the difference between the ASD and MLD groups on discrimination of related timbres to be in favour of the participants with ASD (Figure III:2).

Figure III:2: Performance on Timbre Discrimination Task



EPF theory was proposed in response to findings contradicting the Weak Central Coherence theory proposed by Frith (1989), however EPF theory shares many of the same predictions as WCC theory. One such prediction is that individuals with ASD will demonstrate a local bias in perceptual processing tasks such as this timbre experiment, but also in the visual domain. The Block Design subtest of the Weschler intelligence scales (Weschler, 1996) is one such visual perceptual tasks. In their (1993) paper, Shah and Frith address the question of why participants with ASD show superior performance on the Block Design test. They found that participants were using a strategy of segmentation to complete the task – very literally, they were using local processing. Their conclusion was that this pattern of results on the Block Design test supports the weak central coherence hypothesis of autistic perception.

EPF, too, predicts excellent performance on the Block Design test. EPF theory posits not weak central coherence – global processing is unimpaired in individuals with ASD – but rather enhanced local processing. This enhanced local processing advantages the participants with ASD on tasks such as the Block Design. Thus it was of interest to determine whether performance on the Block Design test correlated with the performance on this test of local processing, the timbre experiment. The result of these correlations can be seen in Table III:F.

Table III:F: Correlations between Block Design scores and Timbre Experiment scores

		Block Design	Same	Unrelated	Related
Block Design	Pearson Correlation	1	.047	.376	.341
	Significance		0.818	0.053	0.082

None of the correlations were significant, however a trend was noted in the correlation between block design performance and both of the unrelated and the related timbres conditions. In both of these conditions block design scores correlated moderately. However, on the same timbres condition, there was no correlation. This is interesting because local processing would not likely advantage an individual on the same timbres task because it was unambiguous, however on the unrelated and related timbres tasks participants had to determine more finely the relationship between the two timbres. Here, a local processing advantage would equip participants to quickly and accurately make the decisions required.

It should be noted that in this sample, participants with ASD did score significantly more highly than control participants on the block design task (ASD: Mean=47.82, S.D.=14.951; MLD: Mean=24.40, S.D.=13.826; F=16.305, p=0.0001) as would be expected.

It is the recommendation of Wilkinson and the Task Force on Statistical Inference (1999) that the analysis may end there. However, for completeness an omnibus MANCOVA was undertaken where diagnosis (ASD, MLD) was the independent variable, performance on the timbre discrimination task in each of the categories (same, unrelated, related) was the dependent variable, and age, verbal IQ (as demonstrated by the BPVS) and non-verbal IQ (as demonstrated by the Ravens) were the covariates.

This model revealed that correcting for age, verbal IQ and non-verbal IQ, the difference between the ASD and MLD groups on all three measures of timbre perception was affected. On the "same" condition, the groups were performing significantly differently (F=2.762, p=0.048), as well as on the "unrelated" condition (F=3.382, p=0.023), however for the "related" condition there was no difference in performance of the two groups (F=2.227, p=0.093) although there was a trend indicating a possible difference.

This is interesting as it is almost a complete reversal of the effects seen on the a priori group comparison. That comparison, however, did not take into account the effects of verbal IQ, which may have affected how participants were able to understand the instructions, or age which may indicate a developmental effect in the cognition of timbre, or even non-verbal IQ which may also have an effect on timbre perception and cognition.

Discussion

From its basis in musical cognitive tasks (Bonnel, Mottron, Peretz, Trudel, Gallun, Bonnel, 2003; Mottron and Burack, 2001; Heaton, 2004) the Enhanced Perceptual Functioning (EPF) model makes strong predictions about the relative strengths of people with ASD in lower-level perceptual tasks. According to the model, people with ASD have finer-grained perception than do people without ASD, and thus on discrimination tasks which pit closely-related stimuli against one another, people with ASD have the upper-hand. On musical pitch discrimination tasks, this strength has been repeatedly observed (Bonnel, Mottron, Peretz, Trudel, Gallun, Bonnel, 2003; Heaton, 2004), however no other areas of musical perception have been tested to date.

In this study, children with ASD performed significantly better than their peers without autism when performing a fine timbre discrimination task (the Related condition), but did not perform significantly better (in fact, it appears that all participants performed at ceiling) when the task was less ambiguous, as was the case in the Unrelated and Same conditions. The graphical representation of these data show that the reason for this sudden significant difference is the poorer performance of the control group as the timbres became more and more ambiguous to discriminate, and the relative sparing of ability in participants with ASD as the task became more difficult.

These results are precisely what would be predicted by the EPF model. In their recent review of the EPF theory, Mottron, Dawson, Soulieres, Hubert and Burack (2006) argue that the default setting of autistic perception is to locally oriented stimuli, unlike those without autism. They are quick to point out, however, that this is not to the detriment of people with ASD; "autistics are not obliged to use a global strategy when a global approach to the task is detrimental to performance...Conversely, autistics are not rigidly stuck with a local strategy that would be beneficial only in a certain type of task." (Mottron, Dawson, Soulieres, Hubert & Burack, 2006; pg. 30) That is, when the task warrants it, people with ASD can be good global processors, they are just better than typically developing people at processing things locally. In this task, it was to participants' advantage to process locally because the timbre of the instrument could be perceived from just one note; the whole melody need not be processed to succeed at this task.

This statement of EPF is in contrast to the original formulation of WCC theory (Frith 1989) which stated that global processing (effected by central coherence) was "weakened" or impaired in individuals with ASD, but that local processing was intact (but not necessarily enhanced). However, in recent years WCC has moved away from this deficit account, and focused more on a detail-focused processing style and an atypical "cognitive bias" to process things more locally than globally (Happé & Frith, 2006). Either way, the results of this experiment could be explicable by WCC, since timbre processing is, strictly speaking, a local task.

Again regarding the EPF model, Mottron, Dawson, Soulieres, Hubert and Burack (2006) also point out that the EPF model posits that current processing styles are vestiges of perceptual regulatory behaviours in early childhood. Parents often report that their child with ASD will explicitly fine-tune his or her discrimination of some category of timbre, be it vacuum cleaners, hair driers, car engines or musical instruments. These low-intensity rumbling timbres are precisely what young children with ASD seem to have sensitivity for, while they ignore even high-amplitude and vocal productions (Samson et al. 2006).

Mottron et al. (2006) then go on to describe how such EPF in a person with autism sometimes develops into savant syndrome. As discussed above, this assertion is central to our hypothesis that individuals with ASD could, if they had all the components, develop musical talent. Timbre is but one such component, and it has been shown here that it is indeed preserved – in fact enhanced – in individuals with ASD.

Regarding these issues, WCC theory remains silent as it is not, as is EPF, primarily a theory about perceptual function, but rather of cognitive function. However, both WCC and the EPF theory bear upon the relationship between these data and the findings regarding the block design test. A trend was found in the correlations between the related and unrelated timbre conditions and performance on the block design. This moderate correlation further supports the assertion that both of these theories of ASD can explain the findings of this experiment. Enhanced Pereceptual Function theory predicts a local enhancement alongside a global preservation. WCC theory predicts a local sparing/enhancement and a global deficit. The Block Design test probes local processing, and those processing by EPF should be able to perform extremely well on the Block Design, while WCC theory predicts that participants with ASD should perform above average on the Block Design, due to at least spared local processing, and the removal of the global bias . In this sample, as expected, the ASD participants do perform extremely well on the Block Design compared to the MLD participants. This increased performance is moderately related to increased performance on the timbre experiment reported here. This relationship could be accounted for by EPF functioning in the ASD participants and lack of local enhancement in MLD participants, or it could be accounted for in WCC terms by local bias in the ASD participants and global bias in the MLD participants.

Both of these competing theories of ASD cognition, EPF and WCC, could be called upon to explain the pattern of results seen here. However, EPF theory more totally explains the findings due to its association with and predictions of enhanced *perceptual* function in individuals with ASD. According to EPF theory (and as discussed above), the enhancement in perception that manifests itself in sensory hypersensitivity in the child with ASD also results in the timbral sensitivity evident in this experiment (Mottron, Dawson, Soulieres, Hubert & Burack, 2006). Further, EPF posits a link between this sensory hypersensitivity and savant syndrome. This affords EPF increased explanatory power, compared to WCC, which is silent on these matters.

While the present experiment was not designed to explicitly test the hypothesis that individuals with ASD process timbre in a more "absolute" manner, much like infants do (Háden, Stefanics, Vestergaard, Denham, Sziller & Winkler, 2009), rather than integrating timbre with pitch in a more "relative" manner, as do adults (Halpern & Müllensiefen, 2008). However, the results in this experiment are consistent with this hypothesis. Increased timbral sensitivity, as seen in this experiment, indicates that the aspects of the sound that were distracting to the non-ASD participants were not distracting to the ASD participants. Further study should focus on integration of the developmental music-listening literature with the experiences of children with ASD with a view to determining whether the development of individuals with ASD has correlates, be they delayed or accelerated, in the development of neurotypical individuals.

The signal detection analysis conducted with the data was also enlightening. Neither the MLD group nor the ASD group showed any significant response bias, thus indicating that our task has, in fact, worked. However, the ASD group was significantly more *sensitive* than the MLD group on this task. In signal detection terms, this means that the ASD group could detect when our stimuli were the same or different more often than could the MLD group. This finding serves to reinforce the finding of our planned ANOVA: participants with ASD were more sensitive to the timbres presented, and thus could pick out even closely-related timbres while the MLD group could not.

A final note on these findings: the omnibus MANCOVA was a mirror reversal of the findings of the more specific *a priori* test. Once age, verbal IQ and non-verbal IQ were controlled for, the two groups were significantly different on the Same and Unrelated conditions (which indicates basic categorical processing of timbre) but were not significantly different (although a trend did emerge) on the more nuanced Related timbre condition. These results, while at first puzzling, do lend themselves to explanation. The group with ASD clearly performed better overall on this timbre perception and cognition experiment. However, verbal IQ (which, apart from diagnosis, was the only other factor reaching significance in this analysis) affected how well participants were able to perform. It is possible that the concept of timbre was a difficult one for participants with a lower verbal IQ. Timbre is a difficult concept to explain and to grasp, and while participants were at no time asked to distinguish between timbres *per se,* the concept of "when the instruments sound the same or different" could easily be captured, for the more verbally able, by the word timbre. The concept thus becomes more explicable and understood, making the task easier for the more verbally able participants.

Whether this explanatory factor, or another, is the true meaning of this difference, it is clear that individuals with ASD were better able to distinguish between timbres, even when age and IQ are controlled for, and it is also clear that replication of this finding is necessary.

Conclusion

Timbre discrimination is a skill that is at least preserved, and in some cases enhanced, in children with ASD. We already know from the work of Heaton (2001, 2006, 2008) and others that pitch discrimination is preserved or enhanced in children with ASD, but this finding with timbre adds one more piece to the puzzle of musicality in ASD. We might have expected, from parental reports and cognitive theorizing, that timbre would be an area of particular strength in people with ASD, but now we can be certain.

IV. Rhythm

Abstract:

Rhythm is a necessary part of human life, and at least one hypothesis of autism has predicted deficits in rhythm and timing processing. Here, two experiments investigating rhythm and timing are reported. In the first participants are required to clap back demonstrated rhythms and in the second they are required to determine whether pairs of rhythmic sequences are the same or different. In the rhythm reproduction experiment, participants with ASD performed significantly better than did the MLD comparison group even when the effects of differeing motor control and dexterity disabilities were controlled for. In the more purely cognitive task of rhythm discrimination, the scores of ASD participants were on par with those of their MLD peers, and signal detection even indicated that ASD participants are more sensitive to the changes in rhythm in this experiment. Results are discussed in the context of memory and attention for musical materials.

Introduction

Rhythm is an integral part of human life. From the heartbeat and circadian rhythms to the rhythms of daily life to the rhythmic variations in temperature and seasons, it is imperative for a human being to perceive and respond to rhythms. According to Jackendoff & Lerdahl's (2006) account, rhythm accounts for fully one half of musical structure, the other half being pitch. Music can be made using rhythm alone (as in percussive traditions) or pitch alone (i.e. Gregorian chant) but is generally comprised of both.

The generation (or even repetition) of rhythms requires a vast neural network and non-linear dynamic coupling of internal oscillators (Fitzpatrick, Schmidt & Carello, 1996). Clapping is a complex task requiring the synchronization of two effectors, the hands. This synchronization begins early, around eight to twelve months of age (Kaye & Marcus, 1981), but interlimb coordination is seen much earlier, in days-old infants (Fitzpatrick, Schmidt & Lockman, 1996). Still, it is unclear precisely how all neural systems processing rhythm at various levels intertwine. However it has been suggested that deficits in rhythm perception and expression correlate with deficits in other rhythmic processes such as circadian rhythm and the expression of clock genes (Wimpory, Nicholas & Nash, 2002). Brock, Brown, Boucher, and Rippon (2002) proposed a time-based model of autistic functioning which stresses abnormalities in functioning related to the circadian clock and its associated physiological measures, which are well-documented in individuals with autism (Nir, 1995; Ritvo, Ritvo, Yuwiler & Brother, 1993; Melke et al., 2008). According to this hypothesis, biological clocks, which operate on the scale of milliseconds, seconds and minutes, (or potentially even hourly, monthly and yearly cycles), directly effect physiological and behavioural systems. Keeping in mind that these physiological and behavioural systems are integrated one into the other, the severity of abnormality caused by these timing deficits would depend upon where, precisely, the effect occurs, and the degree of disruption it causes to this integrated system. These abnormalities could thus affect behavioural systems such as communication, sensorimotor control, and even rhythm, in addition to the biological systems mentioned above (Brock, Brown, Boucher, & Rippon, 2002).

In infants, timing is a crucial precursor for preverbal interactions (Trevarthen & Aitken, 2001) and even quite young infants can synchronise their bodies with salient aspects of an adult's communication (Malloch, 1999). Researchers have even measured the speed of infants' interactions with caregivers, and have noted that speed increases as the child develops (Trevarthen & Aitken, 2001). Newson (1984) described "social timing" difficulties that interfered with pre-verbal social interaction in infants with autism and Kubicek (1980) found that deficits in interactive turn-taking distinguishes autistic infants from their typically developing counterparts. These social timing difficulties in infancy have implications for later development, as the acquisition of social usage of language occurs through precisely the type of prototypical conversations that are affected by these timing difficulties (Ninio & Snow, 1996).

Brock, Brown, Boucher, and Rippon (2002) have shown that even quite able people with autism have a poor sense of time. In their (2002) theory, Brock et al. posit that timing deficits at the level of milliseconds to minutes could be responsible for the behaviours seen in autism. This may be manifested in the fast timing required for communicative exchanges to the much slower rhythms responsible for circadian changes in bodily function.

Neurobiological evidence for the timing impairments observed in autism relates to the observed reduction in Purkinje cells in the cerebellar hemispheres (Courchesne, 1997). The cerebellum is associated with fine control of motor movements, and the Purkinje cells specifically integrate complex inputs within the cerebellum and act as output cells into the motor cortex. However, rather than presenting with gross motor control problems, mice with purkinje cell loss show several timing-related characteristics similar to those observed in autism (Martin et al. 2000). It has therefore been proposed that the rapid attention shifting difficulties in autism are attributed to Purkinje cell loss.

It has also been proposed that clock genes are implicated in the social timing hypothesis of autism. Clock genes are not well understood, but at least one group of researchers has hypothesized that not only aberrations in the circadian clock are accounted for by clock genes, but also the high frequency oscillators that are proposed to be associated with preverbal communication (Wimpory, Nicholas & Nash, 2000). Whilst the extent that timing difficulties will negatively impact on social and communicative disabilities in autism, the extent that they might also impair musical perception and cognition has rarely been discussed.

In populations with intellectual impairment, such as Down's Syndrome and William's Syndrome, several studies have reported no effect of intellectual impairment on rhythm clapping capabilities (Stratford & Ching, 1983; Levitin & Bellugi, 1998). Stratford and Ching (1983) investigated rhythm reproduction in children with Down's Syndrome (DS), in a task where the children were asked to tap on a responding key concurrently with a rhythmic stimulus. They concluded that participants with (DS were not, in fact, abnormally talented compared to TD children matched for mental age (as was thought at the time),. but were only superior compared to other children of the same age with mental retardation. Levitin and Bellugi (1998) tested their young participants with Williams Syndrome (WS) in a naturalistic face-to-face clap-repeat task. Participants were approached in a playground setting, and sat opposite an experimenter. After explaining the task, the experimenter proceeded to clap out a rhythm, and then asked the participant to clap it back to them. Quantitatively, these researchers found that participants with WS performed this task exceedingly well, equal in fact to their comparison group. In addition, the errors made by the WS participants were more likely than the control group to be compatible with musical and rhythmic structure. Qualitatively, this task was highly social and thus very rewarding for these participants. Levitin and Bellugi (1998) noted that participants to WS watched the face of the experimenter and often continued clapping right in time with the exemplar, without taking a break and being told “now it is your turn”. It was a game of musical communication, and one in which that participants with WS were predisposed to engage. However more recent studies have noted a decrement in the accuracy of clapping in participants with Williams Syndrome although it has been proposed that this is balanced by enjoyment of and creativity within musical expression (Hopyan, Dennis, Weksberg & Cytrynbaum, 2001).

With regards to ASD, strangely, the major cognitive theories of ASD, Enhanced Perceptual Functioning (EPF, Mottron & Burack, 2001) and Weak Central Coherence (WCC, Frith, 1989) among them, are strangely silent on the issue of timing abnormalities in individuals with ASD. EPF particularly deals with more perceptual-level processing and hypothesizes enhanced local but intact global abilities. This combination would, should EPF tackle the question of rhythm, render the theory powerless; it could only predict that participants with ASD should be able to perceive rhythmic pulses. WCC theory sheds slightly more light on the issue, at least in its most conservative form (Frith, 1989). This early form of WCC states that individuals with ASD would demonstrate preserved local, but impaired global cognitive processes. An individual that functioned in the manner of WCC theory would thus likely show impairments in creating a centrally coherent rhythmic perception. However, in recent years, WCC has moved away from this sure footing towards a more lenient view that there is a *cognitive bias* towards local and away from global processing, rather than a deficit. Thus as WCC theory stands now, one might expect more "local" rhythmic features (rather than longer motifs) to be processed preferentially, though not exclusively. In fact, while pitch has been extensively researched with regards to individuals with autism, musical rhythm has not been investigated explicitly in any well-controlled study. O'Connell (1974) reported the case of a young boy with autism who had exceptional musical talent, but who had to be taught to play music in the correct rhythm. Thaut (1988), on the other hand, reported that the spontaneous improvisations of his group of children with autism scored highly on a measure of rhythm. One recent study, however, has looked at rhythmic perception in speech stimuli and observed highly detailed memory for rhythmic patterns in speech samples in individuals with ASD (Järvinen-Pasley, Wallace, Ramus, Happé & Heaton, 2008).

These instances of rhythm production are contradictory, and yet one might expect them to be. Difficulties in movement production and motor coordination are an obvious hindrance to rhythm production, and it has long been noted that some children with autism present with some degree motor impairment (Page & Boucher 1998) although the precise nature and its prevalence have yet to be fully determined.

A non-specific motor impairment is observed in many children with autism, including difficulty in imitating movement (Jones & Prior, 1985), generalized clumsiness (Ghaziuddin & Butler, 1998), and gait abnormalities (Hallett et al., 1993; Vilensky, Damasio, & Maurer, 1981). A higher incidence of dyspraxia (impaired performance of skilled gestures) is seen in children with autism. Some of this dyspraxia is due to a generalized motor deficit, but even when motor deficit are controlled for dyspraxia is still more prevalent in children with autism than control children (Dziuk, Larson, Apostu, Mahone, Denckla & Mostofsky, 2007).

Research suggests that motor impairments occur in more than 51% of individuals with autism. Hypotonia, apraxia and gross motor delay were among the motor impairments observed in the sample of individuals with autism studied by Ming, Brimacombe and Wagner (2007). Children's symptoms do seem to improve with age however, as older children show a lower incidence of motor impairment.

Neurological investigations have highlighted brain signs predicting motor impairment in individuals with autism. For example Mostofsky, Burgess & Larson (2007) observed increased white matter in the motor cortex in both the right and left hemisphere that was related to increased motor impairment and suggested that this may be indicative of a pervasive pattern of global abnormalities in the brain that affects not only motor control but other areas of functioning in autism Findings showing an impairment in timing, including social timing in communication may relate to these abnormalities (Szelag, Kowalska, Galkowski, & Poppel, 2004; Wimpory, Nicholas & Nash, 2002).

Recent work has stressed the movement disorders of individuals with Asperger's Syndrome (AS), who appear to be abnormally "clumsy." One study (Green, Baird, Barnett, Henderson, Huber & Henderson, 2002) found that their group with AS fulfilled the criteria for Specific Developmental Disorder of Motor Function. However, as Ghaziuddin and colleagues have repeatedly shown, AS cannot be reliably differentiated from autism or even pervasive developmental disorder, not otherwise specified (PDD-NOS) on the basis of motor impairment (Ghaziuddin & Butler, 1998; Manjiviona & Prior, 1995; Ghaziuddin, Butler, Tsai & Ghaziuddin, 1994; Ghaziuddin, Tsai & Ghaziuddin, 1992). Rather, they argue, intelligence predicts clumsiness, as those with a lower intelligence perform worse on tests of motor impairment. However, it is clear that there is a motor impairment associated with ASD that is independent of levels of intelligence. In fact, there are even indications that deeper biological rhythms, such as sleep-wake rhythms (Richdale & Prior, 1995) may be affected in people with ASD.

One theory which does incorporate this apparent timing deficit in individuals in ASD is the social timing deficit theory of ASD (Wimpory, Nicholas & Nash, 2005). This newer theory focuses on the social, rather than musical, forms of rhythm by looking at the "clock genes" and their purported effects in the body of TD versus ASD participants. This theory has yet to be elaborated, however, extrapolation from the initial report indicates that all levels of rhythmic functioning – from the millisecond, to the minute, to the day, month or year levels – may be disrupted in individuals with ASD. This would predict, as the authors do, that social regulation, for example on the scale of infant-to-parent synchrony, is detrimentally affected, but also that musical rhythm is affected. It remains to be seen whether this hypothesis will be vindicated in the musical domain.

The experiments presented in this chapter will investigate the extent that timing abnormalities in autism influence performance in the music domain. In experiment two, young people with autism were asked, in the style of Levitin and Bellugi (1998) to watch and listen to the experimenter clap a rhythm, and then clap it back. This experiment requires not only that the children represent a coherent in-time musical rhythm in memory, but also that they can *re*produce the rhythm. This activity may draw on any of a number of processes including those involved in imitation. The Mirror Neuron System (MNS) comprises brain cells that are responsible for matching and executing an action just perceived. Interestingly, a deficit in the MNS has been described in individuals with autism (Dapretto, Davies, Pfeifer, Scott, Sigman, Bookheimer & Iacoboni, 2006; Lepage & Theret, 2007; Oberman & Ramachandran, 2007; Iacoboni & Dapretto, 2006; Hadjikhani, Joseph, Snyder

& Tager-Flusberg, 2006). However, this remains somewhat controversial and some researchers have recently questioned whether this MNS deficit is an impairment in the general autism population, or just a select few individuals with the disorder (Hamilton, Brindley & Frith, 2007).

Given this evidence, then, we might conclude that individuals with autism should be impaired on tasks requiring them to reproducing rhythms using their bodies (tapping, clapping, drumming, stomping etc.) although this need not necessarily be the case. There are many reports of patients with movement disorders (such as Parkinson's Disease) who, though immobile under typical circumstances, are able to achieve a level of motor synchrony in response to music (Sacks, 1995, 2007). These patients are not able to initiate movement of their own accord, but when music stimulates them to move they can. Thus whilst there is evidence for motor difficulties in at least some individuals with autism, other evidence suggests that these may be overridden in music related activities. No clear hypothesis for this experiment can therefore be proposed. .

A different, though related question is whether children with ASD who experience difficulties in clapping back rhythms, can still represent and recall the rhythmic material that they hear. The second experiment in this chapter investigates this question in an test asking young people with autism to determine whether two aurally presented rhythms are exactly the same, or different.

Again, no research has been carried out with regards to musical rhythm perception in people with autism. However, we do know that movement and auditory processing of music are closely linked (Phillips-Silver

& Trainor, 2007) and this suggests that early disorders of movement should, co-occur alongside auditory processing abnormalities. However, musical savants, many of whom have autism (Rimland, 1978; Hill, 1977; Rimland & Hill, 1984) can accurately reproduce the rhythmic patterns of the music they hear and it appears that for this minority of people with autism, perception and processing of rhythm is preserved. In addition, perception and processing of rhythmic patterning of speech is preserved, or even enhanced, in autism (Järvinen-Pasley, Wallace, Ramus, Happé & Heaton, 2008)

The two experiments to be presented will extend the findings of preserved rhythmic abilities in musical savants by studying rhythm reproduction and rhythm perception in musically untrained children with ASD. As the evidence suggests that motor difficulties are characteristic in autism and may influence performance on these tasks, motor screening tasks were completed by all participants and are included in the analysis.

Experiment 2: Evaluating reproduction of rhythmic sequences in ASD and matched controls.

Method – Rhythm Reproduction

Stimuli

These consisted of seven rhythmic compositions, all of which featured the repetition of a single bar of music. Time signatures of the music varied between 2:4, 3:4 and 4:4. Rhythms were designed to become incrementally more complex from the first rhythm presented through to the seventh. This was effected by introducing new and higher-order concepts as the experiment progressed. For example, the first two rhythms featured a clap on every main beat (in a 3:4 or 4:4 signature), whilst the third and fourth rhythms featured the introduction of rests. Rhythms five and six introduced the concept of the eighth note, and rhythm seven introduced the triplet. The rhythms, one through seven, were always presented in the same order for each participant and all were presented only once. All of the rhythms created for this Rhythm Reproduction task can be found in Appendix 2.

The rhythms used here were designed to be simple rhythms that one might encounter in a clapping game or when keeping beat in a song. The only stimulus set that might equate is that of Levitin and Bellugi (1998), however it was not thought necessary to precisely replicate their stimuli, as no comparison was to be made between their data and the data collected for this study. Thus it was decided, for convenience sake, that the stimuli would be novel.

Presentation

First, participants were introduced to the equipment used in this experiment. They were shown the microphone and the digital sound recording system which showed in real-time the sound waves generated by ambient noise. Participants were encouraged to sing, speak or tap into the microphone so that they could see the resultant sound wave. Once participants were comfortable with the recording equipment, the microphone was placed on the table and the recording software was set to record.

The experiment was presented as an "echoing" game. Participants were asked to listen carefully to the experimenter clapping, and then, when the experimenter nodded that it was their turn, participants should clap exactly what they had heard. Thus both the experimenter's original clapping and the participant's echo were recorded for one presentation of each rhythm.

Scoring

Each original-echo pair was processed as an individual track. Each track consisted of the original rhythm, a tone indicating that the rhythm has finished, and the response rhythm such that the first rhythm in every pair was clapped by the experimenter and the second rhythm in every pair was clapped by a participant. Each track was then randomly assigned a number which would indicate when, in the list of tracks, the independent rater would hear it. Thus the track assigned number 2 would be the second track on the independent rater's compact disc. As both independent raters were blind to the identity of participants on any given track, independent judgments of all responses was assured.

Two expert trained musicians were recruited for the role rater independent of this research. They were asked to rate the participants' rhythm reproductions in three separate ways. Firstly, each expert was asked to give an overall impression of the matching of the participant's response to the example, on a likert scale of 0 (no matching) to 7 (perfect matching). Instructions for the expert were as follows:

> "Please note that your Overall Impression does not have to correlate in any particular way with the other two ratings. In that measure, we are looking for an objective and professional measure of how well the rhythm (in total) was repeated. We understand that this opinion may choose to take certain measures into account more than others (for

example, a child who does not produce the precise pattern of claps, and does not even produce them at the right tempo, might be seen to have done fairly well at reproducing a replica of the rhythm)."

Two other measures of the participant's performance were also elicited: matching of sequence and matching of tempo. These are more technical measures in which the expert rater was asked to analyze exactly what the participant did clap. These were rated on the same eight-point likert scale where 0 indicates no matching and 7 perfect matching. The expert rater was requested to use only their expert musical sense, and no metronomes or computer software, to complete these ratings.

Several measures of manual dexterity and movement problems were employed in order to screen for obvious deficits in motor control which would hinder clapping ability. The Pegboard Task (Henderson & Sugden, 1992) is a measure of both gross and fine manual dexterity. Participants were asked to place pegs into a board with equally-spaced holes drilled in it. They must thus coordinate gross motor skills such as movements of arm and hand, with the fine motor skills required to pick up each peg and fit it in the hole. Responses to this task were timed, and the time elapsed from beginning of a trial to the end was the child's score on that task. Participants were allowed two trials for each hand (dominant and non-dominant) and the quickest time was recorded as the participant's score for that hand.

Participants

The participants in the autism group were aged between twelve and sixteen years (mean age=13.78) and included one girl and seventeen boys. The control group included two girls and fourteen boys aged between thirteen and sixteen years (mean age 14.19) without a diagnosis of autism, but with moderate learning difficulties (MLD). Children were recruited from local schools with a special provision for pupils with autism spectrum disorders (ASD) or MLD, or dedicated specialist high schools throughout England. All children consented freely to participate in this experiment, and written permission was obtained from legal guardians in compliance with the ethical review board requirements of Goldsmiths College. Psychometric data for the two participant groups is shown below in Table IV:A

Table IV:A: Participants- Rhythm Reproduction

Measure	Diagnosis	Mean	F	p
Age	ASD	13.78	1.151	0.291
	MLD	14.19		
Raven's Matrices	ASD	21.39	0.255	0.617
	MLD	24.00		
BPVS	ASD	59.7778	10.568	0.003
	MLD	98.6429		
Pegboard	ASD	20.0239	5.303	0.028
	MLD	23.7650		

As can be seen in table IV:A, above, the two diagnostic groups did not differ significantly on measures of age or non-verbal IQ (Raven's Matrices). As might be expected, scores for the ASD group were lower than those for controls on the measure of receptive vocabulary (BPVS). Surprisingly, in the Pegboard Task, the participants in the ASD sample completed the peg board task faster the participants in the MLD sample. There is no a priori reason, given recruitment procedures, why the MLD sample should show movement disorders. However there could have been a coincidental concurrence of such, or the unexpected finding could be due to the ASD sample having spared movement ability. In fact, upon examination of the norms for this pegboard task, both groups scored less well than would be expected for their age (ASD: mean age: 13.78, Standard Score: 10; MLD: mean age: 14.19, Standard Score: 8). Thus while both groups were impaired on this task, the degree of impairment was milder for the ASD group than for the MLD group.

Results

To begin, a test of inter-rater reliability was calculated. For a likert scale with no definite start point, the reliability analysis of choice is an intraclass correlation coefficient (ICC; Shrout & Fleiss, 1979). Thus a two-way mixed ICC (case 3 in Shrout and Fleiss, 1979) was undertaken for each of the stimulus types: Overall, sequence and tempo. Reliability for all three measures was good (Overall: ICC=0.648, p=0.0001; Sequence: ICC=0.563, p=0.0001; Tempo: ICC=0.513, p=0.0001) indicating high correlation between the scores given by the independent raters for these three measures. Thus the decision was made to average the scores of the two independent raters hereafter.

Scores for experiment 2 are shown in Table IV:B.

Table IV:B: Results on rhythm experiment for both ASD and MLD participants

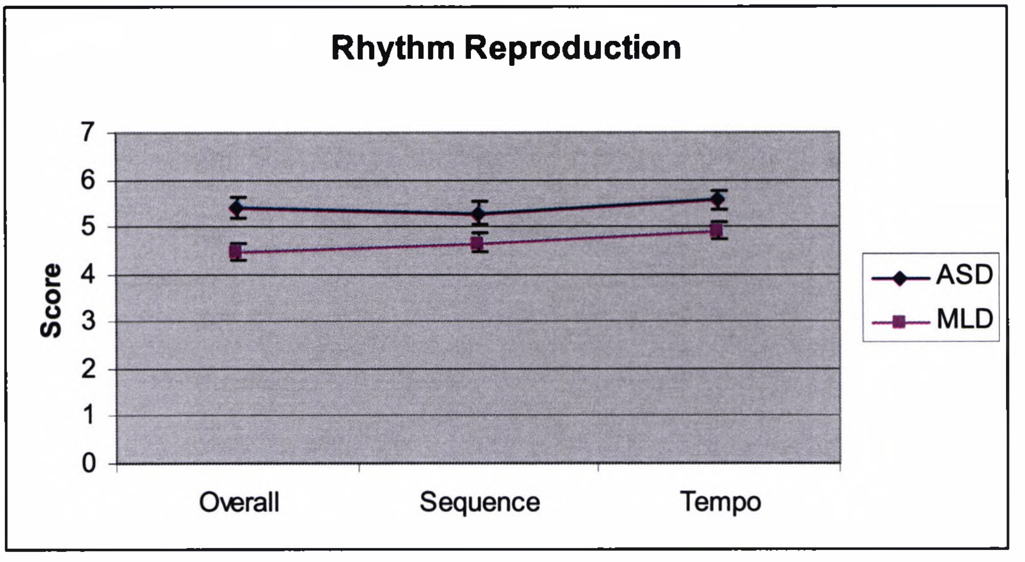
	Diagnosis	Mean Score	Standard Error
Overall	ASD	5.39	0.22
	MLD	4.92	0.17
Sequence	ASD	5.28	0.23
	MLD	4.66	0.21
Tempo	ASD	5.56	0.20
	MLD	4.89	0.17
Total score	ASD	5.41	0.22
	MLD	4.83	0.18

A repeated measures multivariate analysis of co-variance (MANCOVA) was performed, with type of measure (overall, sequence or tempo) the within-subjects factor, diagnosis (ASD or MLD) as the between-subjects factor, and age, non-verbal IQ (Raven's Matrices), verbal IQ (BPVS) and manual dexterity (Pegboard) as the covariates.

There was no main effect of type of measure (overall, sequence or tempo), however there was a main effect of diagnosis (F=5.736, p=0.025), where post-hoc testing revealed that the ASD group scored higher overall than the MLD group (as can be seen in Figure IV:1; p=0.025, bonferroni corrected). The interaction between type of measure and diagnosis was not significant (F=0.364, p=0.697), however.

Between-subjects analyses revealed some interesting results. Age was not related to the participants' scores (F=0.175, p=0.679), however Pegboard performance (F=4.574, p=0.043), scores on Raven's Matrices (F=5.041, p=0.034) and on BPVS (F=11.108, p=0.003) were all significantly related to scores on the rhythm reproduction task.

Figure IV:1: Results for Rhythm Reproduction Task

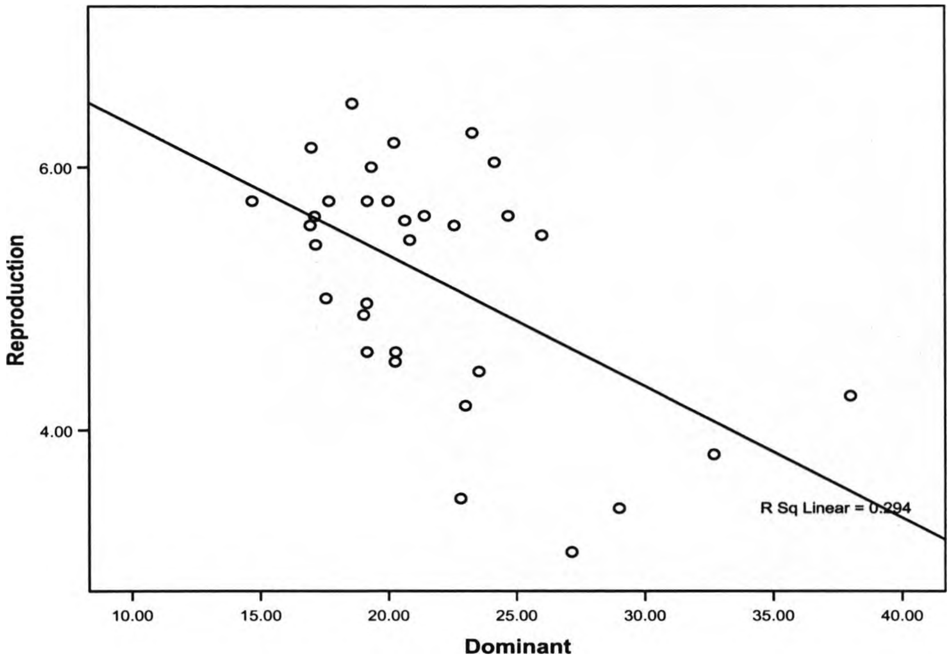


Pegboard

Analysis of scores for speed of completion on the pegboard tasks indicated that the MLD participants were more impaired that the ASD participants (F=5.303, p=0.028).

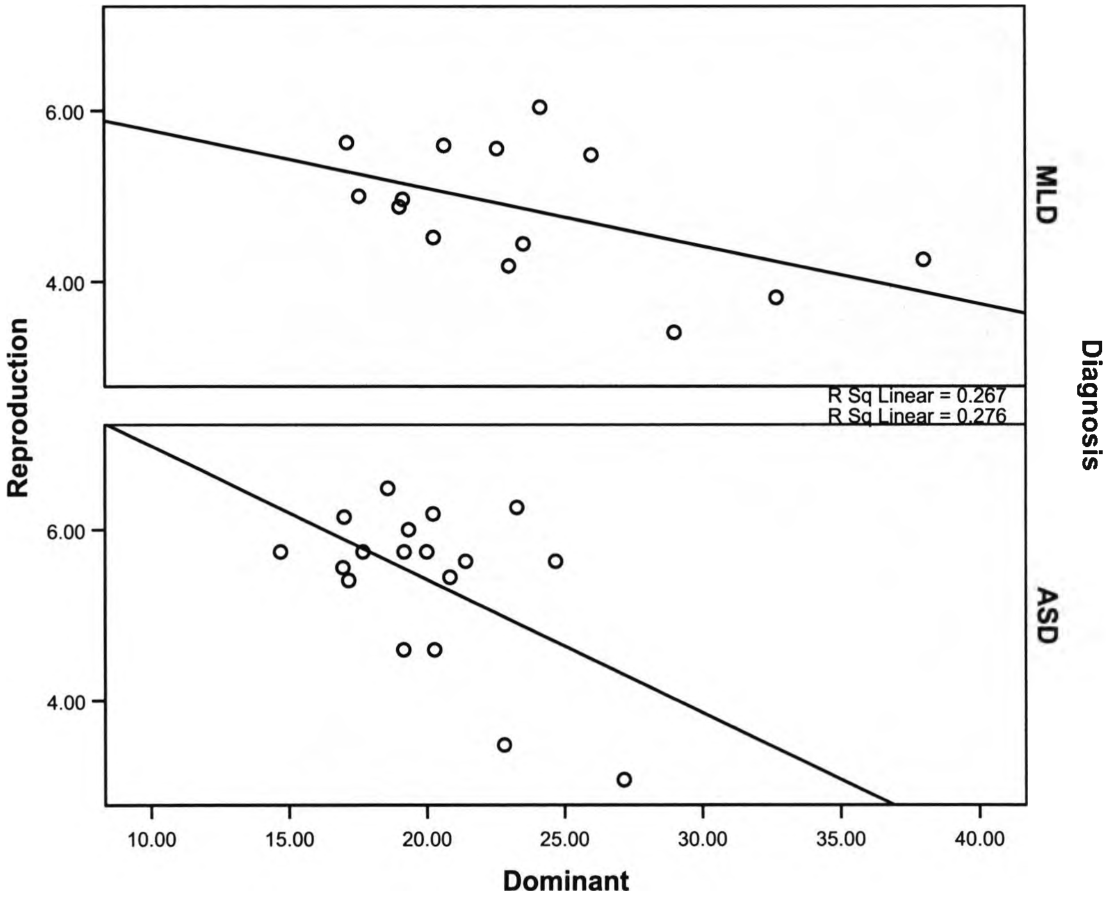
In order to examine the effect of manual dexterity on this rhythm reproduction task, a bivariate correlation between performance on the Pegboard task with the dominant hand, and the mean performance of all three measures of the rhythm reproduction task was undertaken. This correlation was highly significant (r=-0.542, p=0.001; see Figure IV:2).

Figure IV:2: Correlation between Rhythm Reproduction and Pegboard Tasks for all participants



When the correlation was repeated separately for each group, the ASD participants showed significant negative correlation between their performance on the Pegboard task with the dominant hand, and the mean performance of all three measures of the rhythm reproduction task (r=-0.516, p=0.028; see Figure IV:3). This correlation is negative because a lower score on the pegboard indicates better performance. Thus, a negative correlation indicates that better performance on the Pegboard task is correlated with better performance on the rhythm reproduction task.

Figure IV:3: Correlation between Rhythm Reproduction and Pegboard Tasks by diagnostic group



The MLD participants, however, showed only a trend towards this result; their correlation was not significant (r=-0.525, p=0.054; see Figure IV:3).

Discussion

Given that motor impairments have been noted in individuals with autism, it could have been hypothesized that the participants in this study would show some deficit in rhythm reproduction through clapping. Not only was this not the case, but in fact the ASD participants performed significantly better overall than MLD participants on this rhythm clapping task. Whilst this finding directly challenges the social timing deficit theory of autism (Wimpory, Nicholas & Nash, 2005) it may be the case that motor difficulties are not characteristic of all individuals with ASD. Timing difficulties are not currently included as diagnostic criteria for autism. Indeed the ASD individuals who participated in experiment 4, showed better peg-board performance than children matched on age and non-verbal intelligence, but with better speech skills.

Additionally, while our ASD sample was a convenience sample, it would appear that it was largely comprised of individuals with only minor motor impairments who demonstrated only mild difficulty with the Pegboard. Given that, as has been demonstrated in the introduction to this chapter, ASD is generally associated with motor impairment, (see, for example, Ming, Brimacombe & Wagner, 2007), this is a difficult finding to reconcile. However, for the 51% of Ming, Brimacombe & Wagner's children with ASD and a motor impairment, there are 49% that do not have such a motor impairment, and even more whose impairment is mild. It would appear that it is these individuals that were recruited to this study. This may be due to self-selection effects (i.e. parents of children with dyspraxia did not want to subject their child to a frustrating task).

The analysis that was performed on these data took into account the differences between the groups. Despite significant differences in manual dexterity (as measured by the Pegboard task) and verbal IQ (as measured by the BPVS), the effect that having an ASD diagnosis had on performance on this task was significant. Participants with ASD performed significantly better on this task than did MLD participants.

However, Pegboard performance, scores on Raven's Matrices, and on BPVS were all significantly related to performance on this task. It is unsurprising that Pegboard scores, which are a measure of manual dexterity, should be related to performance on this rhythm clapping task. It is less clear why VIQ score was correlated with performance in ASD participants. This may be related to the social timing hypothesis of autism (Wimpory, Nicholas & Nash, 2002). Language is not just about syntax, semantics and pragmatics, it has a "musical" component as well, both tonal (i.e. prosody) and rhythmic. Thus individuals with a higher VIQ may have more practice with rhythm simply because they are more practiced at language. Thus while the performance of participants with MLD (who are slightly older than the ASD participants, who do not, *a priori*, have a language and communication deficit, and who scored higher on the BPVS than ASD participants) may simply reflect poor rhythm processing, the performance of ASD participants may be constrained by their familiarity with rhythm because a) they are not old enough chronologically, and b) they have less experience with rhythm in the context of language. Thus while participants with ASD showed sparing relative to their MLD comparison group on this task, it is argued that should the groups be matched for VIQ participants with ASD may excel at this task and may indeed demonstrate enhancement relative to matched controls.

It is also unknown why non-verbal IQ, as measured by the Raven's Matrices task, would be related to rhythm clapping proficiency. The type of fluid intelligence that is measured by Raven's Matrices is thought to be "on-the-spot" processing and problem solving (Ashton, 2008). Given this description, it is not difficult to surmise that "on-the-spot" processing is indeed quite related to the problems a participant faces when performing the clapping reproduction task. The participant must solve problems of timing and sequence during the task. The fact that many participants responded in time with the experimenter's claps indicates that participants were indeed taking this problem-solving approach.

It is clear that, even with all factors considered, ASD participants performed better on this clapping reproduction task than did MLD participants. With all of these contributing factors, however, future work should focus on matching groups on the variables discussed above.

Motor control abilities are clearly important and should be considered carefully, as should linguistsic competence. And since it is now expected that participants with ASD will show enhancements relative to their control group(s), further investigations would ideally include a typically developing sample in order to be able to investigate whether participants with ASD would show spared or enhanced rhythmic performance relative to those with typical development.

Conclusions

Participants with ASD performed better on this test of on-line rhythmic processing and reproduction than did MLD controls. There were a number of contributing factors, however. While age did not affect performance, non-verbal IQ, verbal IQ and motor dexterity measures were all related to performance on this task. Further work should tease apart the relative contributions of these factors. In addition, comparison of the ASD participants to a typically developing control group will help to determine whether the rhythmic abilities of ASD participants is what we might expect given their general intellectual functioning, or whether rhythm reproduction is a definite strength in individuals with autism spectrum disorders.

Experiment 3: Testing discrimination of rhythmic differences in children with ASD and MLD.

Method

Stimuli

Stimuli were created using the Finale Notepad for Windows 2006, composition software available for free download (http://www.finalemusic.com/notepad/).

Twenty-four novel rhythmic compositions were created which consisted of two to three bars of music in either 2:4, 3:4 or 4:4 time signature. Some of the compositions were repetitive bar after bar, whilst others introduced novelty throughout. The twenty-four compositions are included in Appendix 3.

Each stimulus set consisted of a pair of these short rhythms which were either A) exactly the same, B) slightly different, or C) very different. Both B and C require qualification, however. How can two rhythms be slightly different or very different? In the case that two rhythms are slightly different, this slight change was interpreted to mean that the overall structure, meter, length and complexity should remain the same, but an additional beat could be added in where once there was a rest. Thus, we arrive at Figure IV:4, an example of slightly different rhythms used in this experiment:

Figure IV:4: Slightly different rhythms

Very different rhythms do not share a common structure, they are often not presented within the same meter, and frequently their length and complexity (evident mostly in number of beats played) is quite different too. Figure IV:5 is an example of very different rhythms used in this experiment.

Figure IV:5: Very different rhythms

All stimuli were played at a tempo of crotchet = 120 and a volume comfortable for the participant. The playback feature of Finale Notepad for Windows 2006 was used to play the stimuli and the snare drum was in all cases the voice used.

A stimulus set that would allow signal detection analysis to be used (i.e. half "different" responses and half "same" responses) that also discriminated between slightly and very different rhythms, could not be found in the extant literature. Thus the decision was made to create a stimulus set custom for this experiment.

It is unclear whether movement problems would affect rhythm discrimination. However, it is reasonable to think that the neural structures underlying the execution of rhythmic movement might also be partly shared by those neural structures that perceive rhythm. Thus, the same measures of movement disorder (Pegboard Task and Questionnaire questions) were taken for these participants as well.

Procedure

Participants were instructed that they should listen carefully to the two rhythms played, and then tell the experimenter whether they are exactly same, or different. No repetition of any stimulus set was allowed. The experimenter noted down the participant's answer before proceeding to the next stimulus pair.

Participants

Participants were three girls and twelve boys between the ages of thirteen and sixteen (mean age=14.27) with a diagnosis of ASD, and two girls and seventeen boys between the ages of thirteen and sixteen (mean age=14.32) without a diagnosis of autism, but with moderate learning difficulties (MLD). Some participants, particularly in the MLD control group, were unable to complete the pegboard task because of a specific movement disorder (i.e. cerebral palsy). Thus four participants who could in fact perform the rhythm discrimination task, were excluded from analysis because their datasets were incomplete. Thus two girls and thirteen boys with a diagnosis of MLD (mean age=14.13) remained in the resultant dataset. Children were recruited from local schools with a special provision for pupils with autism spectrum disorders (ASD) or MLD, or dedicated specialist high schools throughout England. Twelve children from the ASD group, and twelve children from the MLD group also participated in the rhythm reproduction task reported in this chapter. Psychometric data for the two participant groups are shown in Table IV:C, below.

Table IV:C: Participants' psychometric data, rhythm perception experiment

Measure	Diagnosis	Mean	F	p
Age	ASD	14.27	0.022	0.882
	MLD	14.32		
Raven's Matrices	ASD	23.13	0.207	0.652
	MLD	25.42		
BPVS	ASD	73.1333	8.762	0.006
	MLD	99.444		
Pegboard	ASD	19.8460	3.840	0.060
	MLD	23.5007		

The participants who completed this task showed a similar, but slightly different background data profile to those who completed the rhythm reproduction task. As before, there is no significant difference in age or in non-verbal IQ scores, however there was a significant difference between the ASD and MLD groups in terms of verbal IQ score, with higher scores for the MLD than for the ASD group. However the difference between scores for the pegboard task showed only a trend towards faster ASD than MLD performance (p=0.06). Thus for this study the groups are marginally more closely matched on motor functions.

Results

The data was analysed signal detection theory (SDA; Green & Swets, 1966). The rationale for doing this was (a) whilst the ASD and control participants were carefully matched on age and non-verbal intelligence, verbal

IQ scores were lower in the ASD group and this may have resulted in difficulties in understanding the task: (b) Control participants had moderate learning difficulties and may also have experienced difficulties in understanding the task: (c) experiments that require dichotomous responses risk misinterpreting a response bias (yes/no) as a measure of sensitivity. D'prime statistics for sensitivity and statistics for response bias (C) are shown in Table IV:D below.

Table IV:D: Signal Detection Analysis, Sensitivity and Response Bias

	Diagnosis	Mean	F-Value	p-value
d'	ASD	0.8695	7.871	0.008
	MLD	-0.6864		
c	ASD	0.0636	0.484	0.492
	MLD	-0.0502		

As table IV:D shows groups did not differ of response bias (F=0.484, p=0.492, ns). The C statistic also did not differ significantly from zero for either of the groups (ASD: t=1.163, p=0.264; MLD: t=-0.363, p=0.721; ns.). This indicates that neither group showed a response bias. Comparison of the d' statistic (indicating sensitivity level) across groups, indicated increased sensitivity in the ASD group in comparison to the MLD group (F=0.7871, p=0.008).

The main analysis was conducted as follows. Firstly normality was tested in this sample using a one-sample Kolmogorov-Smirnov test, and the hypothesis of normality was upheld (see Table IV:E).

Table IV:E: Kolmogorov-Smirnov Statistics

	Same	Unrelated	Related
Kolmogorov-Smirnov Z	.852	.841	1.406
Asymp. Sig. (2-tailed)	0.463	.112	.118

Scores were calculated based on whether the participants were correct or incorrect in their judgment that two rhythms were *exactly* the same, or different. Some of the rhythms were exactly the same, some were only slightly different (related rhythms), and some were very different (unrelated rhythms). See Table IV:F for a summary of the means and standard errors of these data.

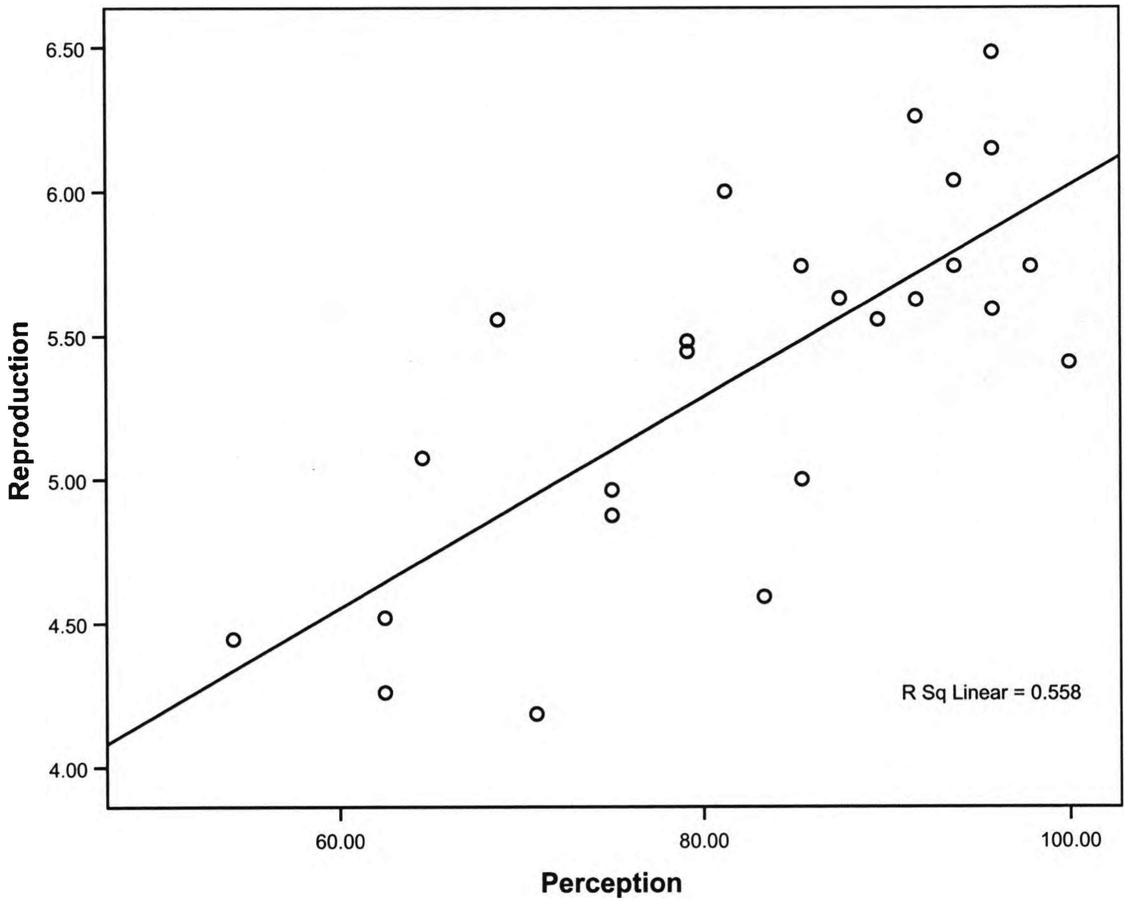
Table IV:F: Results on Rhythm discrimination experiment for both ASD and MLD participants

	Diagnosis	Mean (% Correct)	Standard Error
Same Rhythm	ASD	89.24	2.687
	MLD	75.63	4.546
Unrelated Rhythms	ASD	90.94	3.161
	MLD	81.41	5.595
Related Rhythms	ASD	84.03	3.155
	MLD	74.64	4.472

An initial analysis was carried out using a repeated-measures multivariate analysis of co-variance (MANCOVA), which examined the main effects of rhythm type (same, related, unrelated) and diagnosis (ASD, MLD) , and examined the effect of age, non-verbal IQ (Raven's Matrices), verbal IQ (BPVS) and manual dexterity (Pegboard) as covariates. There was no main effect of rhythm type (same, related or unrelated; F=0.542, p=0.585). There was no main effect of diagnosis (ASD or MLD; F=1.596, p=0.219). One element of the model did make a significant contribution. The measure of manual dexterity was shown to affect rhythm discrimination performance (F=5.062, p=0.010).

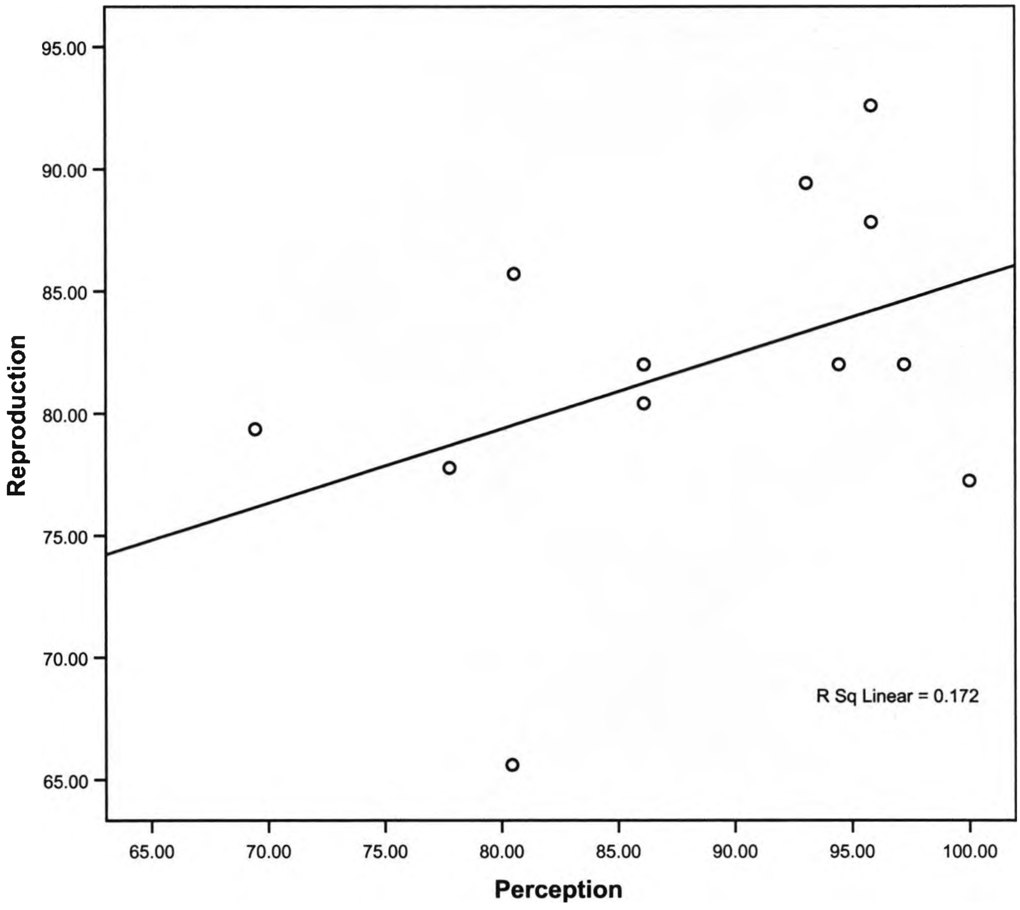
The question of rhythm production ability bears some relevance to this question of rhythm perception ability. It is a circular argument, but it is reasonable to hypothesize that either rhythm production is reliant somewhat on a participant's ability to perceive what they are to clap, or that rhythm perception is reliant somewhat on a participant's ability to represent the rhythm in terms of motor plans. Either way, it is not unreasonable to expect that the results from this rhythm perception task will correlate highly with both the results from the rhythm reproduction task and with the results from the pegboard task. Therefore, a correlation was calculated with the number of correct responses on the rhythm perception task, and the mean score on the rhythm reproduction task. The result was highly significant (r=0.747, p=0.0001) and the correlation was strong (see Figure IV:6).

Figure IV:6: Correlation between Rhythm Perception and Rhythm Reproduction tasks



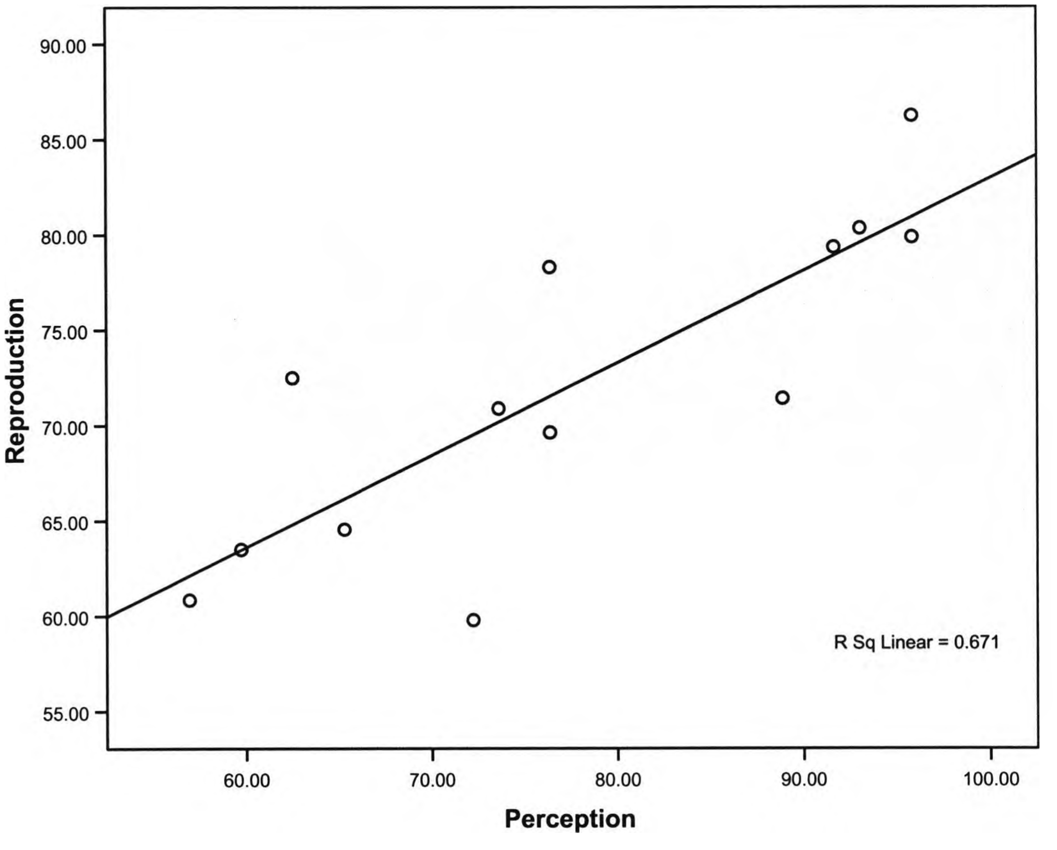
The correlation between the two tasks was also calculated for the two groups separately. In the ASD group, the correlation was not significant (r=0.414, p=0.181). See Figure IV:7.

Figure IV:7: Correlation between Reproduction and Perception experiments in ASD participants



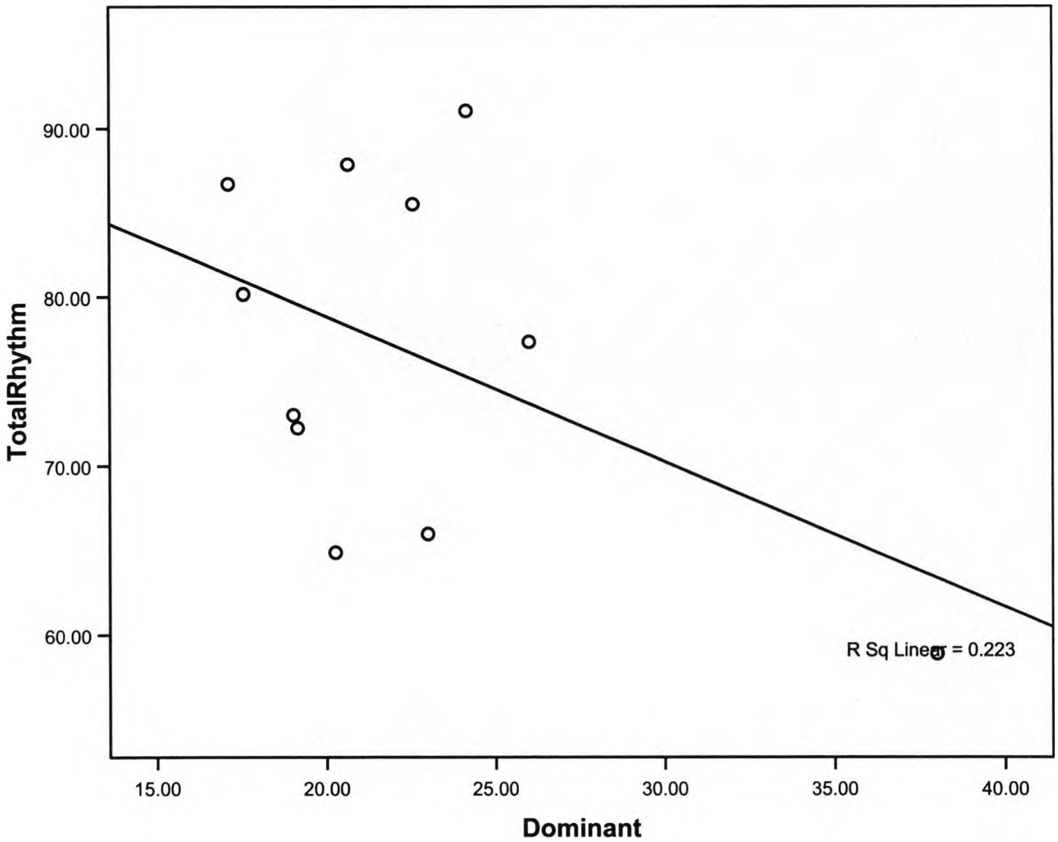
For the MLD group the correlation between rhythm reproduction and perception tasks was highly significant (r=0.819, p=0.001) See Figure IV:8.

Figure IV:8: Correlation between rhythm Reproduction and Perception tasks in MLD participants



As the correlation between the two experimental tasks was high for this group, this justified summing of scores across experiments to create a new variable (total rhythm). This was then correlated with performance on the pegboard task for the MLD group. However, the correlation was not found to be significant (r=-0.472, p=0.142). See figure IV:9 for graphical representation.

Figure IV:9: Correlation between Total Rhythm and Pegboard task for the MLD group



Discussion

A major and unexpected difficulty that influenced the results from the rhythm reproduction task, was that motor dexterity was significantly weaker in the participants in the MLD group that in the ASD group. This brought the result from the initial analysis, showing superior performance in the autism group into question and made it difficult to interpret. However, when the results from the pegboard task were factored into the analysis, the group differences remained and it appeared that the ASD group, matched with an

MLD group on chronological age and non-verbal intelligence, were in fact superior in a rhythm reproduction (clapping) task.

However, experiment 3 did not have a motor component and was a more purely cognitive task that measured of how well individuals with ASD processed rhythmic information.

The signal detection analysis showed that neither group displayed a response bias, that is, neither group was answering “same” or “different” more often. However, the ASD group showed greater sensitivity when detecting the rhythmic stimulus; they could more often detect the differences or similarities in the stimuli than could the MLD participants. This surprising strength might be attributed to the Enhanced Perceptual Functioning (EPF) model of autism. According to EPF, individuals with ASD are better attuned to the perceptual aspects of their environment, and are able to more finely differentiate between slight differences in observed stimuli. Previously, this has been shown in pitch (Heaton 2003,1998; Bonnel, Mottron, Peretz, Trudel, Gallun, Bonnel, 2003) and in timbre (Chapter 3), but has never yet been demonstrated in musical rhythm perception.

However, EPF is possibly not the best model for thinking about rhythmic aspects of music. In EPF, specifically low-level perceptual aspects of the stimulus in question are targeted for enhanced performance, while the more complex aspects of the stimulus are processed well, but with no enhancement. Rhythm is the relationship between two (or generally more) elements in time, and by this definition, rhythm might be better understood as a complex characteristic of a stimulus. This binding together in time aspect of rhythm is important when considering the social timing deficit hypothesis of autism, which states that individuals with ASD have problems with their "clock genes" and other biological mechanisms implicated in timing. According to this hypothesis, the circadian rhythm of persons with ASD would be affected, as would social timing, synchrony, and turn-taking in communication. It is reasonable to expect that musical timing (and rhythm and tempo along with it) would also be affected according to this hypothesis. Interestingly, a relatively new hypothesis of autism refers to a temporal binding deficit evidenced in electrophysiological studies of individuals with ASD (Brock, Brown, Boucher & Rippon, 2002). These authors demonstrate that connectivity (simultaneous coupled firing of neurons) in the brains of individuals with ASD is reduced, leading to the reduction in binding of mental events in time (temporal binding). They argue that this reduced temporal binding can explain, in neural terms, much of WCC theory, and that it can explain the atypical visuospatial and linguistic functioning evident in the ASD population. However, these temporal binding hypotheses presume that individuals with autism would show *deficits* in rhythmic processing, when in fact the findings of this study indicate, some aspects of rhythm processing are superior. This suggests that the proposed deficit in rhythm and timing, occurs in social but not in musical processing.

A plausible suggestion for why participants with ASD showed increased sensitivity on the task overall is that their memory for rhythm was superior. The "same" condition always required the participant to listen attentively and to remember fully both rhythms. Considering that each rhythm was two to three bars in length, with one bar interval between rhythms, that would be anywhere from five to seven bars of rhythms that a participant would have to process at a time. In the "related" category, often the difference in rhythms did not occur until the final bar of the stimulus, and thus the participant's attention and memory load would again be called on to process several bars of music. In the "unrelated" condition, the difference between rhythms was always apparent in the first bar of the second rhythm – that is, three to four notes in. Participants could (and often did) respond at this point already that the rhythms were different, and their attention and memory need not be used further in that trial. Thus it appears that as the attention and memory load became less, the difference in performance of the MLD participants as compared to the ASD participants also became less.

There is an approximately forty-year history of research into memory processes in autism (Shalom, 2003). Early work focused on the apparent "amnesic syndrome" in ASD, which noted the similarities between ASD and adult onset amnesia (Boucher & Warrington, 1976). However, more recent work has pulled apart this general memory dysfunction to discover that many types of memory are intact (even enhanced!) in ASD, while others do demonstrate the amnesic syndrome. For example, Minshew and Goldstein (1993) showed normal recognition and free recall in individuals with high-functioning autism, abilities which are not present in those with adult-onset amnesia. One area of memory function that is consistently reported as impaired is working memory.

Working memory is that ability which allows one to hold information readily accessible for processing. Thus this task, which requires holding one rhythm in the mind while listening and comparing it to another, requires working memory. While this ability is consistently reported as impaired in people with ASD, several modern researchers have shown that the task demands of the tests used predict the success of ASD participants on these tests. For example, Ozonoff and Strayer (2001) demonstrated that working memory was not significantly impaired in individuals with ASD, but suggest that the format of the memory tests presented may be to blame for the findings of impairments, while Williams, Goldstein, Carpenter and Minshew (2005) showed that spatial, but not verbal working memory was impaired in individuals with ASD, but only because the spatial memory task had increased cognitive demands relative to the verbal memory task. In later work, Steele, Minshew, Luna and Sweeney (2006) again demonstrated an impaired spatial working memory ability in participants with ASD, but suggest that this occurs only when working memory load exceeds some (somewhat limited) capacity.

While we see differences in the working memory function for spatial materials (subserved by the visuo-spatial sketchpad (Baddeley, 1990)) and verbal materials (subserved by the phonological loop (Baddeley, 1990) working memory for musical materials, which is not covered by Baddeley's (1990) elaboration of working memory, and has recently been proposed to be subserved by its own separate "slave system" (Berz, 1995) has never been studied in ASD. As it is a separate module of working memory, however, it is possible that musical processing is not impaired in individuals with ASD; indeed, this would seem likely. It is clear that even non-savant individuals with ASD are able to store pitch information in mind for long periods of time (Heaton, Hermelin & Pring, 1998) and that savants with ASD have exceptional musical memories (Pring, Woolf & Tadic, 2008; Ockelford, 2007; Miller, 1987).

The musical working memory spans of children with MLD have not been reported in the literature either, however the working memory abilities of

MLD children have been evaluated, and indeed directly compared to those with ASD. Russell, Jarrold and Henry (1996) investigated the working memory capacity of MLD and ASD participants and demonstrated that the ASD participants had a higher working memory capacity in general than did the MLD participants. Thus, the hypothesis put forth here, that as the capacity demands of the rhythm task became greater, participants with MLD performed more poorly on the task, is consistent with this body of research. However, future work should be designed to directly asses “melody span” (and other measures of musical working memory) of non-savant individuals with ASD.

Another finding in this experiment is quite surprising. The MANCOVA, which was carried out on the rhythm perception data, revealed that there were contributors to the success of the ASD group (as shown in the signal detection) that were unexpected. There was a significant contribution of motor control (as measured by the pegboard task) to the performance on this perception task. None of the other factors tested – age, IQ or diagnosis – contributed significantly to performance. It is surprising that a measure of manual dexterity would be so related to a purely cognitive measure of rhythm processing. However, taking into account that so much of the development of rhythmic ability hinges on clapping games and dancing, this is not quite as perplexing.

One very surprising finding was that, whilst performance across the two experiments correlated significantly and positively for the MLD group, this was not the case for the ASD group. The correlations between this rhythm perception task and the rhythm reproduction task are not unexpected. Part of being able to reproduce a rhythm is being able to perceive and process it, and thus being particularly good at one task does imply success at the other. The Pegboard task was highly correlated with performance on the rhythm reproduction task, as might be expected. In that task, manual dexterity actually had to be exercised, and a lack of it would spell poorer performance on the task. It was hypothesized that poorer motor control and manual dexterity might be symptomatic of a poorer rhythm and timing processing (rather than the other way around). This is the pattern of results seen in the MLD group; while the results on the pegboard task did not directly correlate with results on this rhythm cognition task, rhythm production did correlate with this task, and a collapsing of the scores across the two rhythm experiments correlated with performance on the pegboard.

What is interesting is that the ASD participants did not show this pattern of behaviour. Their performance on the rhythm perception task did not correlate at all with their scores on the rhythm reproduction task. This may be because of a dichotomy between music cognition, and music execution; there is a known motor impairment associated with autism (Ming, Brimacombe & Wagner, 2007) which may impair the ability of an individual with ASD to reproduce a rhythm correctly, however correctly the individual might perceive and process the sound of that rhythm. Thus, the participants with ASD show a lack of excellence (a sparing, rather than an enhancement, relative to controls) when reproducing the rhythm, but an enhancement when simply representing the rhythm cognitively. This is backed up by the lack of correlation between this rhythm cognition task and performance on the pegboard task.

Thus it would appear that there are two different mechanisms working in the ASD participants and the MLD participants with regards to rhythm. The ASD participants are spared (or in one case enhanced) with respect to rhythm cognition (relative to the MLD comparison group) but find that motor impairments cause some trouble when reproducing a rhythm by clapping. MLD participants show overall impairment in cognition of rhythms, and a motor functioning impairment that causes difficulty also when reproducing a rhythm by clapping. This pattern supports the assertion that musicality (or, music cognition) is possible (and even probable) in individuals with ASD, as rhythm cognition does not appear to be impaired in these individuals.

Conclusion

There is no apparent rhythm processing deficit in autism. Further research could focus on this relationship between memory, attention, motor control and rhythm in order to tease apart the factors involved in this ability.

V. Chord Priming and Tempo

Abstract:

The Weak Central Coherence (WCC) theory of autism predicts that individuals with ASD are advantaged when processing local aspects of a cognitive task, but impaired when processing the global aspects of a cognitive task. This study is the musical corollary of an earlier linguistic task (Happé, Briskman, & Frith, 2001) where participants are asked to pay attention to the context of an ambiguous sentence before deciding on an appropriate ending for that sentence. In this task, musical contexts are created using the rules of Western Tonal music, and the ability to integrate a target into this context is tested. Children with ASD and those without are asked to identify whether or not a melody sounds "good" based on tonality. Another manipulation of tempo of stimulus presentation probes temporal processing of musical information. Results indicate that the ASD and MLD participants are indistinguishable from one another on both aspects of this task. Participants with ASD are thus able to integrate musical information into a context as well as age- and IQ-matched controls. These findings are discussed within the context of the major perceptual/cognitive theories of autism.

In their (1999) report, Mottron, Belleville and Menard described a group of non-savant individuals with autism who evidenced increased local processing while they copied drawings. Rather than beginning with the global aspects of the picture, for example, the outline of a house, they began their drawings with more local elements, for example, windows, the chimneys and doors. Similarly, when non-savant persons with autism are asked to draw a picture from memory, they begin by drawing local elements. However, importantly, Booth, Charlton, Hughes and Happé (2003) found that this does not influence their ability to plan the drawing as the finished pictures were coherent. Thus, it seems as though this local bias, reflects cognitive style, rather than a global deficit, in autism. In addition, when these non-savant individuals with autism look at a drawing, they are better able to pick out local elements in that drawing than are persons without autism whose attention is captured by the global effect of the picture (Happé, 1999). This bias for local elements of stimuli, especially to the detriment of processing global levels, is the starting point for the first Weak Central Coherence (WCC) model of autism first outlined by Frith in 1989.

WCC, as proposed by Happe in 1999, is a model of autism that proposes a unique different cognitive style. This cognitive style, or bias, predisposes individuals with autism to process local elements more quickly and accurately than global elements of stimuli. This is further evidenced in their performance on navon-type figure tasks which consist of a global image of a letter (say A), that is itself created by local elements of another letter (say H). Individuals with autism are quicker at identifying the local elements than they are at identifying the global image; conversely individuals without autism are generally quicker at identifying the global figure in such tasks. However, findings with this particular task have been mixed, with differences in responses of the ASD group depending somewhat on task demands (see, for example: Plaisted, Swettenham & Rees, 1999; Jolliffe & Baron-Cohen, 1997)

The block design subtest of the Weschler Intelligence Scales for Children (WISC) is another task at which the WCC cognitive style advantages autistic participants (Shah and Frith, 1993). In this task, the participant is presented with a group of blocks whose sides are either all red, all white or half red, half white. Their task is to assemble these blocks such that the facing edge creates designated designs as quickly as possible. As predicted by WCC, individuals with autism are faster and make fewer mistakes than do matched controls when performing this task. However, in a recent detailed analysis of performance on the block design task Caron, Mottron, Berthiaume & Dawson, (2006) showed that peak performance on the block design was not characteristic of all participants with ASD, although all did show enhanced visual perception. .

In her 1999 version of the WCC theory Happe described a local bias at verbal semantic levels. Evidence for WCC at this level had previously been provided by findings showing that autistic people were less able to disambiguate words using sentence context than typical controls Frith & Snowling, (1983), Snowling & Frith, (1986) and Happé, (1997).

In another task testing WCC at verbal semantic levels, participants with autism and matched controls without autism were presented with a sentence (global context) that could be completed using the contextual information in the sentence, or could be completed using only local information (Happé, Briskman, & Frith, 2001). For example, "The sea tastes of salt and ___________" could be completed globally by the word "seaweed" but locally by either "vinegar" or "pepper". In that study, it was shown that whilst individuals with autism did not show a semantic deficit, the semantic bias was considerably weaker that that evidenced by the participants without autism.

This linguistic task provides the basis for the musical task used here, but it was not the first musical task used to probe global/local differences in processing. Earlier musical tasks, showing a superiority in associating tones with animal pictures (Heaton, Hermelin & Pring, 1998) and discriminating pitch direction in pitch intervals (Heaton, Pring & Hermelin, 1999) in autism were interpreted as evidence for a local bias in autism.

In their (1998) study, Heaton, Hermelin and Pring trained participants (ten musically naïve boys with autism) to associate four tones with four animal pictures. This procedure was followed, rather than conventional tests for absolute pitch which ask participants to assign the common name (A, F#) for the note in question, so as not to disadvantage these participants with autism who had neither the musical knowledge, nor (potentially) the verbal ability requisite for such tasks. This simpler procedure allowed a visual tag to be used by the participants, who needed only to point to the picture in order to answer the experimenter. Once this familiarization was accomplished, time was left to elapse so that the experimenters could be reasonably certain that the memory trace of the pitches had dissolved (if they were still present for the participant to refer to, then relative pitch and not absolute pitch would be tested). The participants were then tested through a procedure of playing the note, and being asked to point to the picture to which that note belonged.

This entire procedure was also repeated using speech sounds rather than musical notes. Heaton, Pring and Hermelin (2003) found that both the group of participants with autism and the typically developing group were able to classify the speech sounds equally. However, in the pitch condition, participants with autism performed significantly better than their typically developing peers, demonstrating enhanced pitch processing, which the authors argue is akin to absolute pitch. This fine discrimination of pitch is purported to be indicative of a strength by the ASD participants in local processing. In 1999, these authors reported the case of a young boy with autism who was also musically untrained, but who also demonstrated absolute pitch abilities which serve to strengthen the authors' case that enhanced local processing is evident within the musical domain in individuals with ASD.

However, in their (2000) study, Mottron, Peretz and Menard pointed out that local/global judgments are relative, and thus examined several levels of the local/global hierarchy in one study. They defined the hierarchization of levels of processing as follows: Local processing was used for individual pitches, increasingly global processing was used for intervals between pitches, and the most global processing was employed for the contour of whole melodies, which specifies the direction of intervals without specifying specific pitch frequencies (along the lines of Dowling, 1978a). Counter to the predictions of WCC, Mottron, Peretz and Menard (2000) found that participants with ASD were not impaired relative to controls on the global processing conditions, but rather that they showed enhanced performance on the local processing conditions. These findings were consistent with those obtained by Heaton (2003) where children who processed contours globally where nevertheless superior on a more “local” pitch interval discrimination task. However, a musical contour without harmony or variations in rhythm and tempo, is a relatively simple stimulus and may not provide a good test of global processing.

Foxton et al. (2003) published a report of local/global auditory processing that supported the tenets of WCC and seemingly contradicted the finding of previous researchers. In this study the effects of global interference on a pitch change task was tested in individuals with ASD and controls. The findings from the study showed that the groups’ discrimination scores did not differ in no-interference trials, but ASD participants were better able to maintain good levels of performance in interference trials than controls. Foxton et al. (2003) interpreted their findings as evidence that individuals with autism do not process global aspects of music well. This is the only report of weakness for musical processing that is found in the literature.

How can this result fit in with the results of Mottron, Peretz and Menard (2000) and Heaton (2005)? Firstly, in all three experiments the definition of global/local aspects of music are different. Secondly, participants are different; Heaton (2005) worked with children, while Mottron Peretz and Menard (2000) and Foxton et al. (2003) worked with adults. But more importantly, the task demands in the three experiments were also different. This experiment tested the ability to stay “on task” and did not measure the ability to integrate information into a coherent whole. It is unclear whether this paradigm provides a good test of a global processing bias outlined in WCC theory. In addition, in both the Mottron, Peretz and Menard (2000) study and

Heaton's (2003) study, the groups with autism responded in a way that was maximally adaptive. The ability to represent musical melody holistically is crucial for music perception and the findings from the two studies indicated that such abilities were in evidence in the autistic participants. In this study by Foxton et al. (2003), participants with autism also performed as well as they could on the task that was set before them. However, this involved adopting a strategy that enabled them to attend preferentially to local elements in the stimulus. This study cannot make claims about deficits, since the ASD group did as well or better than typically developing controls on all aspects of the task. What this tells us is that attention to global information or context appears to be less mandatory in ASD than in typical development. Such a claim has recently been made by Mottron (2006), and equates to the claim of EPF theory that there is enhanced local, but preserved – not deficient – global processing. This is the conclusion that can be drawn from the data of Foxton et al. (2003).

A different approach to studying a local/global processing bias in auditory perception, has been to adopt a musical paradigm that more closely reflects the demands of linguistic tasks that have yielded data supporting WCC theory. In their (2007) paper, Heaton, Williams, Cummins and Happe described a musical task that is something of an analogue to the sentence priming task that included "The sea tastes of salt and ______________" as described above. In this priming study, a sequence of chords, establishing the musical context (key signature) are heard. The final chord of the piece is the target chord and is related to the preceding context at one of four levels. It could be (1) globally and locally related (GRLR), (2) globally related but locally unrelated (GRLU). In this condition the target is related to the harmonic context at a global level but not at the local level, operationalised as the chord immediately preceding the target. There is also a globally unrelated but locally related (GULR) condition (3) where the target is related to the penultimate chord, but not to the preceding harmonic context; or (4) globally and locally unrelated (GULU), that is, it is neither related to the preceding harmonic context, nor to the penultimate chord. Participants asked to say whether the final chord sounds correct or incorrect. Thus, as was the case for the free-response language task, where participants could either favour local sentence completions, participants are able to show a global or local bias or indeed may perform at random.

In their (2007) study, Heaton, Williams, Cummins and Happe found that their participants with ASD showed a strong global bias on the task, with increasing levels of "correct" categorizations falling in line with the extent of the global context. Whilst this paradigm provides a good analogue for the previously described language task and a better test of global processing than those previously used, limitations in the sample used by Heaton et al., bring the findings into question. Only participants who achieved high scores on the unambiguous GRLR (correct) and GULU (incorrect) conditions were included in the study, and it may be that this resulted in an ASD group with good global processing skills.

It is worth noting that this experimental design is not without faults. As Mottron, Peretz and Menard (2000) point out, there is no clear delineation between what is "local" and what is "global" in the musical sphere. Thus a tone is local to an interval, but an interval is local compared with a contour, and a contour is local compared to a song. In this experiment, the interval between the final two chords is considered the local element, while the tonal centre, as established by the preceding melody is considered the global context. This is done in much the same way as the linguistic version of the task was developed; the global context is set by the first words of the sentence (the sea tastes of…), but the final word (salt…) creates the local expectancy. Just like in the verbal form of the task, it is not any one note that creates the global tonal centre; some notes are better indicators than others (sea and taste in the verbal; the first note (which is likely to be on the tonic) in the musical task), but all of the notes together are required to establish the expected context. It is possible to see other configurations, however; the local expectancy may be the final note (or, chord in this instance), while the global expectancy is created by the interval between the last two chords. In this case, what is considered “Globally related, locally unrelated (GRLU)” would actually be globally unrelated (because, in the case of GRLU, the final two chords are from different keys. This might be akin to the verbal task “the sea tastes of *pomegranate* and seaweed”). This inability to define absolutely what is local and what is global is a potential downfall that is impossible to rectify when experimenting in the musical medium, because global and local are relational concepts. For this reason, the present interpretation is adopted with confidence, while the knowledge that there are other possible interpretations is also acknowledged.

Heaton, Williams, Cummins and Happe (2007) added a further manipulation to their study. They presented some of their stimuli at a slow tempo, and the remainder at a more moderate tempo. The reasoning behind this manipulation hearkens back to WCC, whereby the concept of central coherence is threatened in autism. In music, another variable that can influence the coherence of a piece is tempo. Like the word-length effect in the storage of memories, whereby the longer it takes to sub-vocalize a word, the more difficult it is to remember that word (Lovatt & Avons, 2001), the longer time it takes for a melody to be presented the more difficult it may be for people with autism to process. Thus, deficits in short-term auditory memory would impact on task performance. It has been proposed that people with autism have problems with what have become known as “clock genes” and that this may translate into an overall “timing deficit” for people with autism that could affect even their musical timing abilities (Wimpory, Nicholas & Nash, 2002). Thus by simply manipulating the tempo of melodies with Global/Local endings we may see a change in the performance of our sample with autism. Heaton, Williams, Cummins and Happé (2007) used a temporal manipulation of moderate/slow with this task and found no difference in performance on the task across the two tempi, however, as previously suggested, criteria for participation was set very high and may have excluded children with sequential auditory processing deficits. In order to clarify the question of whether speed of presentation would influence performance in a sample of children not selected according to such strict criteria as that adopted by Heaton et al. (2007).. Therefore, in order to increase global demands in experiment four, chord sequences will be presented at slow (crotchet = 70), moderate (crotchet = 100) and fast (crotchet = 130) tempi.

In line with WCC it is hypothesized that manipulation of tempo will influence performance in the ASD but not in the control group. It is specifically predicted that the faster the stimuli are presented the more ASD participants will make global responses. As tempo slows, it is proposed that the coherence of the whole melody will be threatened and participants with autism may make increasingly local responses. Such an effect of tempo is not predicted for the controls, as there is no *a priori* global processing deficit in the general MLD population.

Method

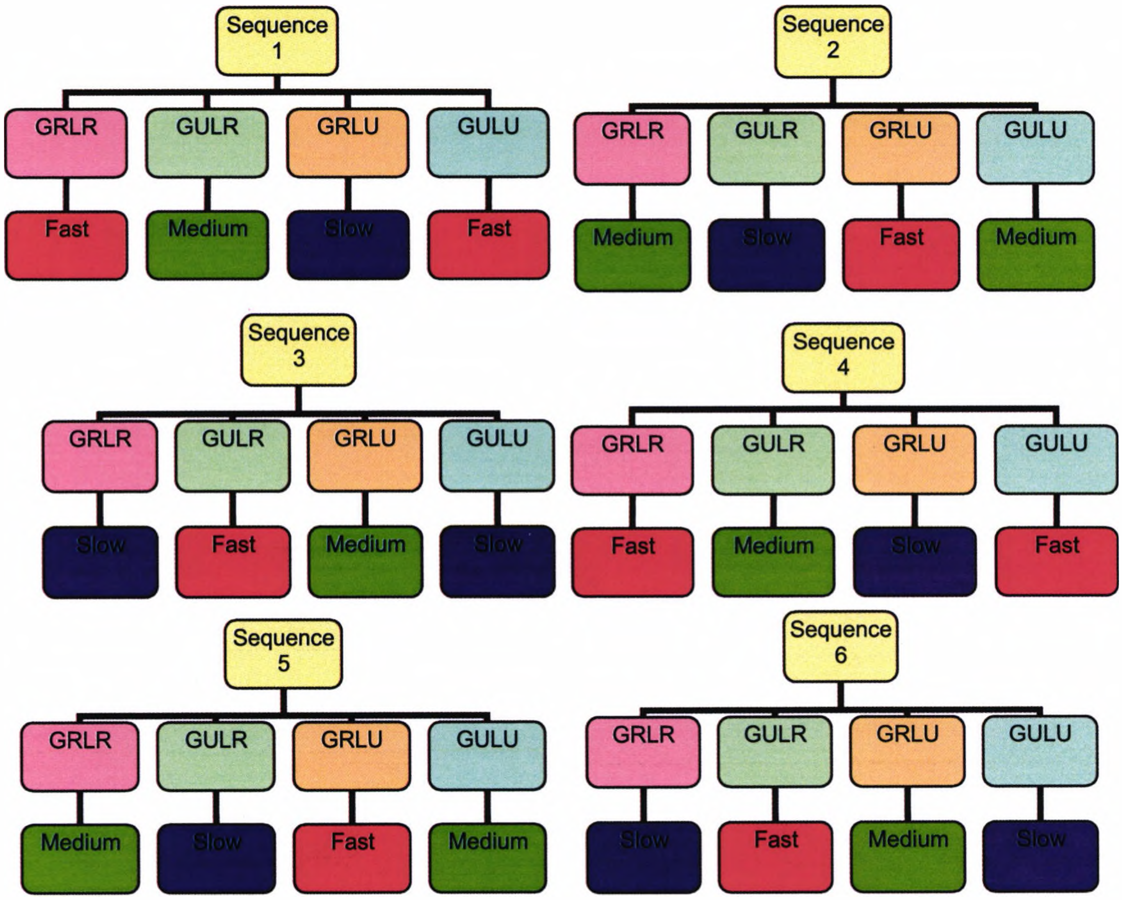
Stimuli were created using the Finale Notepad for Windows 2006, composition software available for free download (http://www.finalemusic.com/notepad/).

Six novel harmonic compositions were created which consisted of two bars of music in 4:4 time signature. The compositions were in various keys, but all fulfilled the expectation of Western music that they begin and end on the tonic. These were the Global Related, Local Related (GRLR) compositions. Each harmonic composition was then transformed in three different ways which altered the last two chords in some way. Firstly the Global Related, Local Unrelated (GRLU) featured a penultimate chord that was transposed up or down a fifth, while the ultimate chord remained as the tonic. In this case, the last chord was not (locally) related to the penultimate chord, but it remained (globally) related to the remainder of the harmonic sequence. Secondly, the Global Unrelated, Local Related (GULR) sequence featured the final two chords transposed up or down a fifth. In this case, the last chord was (locally) related to the penultimate chord, but was (globally) unrelated to the remainder of the sequence. Finally, the Global Unrelated, Local Unrelated (GULU) sequence featured the final chord only transposed up or down a fifth so that it was neither (locally) related to the penultimate note, nor (globally) to the remainder of the sequence.

Thus from six GRLR compositions, twenty-four compositions were created, including six each of GRLU, GULR, and GULU. The twenty-four compositions are included in Appendix 4. These compositions adhere to the same set of rules as those set out in Heaton et al. (2007). It was not possible to use the same stimuli as those investigators, however the principles behind the creation of the stimuli are the same.

Each type of harmonic sequence was played equally in all three tempos, with 2 of the GRLR sequences being played at Slow, 2 being played at Medium and 2 being played at Fast tempos. The same applies to each type of sequence (GRLU, GULR and GULU). (See Figure V:1 for summary of stimuli).

Figure V:1: Summary of stimuli



All stimuli were played at a volume comfortable for the participant. The playback feature of Finale Notepad for Windows 2006 was used to play the stimuli and the concert piano was in all cases the voice used.

Scoring

Participants were asked a simple question about each stimulus – does it sound "good" or "bad"? Before the experiment, it was explained that "good" stimuli sounded like nice music, that didn't go off at all. "Bad" stimuli, on the other hand, sounded like at least one note went off. Examples of each type of closed-ended stimulus (GRLR and GULU) were then given and the participant was asked whether it was "good" or "bad". If the child got an example wrong, the participant explained why it was wrong, and the participant was allowed to hear it again, until they agreed that they could hear the difference. There were two unambiguous conditions – when it did indeed sound "good" (GRLR) or when it definitely sounded "bad" (GULU) – and two ambiguous conditions, GULR and GRLU, which were neither definitely good nor definitely bad sounding. Each time the participant said an item was good a point was awarded.

Participants

Participants were three girls and fifteen boys between the ages of thirteen and sixteen (mean age=14.17) with a diagnosis of autism, and two girls and ninteen boys between the ages of thirteen and sixteen (mean age=14.24) without a diagnosis of autism, but with moderate learning difficulties (MLD). Children were recruited from local schools with a special provision for pupils with autism spectrum disorders (ASD) or MLD, or dedicated specialist high schools throughout England. All children consented freely to participate in this experiment, and written permission was obtained from legal guardians in compliance with the ethical review board requirements of Goldsmiths College. Psychometric data for participants are shown in Table V:A.

Table V:A: Participants

	Diagnosis	Number	Mean	Standard Error	F	p
Age	Autism	18	14.17	0.218	0.053	0.819
	MLD	21	14.24	0.217		
Raven's Raw Score	Autism	18	21.61	3.334	0.281	0.599
	MLD	21	24.05	3.150		
BPVS Scaled Score	Autism	18	69.17	6.566	11.116	0.002
	MLD	21	99.44	6.273		

There was no significant difference between the groups on age, or non-verbal IQ (Raven's Standard Progressive Matrices), however as expected, the autism group scored significantly lower on the measure of verbal IQ (VIQ), the British Picture Vocabulary Scale (BPVS).

Results

Total global scores for all experimental conditions are shown in percent in Table V:B below. Percentages indicate the number of "good" endorsements for a particular type of stimulus. Thus GRLR stimuli, which were "good" stimuli, were judged so quite a high percentage of the time, while the GULU stimuli which were unambiguously "bad" stimuli, were judged to be "good" quite a low percentage of the time. GRLU and GULR stimuli, which were ambiguous, were judged to be "good" an intermediate percentage of the time. This pattern of results is as expected.

Table V:B: Results of Tempo task (in percent)

Diagnosis	Speed	GRLR	GRLU	GULR	GULU	Total
ASD	Fast	97.2	30.55	30.55	22.2	79.1625
	Medium	94.45	41.65	22.2	16.65	79.1625
	Slow	91.65	47.2	52.8	13.9	72.225
MLD	Fast	80.95	21.45	19.05	40.5	76.1875
	Medium	78.55	30.95	26.2	16.65	75
	Slow	90.5	59.55	47.6	14.3	64.8875

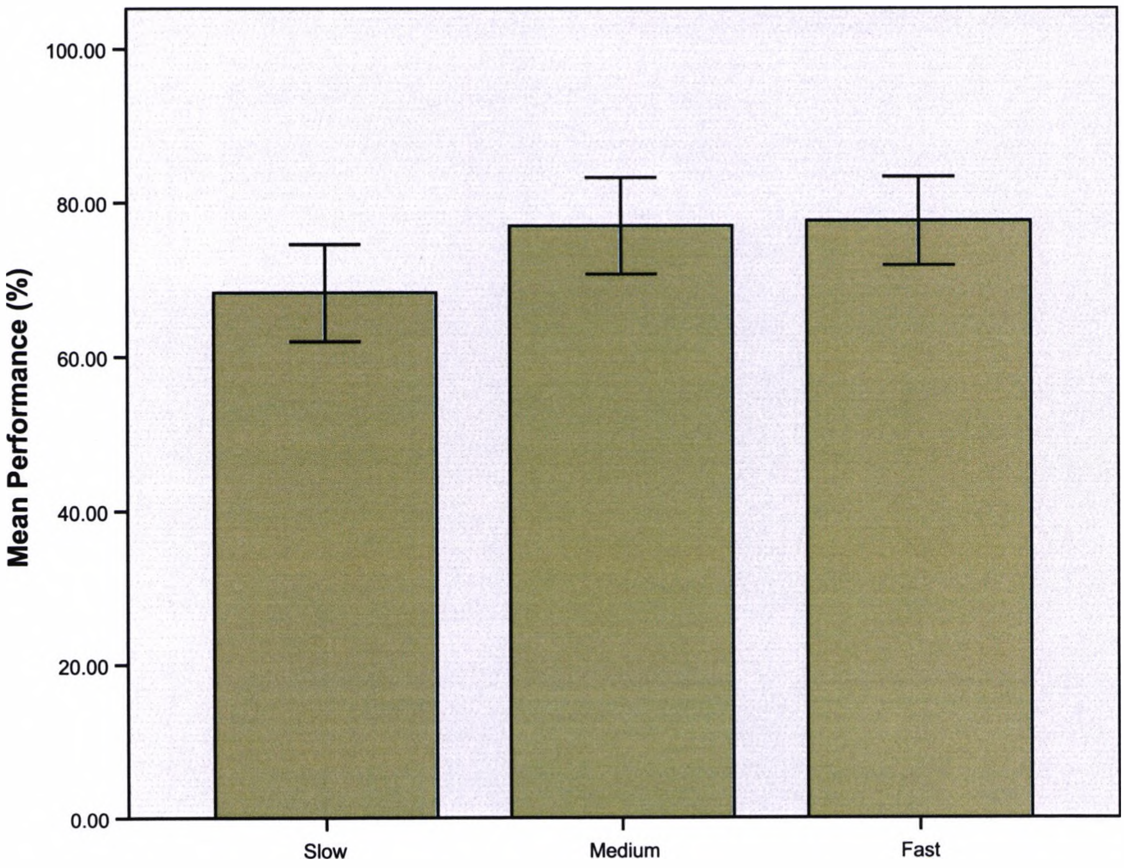
In the study by Heaton et al., (2007) only participants who correctly identified a high proportion of the unambiguous GRLR and GULU stimuli were included in the analysis and it was hypothesized that this may have biased the results from the study. In order to explore performance on this most basic, unambiguous aspect of the task, performance on these conditions only were tested first. Correct responses for GRLR and GULU were summed as a measure of task understanding. See Table V:C for means and standard deviations for lumped unambiguous stimuli. An analysis of variance with group (ASD/Controls) as the between-group factor, and speed (slow, moderate, fast) was carried out on this data.

Table V:C: Results for Unambiguous Stimuli

	Diagnosis	Mean	Std. Deviation
Fast	Autism	59.7222	15.19212
	MLD	60.7143	20.26609
Medium	Autism	55.5556	13.70797
	MLD	47.6190	17.50850
Slow	Autism	52.7778	14.57458
	MLD	52.3810	15.62202

There were no significant effects of diagnosis, (F=0.565, p=0.457) and no interaction effect between diagnosis and tempo (F=0.893, p=0.414) but there was a significant main effect of tempo (F=3.450, p=0.037). T-tests were then undertaken in order to investigate the source of the significant difference. The t-test between fast and medium tempo stimuli was significant (f=2.337, p=0.025) with participants scoring higher on fast tempi. The test between fast and slow tempo stimuli was also significant (t=2.022, p=0.050), again with participants scoring higher on fast tempi. However, the difference between medium and slow tempo stimuli was not significant (t=-0.422, p=0.675). See Figure V:2.

Figure V:2: Performance by Tempo



The means for "good" responses to the open-ended stimuli (GRLU & GULR) are shown in table V:D.

Table V:D: Results for Ambiguous Stimuli

	Diagnosis	Mean	Std. Deviation
Fast	Autism	30.556	34.890
	MLD	23.810	24.336
Medium	Autism	31.944	23.957
	MLD	29.762	27.182
Slow	Autism	33.333	25.724
	MLD	33.333	27.763

These stimuli were analysed in the same way as the unambiguous stimuli. This analysis, however, resulted in no significant difference either between tempi, or between diagnosis.

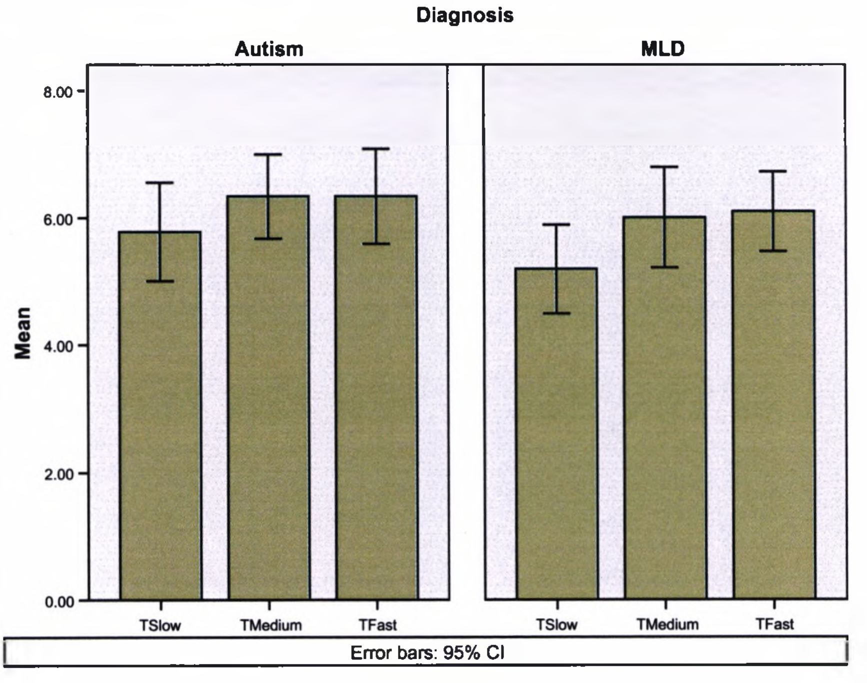
Thus participants were more susceptible to effects of tempo when the task was unambiguous. When the task demands increased, tempo was no longer a contributing factor to the participants' performance.

Ambiguity of the stimulus shared a complex relationship with the performance on the task. However, it was not thought prudent to exclude participants on the basis of suboptimal performance on the unambiguous stimuli as did Heaton et al. (2007). Instead, all trials were entered into a repeated-measures MANCOVA analysis where "goodness" was the within-subjects variable ("goodness" = GRLR, GRLU, GULR, GULU) and the between-subjects factor was diagnosis. The covariates were age, score on Raven's matrices, and score on BPVS. Once covariates were partialled out, this analysis revealed no main effect of "goodness" ($F=0.173$, $p=0.914$), and no effect of diagnosis or interaction between diagnosis and "goodness".

There was, however, an interaction effect between "goodness" and score on the BPVS (F=3.563, p=0.017).

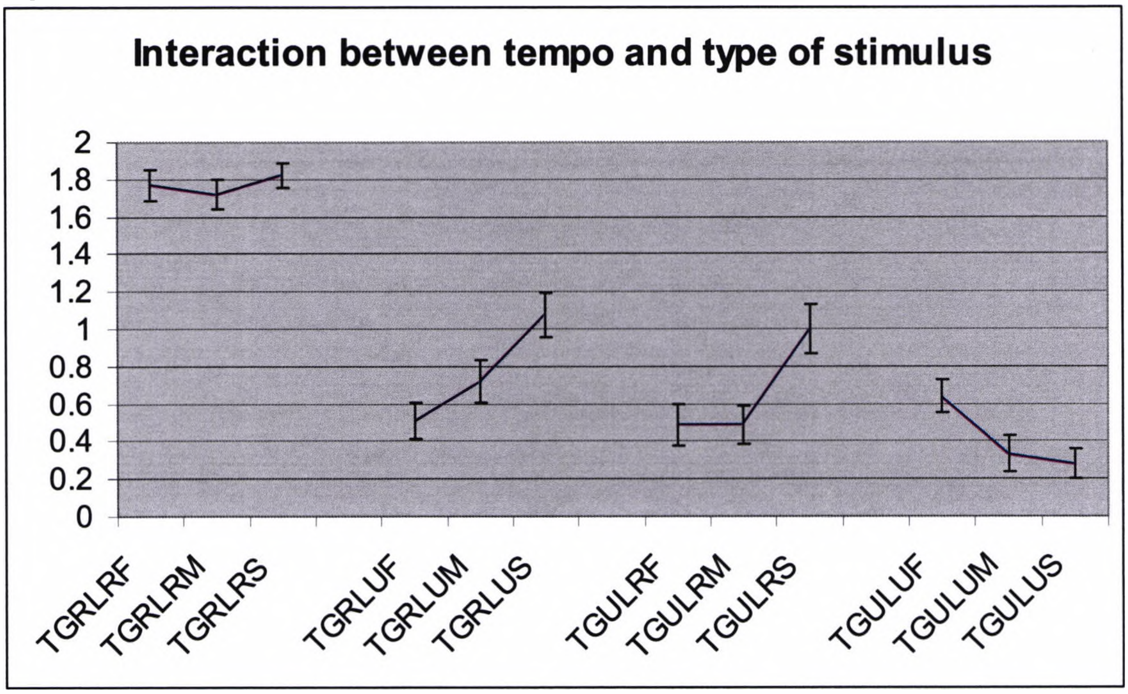
The effect of the independent variable, Tempo, was examined using a repeated-measures MANCOVA with "Tempo" (Fast, Medium, Slow) as within-subjects factor and diagnosis as between-subjects factor. This analysis revealed that, surprisingly, there was no main effect of tempo, or interaction effects between tempo and diagnosis once covariates were partialled out (see graphical representation of these results in figure V:4).

FigureV:3: Performance by Diagnostic group, by Tempo



The interaction between tempo and type of stimulus is a complex one, and is illustrated in Figure V:6.

Figure V:4: Interaction between tempo and type of stimulus



Discussion

In their (2007) task probing the extent to which global and local harmonic contexts influence musical expectancies, Heaton, Williams, Cummins and Happé found that participants with ASD did not perform differently to controls matched on age and intelligence. This evidence suggested that these is no global deficit (less likely to think that global information sounds correct) or local bias (likely to think it sounds correct when the adjacent previous chord was related to it harmonically) was present, relative to control participants. However, they presented their stimuli at two tempi (slow and moderate) and found that stimuli that were related only at the global level were processed more efficiently when they were played slowly. They found no other effect of tempo. They interpreted these findings as confirming the effects of contextual priming observed in typically developing individuals, in children with autism. Furthermore, for all participants priming effects were stronger for global context than for local context. However, local cues did cause priming effects as participants were significantly more likely to judge stimuli related at local levels as correct than stimuli that were unrelated to the context. This was especially true when the stimuli were played slowly (Heaton et al., 2007).

This experiment reported replicated those earlier findings showing that participants with ASD perform like matched controls on a task that probes local/global priming effects of musical expectancies. However, unlike in the original experiment, there was no main effect of “goodness” once the covariates were accounted for. This is a puzzling finding, since it would appear (from graphical representation of findings) that there was a main effect of “goodness”, namely that GRLR stimuli were judged to be “good” significantly more often than other stimuli. However, with the covariates of age, Raven’s Matrices scores, and BPVS scores factored in, that apparently significant finding dissolves.

It is interesting, in this context, to note that verbal IQ scores (on the BPVS) were a significant contributing factor to success on this task. This may indicate that the task was too complex for some of the less-linguistically-able participants to understand. Since the ASD group on average scored quite substantially lower on the BPVS than did the MLD group, this would be expected to be a barrier to the ASD participants in completing this task. Since this task was originally in a linguistic format (and showed usefulness in that format) it may be that this task is appropriate only for higher-functioning children and adults with ASD who can bear the high linguistic load of the task.

The tempo manipulation of this experiment was slightly more fine-grained than that of Heaton et al. (2007), with three tempi represented (slow, medium and fast) however a main effect of tempo was observed only for the unambiguous stimuli, and not when the full model was tested.

Participants actually performed worse when unambiguous stimuli were presented at a slow tempo than when they were presented at either a medium or a fast tempo. This result indicates that when temporal coherence is threatened, which can occur when the tempo is quite slow, participants are less sensitive to the global priming in this task, which probes the effect of contextual cues on the understanding of music.

However, upon further scrutiny of the data, it becomes apparent that participants did worse at both the ambiguous test of global processing (GRLU) *and* did worse at the ambiguous test of local processing (GULR) at the slower tempo. It might be expected that the slower tempo would disrupt processing of the global context, as it was six notes and about four seconds long. However, the local context, which consisted of the penultimate chord, and was never even one second away from the target chord, perhaps should not be affected by the speed of presentation of the global context.

This logic, however, is in error. With either type of stimulus, the participant is required to make a judgment about both global and local elements of the stimulus. GRLU stimuli are related on a global context (the final note is related to the first six notes) but are not related on a local context (the final note is not related to the penultimate note). GULR stimuli are related similarly, but oppositely. To judge whether the sequence is “good” or “bad”, participants must be able to discern whether the final note is related to either/both of the preceding contexts because only if it relates to both contexts is it "good". Thus, if a participant is presented with a GRLU stimulus they must know what the context is in order to decide that the penultimate note is unrelated, and similarly with a GULR stimulus the participant must know what the original context is in order to decide that the penultimate and the final note are unrelated. Either way, slow stimulus presentation might be expected to disrupt the perception and cognition of this contextual information.

This effect of tempo may easily enough be predicted, but only in the ASD group, who are hypothesized to succumb to weak central coherence, and thus might have trouble with temporal coherence. Following that logic, WCC theory would predict that, for the ASD group, cognition of global elements in this task would be impaired relative both to cognition of local elements and the cognition demonstrated by the control participants. None of these predictions have been borne out by this experiment.

The enhanced perceptual functioning hypothesis of autism (Mottron & Burack, 2001) would not (necessarily) predict an effect of tempo, but would predict that participants with ASD would show better processing for local elements than for global elements. This prediction has not been borne out by this experiment. In their recent study, Tillmann, Janata, Birk and Bharucha (2008) used this chord priming task with endings that were perceptually, but not harmonically, related. This paradigm should be used in future to probe the EPF processing model more directly.

The social timing hypothesis of autism (Wimpory, Nash and Nicholas, 2002) is a new (and largely untested) hypothesis that posits that the neurobiological systems responsible for timing (both biological (circadian rhythm etc.) and social (rhythms of social interaction etc.)) are somehow disrupted in individuals with autism. This hypothesis would predict that temporal processing would be impaired at certain speeds, and would furthermore predict that the impairment that participants with ASD evidence on trials with a slow tempo is indicative of their social timing deficit. However, in this experiment it was not only the participants with ASD who showed impairment in functioning at the slow tempo; age- and IQ-matched controls did as well.

Thus the major perceptual/cognitive hypotheses of autism do not account for these findings, largely because no difference between the ASD group and the control group were found. One factor which alters working memory limits (and may help to account for this finding) is age; all people have limits, but they increase over time. Thus, it is questionable whether this observed temporal dysfunction at slower tempi is typical for the age of participants or not. It would be interesting to look at the manipulation of speed of presentation on a priming task in typical children at different stages of development.

Findings with the linguistic version of this task, where participants were asked to complete sentences with ambiguous endings that could either be local or global (i.e. "The sea smells of salt and _______" local: vinegar, global: seaweed) participants with autism answered more locally than their controls (Happé, Briskman, & Frith, 2001). As language and music are served by some of the same neural mechanisms and are posited to develop similarly (Fitch, 2006), it might be expected that results seen in the linguistic version of a task would also be seen in the musical version. However, this has not been found to be the case. This implies that there are different higher-level post-perceptual mechanisms serving both language and music that diverge, likely at an early age when domain-specific processes begin to drive perceptual processing (Trainor & Trehub, 1992). In individuals with autism, the linguistic mechanisms apparently do not develop readily and to pace, as the autism-associated language delay and often life-long language impairment indicate. However, in music there is not indication (nor do these results indicate) that a commensurate impairment exists. In fact, in studies probing musical functioning, individuals with autism almost exclusively perform at or above the level that would be expected based on their intellectual and developmental level.

In terms of musicality, the initial concern has been that if linguistic development shows a delay and an impairment (and since language development and musical development follow a similar trajectory) then musical development may show a similar delay and impairment. This does not appear to be the case, however. Evidence gained from this experiment bolsters the hypothesis that individuals with autism are able to acquire musical knowledge implicitly and develop musicality, without delays or impairments in understanding the contextual information provided by musical grammar.

Conclusions

The impairments in global structure processing and temporal processing that are predicted by the different explanatory hypotheses of autism and that are found, most notably, in the communicative and linguistic domain are not found in the musical domain. Participants with ASD were as able as their age- and non-verbal IQ matched controls, to process local and global musical priming, and to process this at a variety of tempi. This evidence again suggests that music processing is spared in ASD.

VI. Implicit learning

Abstract:

Implicit learning has been implicated in the acquisition of linguistic as well as musical information in infancy and throughout life. In this experiment, participants with ASD and an age- and IQ-matched comparison group with MLD completed two versions of an Artificial Grammar Learning paradigm, one with pseudo-linguistic stimuli, and the other with musical stimuli. The results showed that participants with MLD were unable to perform either conditions of the task at levels that were better than chance. This finding may result from a speed-of-processing deficit that is associated with nonspecific mental retardation. Participants with ASD scored better than chance on both the pseudo-linguistic and the musical tasks. In addition, for ASD participants, performance on the pseudo-linguistic task correlates with performance on the musical task, indicating that both tasks probe similar functions. These results are discussed in the context of debates about modularity and brain functions shared for music and language, as well as with reference to the speed-of-province debate in learning disabilities research.

The preceding four studies have examined some fundamental aspects of music cognition in individuals with ASD: timbre, rhythm and tempo. In addition, in chapter five, the ability to process the tonal context of short melodies was examined, on the grounds that developmentally, human infants are able to recognize the tonal context of a piece very early on (Trehub, Schellenberg & Kamenetsky, 1999). In that experiment, it was found that individuals with ASD could process tonal context as well as their age- and IQ-matched controls. The mechanism by which this understanding develops, however, has never been explored in an autistic sample. Implicit learning, the process by which individuals unconsciously absorbs and processes statistical information in a complex data set, is an essential process for the learning and cognition of music throughout the developmental trajectory. If this process is disrupted in an individual, then it would be impossible for musical learning to continue in the typical fashion. Thus it was determined that implicit learning for music is a fundamental aspect of music cognition that, while not forming part of musical structure in the manner that timbre, rhythm and tempo do, does form an essential part of the developmental trajectory of music learning (much like the understanding of tonal context) and thus was considered in this survey of music cognition in individuals with ASD.

As discussed above, explicit learning, whereby an individual consciously stores information they have been formally taught in memory, cannot account for all human learning (Posner, Rothbart, Thomas-Thrapp & Gerardi, 1998). Especially those things that an infant learns in the first years of life must be accounted for by another, unconscious form of learning whereby the individual simply "picks up" information unintentionally (Van der

Kamp, Oudejans & Savelsbergh, 2003). This form of learning has been called implicit learning, and has been implicated in language learning, especially grammar (Reber, 1989; Dulany, Carlson & Dewey, 1984; Reber, 1967), as well as musical learning (Kuhn & Dienes, 2005; Dienes & Longuet-Higgins, 2004; Bigand, Perruchet & Boyer, 1998), motor task learning (Berger et al., 2005; Green & Flowers, 1991), and learning across a host of other doamins.

Explicit memory is an ability of especial pride to many individuals with autism and memorizing vast quantities of information such as bus routes or telephone books is a major pre-occupation for some autistic people. (Mottron, Belleville, Stip & Morasse, 1998; O'Connor & Hermelin, 1991). Whilst much research has dealt with the memory impairments found in people with autism (Bowler, Gardiner & Grice, 2000; Bruck, London, Landa, & Goodman, 2007; Crane & Goddard, 2008), a substantial body of work examining memory functions in autism has observed preserved or enhanced abilities (Bennetto, Pennington & Rogers, 1996; Williams, Goldstein, Minshew, 2006; Heaton, 2003; Bor, Billington & Baron-Cohen, 2008; Baron-Cohen et al. 2007; Lyons & Fitzgerald, 2005; Bolte & Poustka, 2004). Possibly the first neurobehavioural model of autism was the amnesia theory (Boucher & Warrington, 1976). According to this theory, all of the social, language and behavioural symptoms of autism could be explained by an amnesic syndrome. Whilst this hypothesis has been largely discredited (Minshew & Goldstein, 1993), the central importance of memory function in individuals with autism remains an impetus for research, although consensus about its precise role in the genesis of the disorder is still lacking (Williams, Goldstein & Minshew, 2006). Williams, Goldstein and Minshew (2006) point out that one problem in the research surrounding this issue is the inconsistency of findings. Many provocative findings remain un-replicated. Williams, Goldstein and Minshew indicate that this might be due to the heterogeneity in the autistic population which results in differences in cognitive profiles in individuals in research groups. However, there are some robust findings in the field. Early findings suggested that children with autism do not use semantic categories to remember word lists (e.g. Hermelin & O'Connor, 1970) although these results have been contested by Lopez and Leekam (2003). This indicates that contextual information facilitates memory to a lesser extent in autism than in typical populations. In addition, complexity of information to be remembered affects the performance of individuals with autism; low-complexity stimuli are remembered well, but as complexity increases performance decreases (Burke & Cerniglia, 1990). Sequential information, both in the visual and auditory modalities is often reported to be impaired (Minshew, Goldstein, & Siegel, 1997) although some studies have found sequential processing in the visual domain to be intact (Hermelin & O'Connor, 1970). Memory for faces is consistently reported to be impaired (Boucher & Lewis, 1992; Boucher, Lewis, & Collis, 1998; Gepner et al., 1996; Klin et al., 1999) and the prevailing theory is that this is because of the high complexity of the stimulus and the importance of contextual information typically required for its interpretation. Working memory has also been shown to be impaired, although again this depends on several factors including the aspect of working memory probed and the complexity of information that is required to be remembered (Williams, Goldstein & Minshew, 2006). It also seems likely, given the degree of heterogeneity characteristic in autism, that variability in global intelligence scores and in cognitive profiles will influence results on memory studies. Thus it appears that although autism is not an amnesic disorder, as early theorists thought, there is certainly a phenomenon of memory impairment within autism. However, the impairment is not universal; while spatial working memory and autobiographical memory are almost universally deficient in individuals with autism, rote memory is a definite strength. Indeed findings from Young's large scale survey (1995) that memory abilities are implicated in the development of savant abilities in individuals with autism and intellectual impairment. It is becoming clear that it is in concert with these special capabilities that many autistic savants are able to do what they do (Happe, 1999).

Implicit learning, unlike explicit learning, is much less affected by general intellectual ability. Intellectual disability does not appear to cause much impairment on implicit learning tasks (Atwell, Conners & Merrill, 2003). However, implicit learning has been shown to be impaired in some developmental and psychiatric disorders, for example attention deficit hyperactivity disorder (Aloisi, McKone & Heubeck, 2004), Down and William's Syndromes (Vicari, Verucci & Carlesimo, 2007) obsessive compulsive disorder (Kathmann et al. 2005), schizophrenia (Marvel, Schwartz, Howard & Howard, 2005) and Parkinson's disease (Siegert, Taylor, Weatherall & Abernethy, 2006). Whilst implicit learning has not been extensively investigated in autism, the few studies that have been carried out suggest that this ability is largely unimpaired (Renner, Klinger & Klinger, 2000; Barnes et al., 2008).

In their study, Renner, Klinger and Klinger (2000) investigated whether autism was an amnesic disorder. In amnesic individuals, explicit memory measures highlight their impaired function, while implicit memory continues to function. They used a perceptual identification task to probe implicit learning, and a recognition and a recall task to measure explicit learning and found that, while implicit memory is indeed unimpaired in participants with ASD, the measures of explicit learning were also unimpaired, indicating that ASD is not, in fact, an amnesic disorder.

Barnes et al. (2008) further investigated implicit learning in individuals with ASD using two implicit learning tasks that are linked to specific brain circuits, the contextual cueing task and the alternating serial reaction time task. On both measures, individuals with ASD were unimpaired, leading these authors to conclude that implicit learning is unimpaired in individuals with autism.

Another paradigm developed to probe implicit learning is Reber's grammar learning paradigm (Reber, 1967). This paradigm monopolizes on the use of implicit learning to acquire grammatical structures. Originally it made use of a finite-state grammar (see Figure VI:1) with which participants are trained, and then tested, employing nonsense words as stimuli. Since then, however, this paradigm has been tested within music and pictorial symbolic domains and found to function well (Altmann, Dienes & Goode, 1995). This demonstrates that implicit learning for grammar is not confined to linguistic grammar, but is relevant as well in the musical domain.

Chomsky (2006) defines grammar as the structure defining the lawful relationship between elements. This is why it is not confined to language alone, which requires a structure to define the lawful relationship between words, but also applies to music, where the lawful relationship is between notes (Lerdahl & Jackendoff, 1983). Western tonal music has a very clearly defined grammar, which delineates what is and is not acceptable form in a composition. Thus, it is plausible to suggest that musical grammar would be learned in much the same way as linguistic grammar. Indeed, several studies with infants have demonstrated that this is the case (Saffran, 2003). However, in their (2003) review, Peretz and Coltheart argue that while there is evidence that learning across domains is similar, there are different modules subserving processing in both domains.

In his (2003) review, Patel discusses the evidence for and against the modularity of language and music. If both language and music are separate modules of ability, then the factors that influence processing or learning of language do not necessarily influence the processing or learning of music. Evidence from neuropsychology seems to support this modularity, due to the dissociation of language and music present in aphasics who are not amusic, and vice versa (see Peretz & Coltheart, 2003) In addition, theories of syntax for music and for language are quite separate (see Brown & Fraser, 1963; Peretz & Zatorre, 2003) Patel (2003) argues against this modularity, providing converging evidence from both cognitive theory and neuroscience, that the areas of the brain responsible for language syntax processing are also involved in the processing of musical grammar. Patel argues for SSIRH, the Shared Syntactic Integration Resource Hypothesis, which state that both music and language are subserved, in the brain, by a shared module that processes relationships between low-level elements of a syntax, and then sends them for higher processing in their respective areas of the brain. Even more recently, evidence from Patel's lab has shown that linguistic grammar and musical grammar are processed similarly in the brain, both by Broca's area, which has been long known to be involved in processing grammatical aspects of language (Patel, Iversen, Wassenaar & Hagoort, 2008).

However, Peretz and Coltheart (2003) persuasively argue to the contrary. According to these authors, musical ability is definable not exclusively as *a* module in the brain, but as a *network* of modules (or subsystems creating one module) in the brain. They take as their model, Fodor's (1983, 2001) model of modularity, but they tweak it slightly. Fodor gives examples of features that a typical module has: rapidity of operation, automaticity, domain-specificity, informational encapsulation, neural specificity and innateness. None of these are necessary, nor are they sufficient of modularity. Informational encapsulation seems, to Fodor, the most important aspect of modularity, as it posits that the modular ability is, in fact, modular; that is, it works separately from the "central system" and largely impervious to its influences. Peretz and Coltheart add to this list domain-specificity, and name it as a necessary component for modularity. Their argument is that it is unthinkable to have a module that can subserve more than one domain. Thus for them, the idea of the SSIRH module that can deal with both musical and linguistic information is a non-starter. They present cases from the neuropsychological literature of music/language dissociations usually acquired through brain insult, but some also congenital. Peretz and Coltheart even propose a model of auditory function that features two separate areas for the processing of musical and linguistic information, which has been referred to earlier in the discussion of rhythm (Pg. 49)

The apparent plight of the individual with autism is best accounted for by this modularity hypothesis, which most readily accounts for dissociations in music and language. In the individual with autism, there is always a history of language delay and in every individual diagnosed with an autism spectrum disorder, there are communication deficits which can manifest themselves in linguistic difficulty. This difficulty will often present in infancy, before any linguistic output has begun, with pre-verbal attention sharing, gaze following and pointing behaviours showing atypical development. Preverbal communication is only the beginning of autistic communication difficulty, however. Communication impairments are diagnostic of autism (APA, 2000). However, while modern interpretations of this criterion tend to focus on nonverbal aspects of communication, such as joint attention, which predicts language acquisition in autism as well as in typical development (Luyster, Kadlec, Carter & Tager-Flusberg, 2008) it is certain that delays in language learning is present in individuals with autism, and that these delays often persevere (Sigman & McGovern, 2005).

Whilst the language profiles of verbal individuals with autism tend towards heterogeneity, several studies have found that difficulties cluster in semantic and lexical domains. Often vocabulary and grammar are relatively spared and may be chronological-age appropriate in individuals without concurrent intellectual impairment (Bartak, Rutter, & Cox, 1975; Pierce & Bartolucci, 1977; Tager-Flusberg, 1981). However, as Landa and Goldberg (2005) note, some researchers have found impairments in grammatical development, for example in understanding grammatical markers (Scarborough, Rescorla, Tager-Flusberg, Fowler, & Sudhalter, 1991) and difficulties in comprehending syntax (Minshew, Goldstein, & Siegel, 1995). However, some researchers have found no differences exist across the different domains of language learning and production, describing instead uniformly impaired language ability (Jarrold, Boucher & Russell, 1997).

There is a great variation in linguistic competence amongst individuals with autism, however all individuals with a diagnosis of autism show linguistic impairment early on. Most begin to speak late, and evidence delays all throughout development (Tager-Flusberg, Paul & Lord, 2005). Diagnostic criteria for autism (APA, 2000) does require that language is observed to be delayed at three years. Subsequently, language develops to extraordinarily variable degrees, ranging between mutism, and language skills that are chronological age appropriate when tested with standardised language tests (Tager-Flusberg, Paul & Lord, 2005). Tager-Flusberg and colleagues did find, however, that grammar and syntax follow a normal developmental course in children with autism. That said, children with autism do still evidence restricted grammar usage which is characterized by asking fewer questions and making a fewer constructions of a similar type (Scarborough, Rescorla, Tager-Flusberg & Fowler, 1991). Bartolucci, Pierce and Streiner (1980) and Howlin (1984) both found that children with autism are poorer than typically developing children at mastering certain kinds of grammatical morphemes. However, several studies have found that children with autism, in general, have no trouble acquiring rule-governed syntactic systems when compared with mental-age matched controls (Bartak et al., 1975; Pierce & Bartolucci, 1977). In the words of Tager-Flusberg, Paul and Lord (2005) "It seems very likely that syntactic development in children with autism is more similar than dissimilar to normal development" (p. 345), although they do concede that it is generally slower than typically developing children and is more related to developmental level than to chronological age.

It should be noted that the definition of language differs dramatically among theorists. For example, according to Tomasello, it would be impossible to have a communication impairment alongside intact language (i.e. see Goldin-Meadow, 2007). However, if one defines language simply as a technical accuracy with syntax and vocabulary, then certainly there are people with autism with "unimpaired language".

Research into language in autism has not presented a very clear picture of where specific deficits lie. It is the case, however, that very young children with autism show a reduced orientation to speech stimuli (Kuhl, Coffey-Corina, Padden & Dawson, 2005) and this will in turn constrain opportunities for learning about language (Paul, Chawarska, Klin, & Volkmar, 2007), and likely constrains joint attention too.

This "neglect" does not appear to extend to music, however, and this is where the modularity of music and language hypothesis becomes so compelling. Music learning does not appear to be affected in individuals with autism. Many children with autism are avid music performers, and even more are avid listeners. Thus there appears to be a dissociation between language and music in individuals with this neurodevelopmental disorder, more specifically with respect to the automatic, or implicit, processing of music and language that can begin from very early infancy.

However, no studies to date have tested implicit learning across music *and* language domains in autism in an experimental context. Findings from chapter 5 and published work (Heaton, Williams, Cummins & Happé, 2007 Heaton, 2005) show that autistic children are able to learn about harmonic structure and other findings show that they are able to learn about what music portrays, for example, feeling and thinking states like happiness and tenderness (Heaton, Hermelin & Pring, 1999; Heaton, Allen, Williams, Cummins & Happe, 2008). However, whilst this shows that they are able to acquire this knowledge, little is known about how this process occurs. Findings from studies with savants have identified exceptional musical memory and exceptional musical memory in musically talented persons with autism and other developmental disorders (Sloboda, Hermelin & O'Connor, 1985; Miller, 1989; Treffert, 1989; Hermelin, 2001) and it may be that children with autism, who do not meet criteria for savant status, also acquire musical information rapidly. Kanner (1943) described a child with autism who had learned eighteen symphonies by eighteen months and this lends plausibility to this suggestion.

Koelsch (2005) highlights the research using ERP to investigate expectancies for musical grammar, and cites findings showing that the brain responds to musical grammar in Broca's area (in the left hemisphere), and its homotope area in the right hemisphere. Behaviourially, Koelsch notes that this particular brain response can be elicited even in those who have never been musically trained, and that these participants can spot musical features that they have only ever learned implicitly (for example, the idea of the 'tonic', or the 'dominant' in music.) These responses, based on implicit learning, are quick and accurate, and fall in line with similar findings showing non-explicit learning for musical structures (Tillman, Bharucha & Bigand, 2000). Taken together this evidence suggests that the ability to acquire musical knowledge implicitly and to utilize this information effectively and efficiently is a general feature of the human brain.

In chapter five the experiment explored the participants' understanding of musical context and tempo and showed that those with autism were just as able as those without autism to process and understand grammatical, implicitly learned musical material. Because the participants were all able to use the contextual information to decide whether a target "fit" within the preceding musical context, it can be concluded that the participants were able to use their knowledge about western musical relatedness, to complete the task. It is extremely unlikely that explicit learning was implicated in these participants abilities' as most had had very little musical instruction. However they live in a musical envirómment and this exposure enabled them to learn the required aspects of musical grammar (just as they learn linguistic grammar implicitly from infancy).

The research presented in this chapter examines implicit learning of grammar using linguistic and musical stimuli in children with autism. In addition to the initial analysis comparing participant groups within and across music/language domains, the findings from the experiment will also be evaluated in the context of the degree of grammatical competence measured by a standardized test of receptive grammar (TROG-2) (Bishop, 1982)). Hypotheses proposing that music and language perception are underpinned by separate modular processing systems, and that perception and cognition of music and language is underpinned by shared mechanisms have been described and will be evaluated in the light of the findings from the current experiment.

In the introduction to this chapter, various hypotheses about delayed acquisition of language, including grammar were described. However, no data address the question of when and how children with autism acquire knowledge of musical grammar. The only evidence available comes from clinical and anecdotal sources and these suggest that many individuals with autism with and without significant language impairments show a orientation to listen to music and appear to enjoy a rich musical life. In this experiment the implicit grammar learning of both language and music is tested with the hypothesis that learning of musical grammar will be unimpaired in participants with ASD relative to controls matched on age and intelligence. The hypothesis for the language condition is two-tailed. This is because whilst language impairment is characteristic in autism, these difficulties may be more marked in non-grammatical areas and experimental studies suggest that implicit learning may be unimpaired in autism. It may also be the case that the "neglect" of social stimuli, characteristic in autism, does not extent to the musical domain. The testing of implicit learning across language and music domains in autism and moderate learning difficulties may serve to extent the question of modularity to atypical populations.

The use of the TROG-2 as a cognitive measure of receptive linguistic grammar enables investigation of the correlation between current levels of grammar and artificial grammar learning as tested in the experiment. The hypothesis drawn from the "Modularity account" is that TROG-2 scores will correlate with the linguistic grammar learning ability, but not with musical grammar learning ability. However, if correlations across the two experimental conditions (music/language) are significant, this would pose a challenge for the modularity account and suggest that learning across music and language domains depend on shared mechanisms.

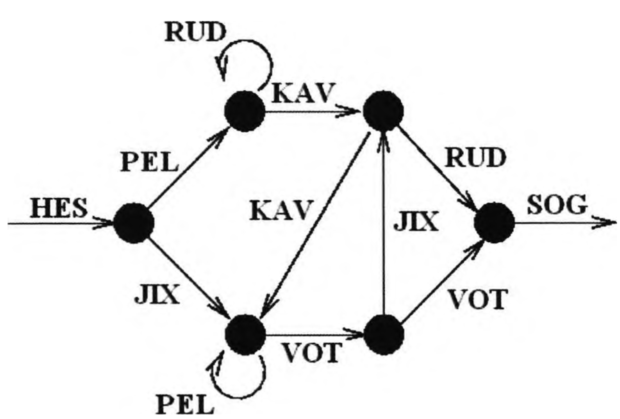
In order for an individual to develop musicality, for example the ability to improvise, to compose, or even to understand musical scores, they must be able to learn, and correctly apply, the rules of musical grammar. This experiment will examine whether children with ASD are able to efficiently utilize implicit learning mechanisms within the music and language domains. .

Methods

Stimuli were created using Reber's Finite-State Grammar (Figure VI:1). The grammar itself consists of a network of lawfully and directionally interconnected nodes. At the nodes are placed the vocabulary of the grammar; in Reber's original paper these were monosyllabic nonsense words; three-letter strings that sound convincing as English words, but are not. Using this linguistic grammar, 48 grammatical strings were created, "phrases" of 3-5 "words" in length. Then, bearing in mind the grammar, 23 non-grammatical phrases of 3-5 words in length were also created. A native English speaker was asked to speak the 71 strings while being recorded, unaware which strings were grammatical and which were non-grammatical. Twenty-five of the grammatical strings were then compiled into a training tape, each string being separated by one-second intervals, and the entire list being played through twice resulting in approximately two minutes of recording. This is an appropriate quantity of time for an individual to implicitly learn a grammar, in keeping with other research in the field (Altmann, Dienes & Goode, 1995;

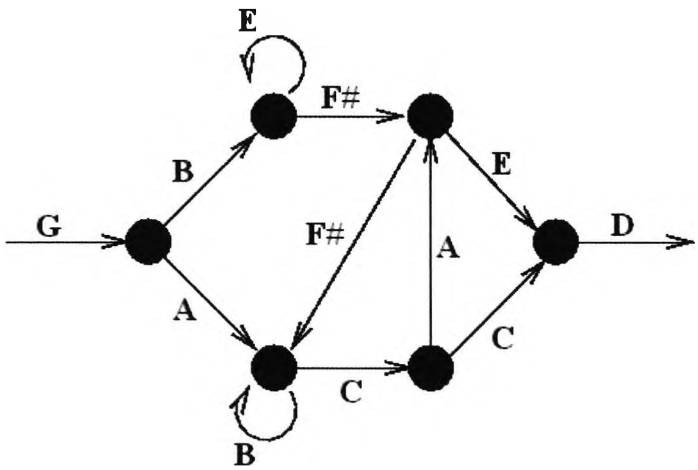
Gomez & Gerken, 1999; Marcus, Vijayan, Rao & Vishton, 1999; Saffran, 2003). The remaining 23 grammatical strings were then interspersed randomly with the 23 non-grammatical strings to create the test stimuli. An equal proportion of three, four and five string phrases were included in both training and test stimuli.

Figure VI:1: Finite-State Grammar using Spoken Monosyllabic Nonsense Words (e.g. Altmann, Dienes & Goode, 1995; Reber, 1989)



The musical stimuli were then made again using the finite-state grammar, copying the 46 grammatical and non-grammatical phrases used in the linguistic task, but substituting in musical notes as shown in Figure VI:2.

Figure VI:2: Finite-State Musical Grammar
(Adapted from Reber, 1989; Altmann, Dienes & Goode, 1995)



The presentation of the task was as follows. Participants were asked simply to listen to the training stimuli, with the instruction that they must concentrate on what they were hearing because they would be questioned about it later. After listening, an intervening task was undertaken for about five minutes in order to distract participants' and avoid rehearsal. Then the participants were asked to recall what they had heard before (either the music or the "funny talking" and were told that they would now hear phrases one at a time. Some of the phrases, they were told, they had heard before, and some they had not. The examiner stressed that she was not expecting that the participant would have memorized and be able to recall particular phrases. Instead they were told that they should repond on the basis of their perception of familiarity. Each individual test phrase was then played to the participant, and they were asked whether the phrase was familiar or not familiar. The participant's response was recorded by the examiner before proceeding to the next item.

Responses were scored as follows: a point was given each time the participant responded that the sequence was unfamiliar when it was agrammatical, and familiar when it was grammatical.

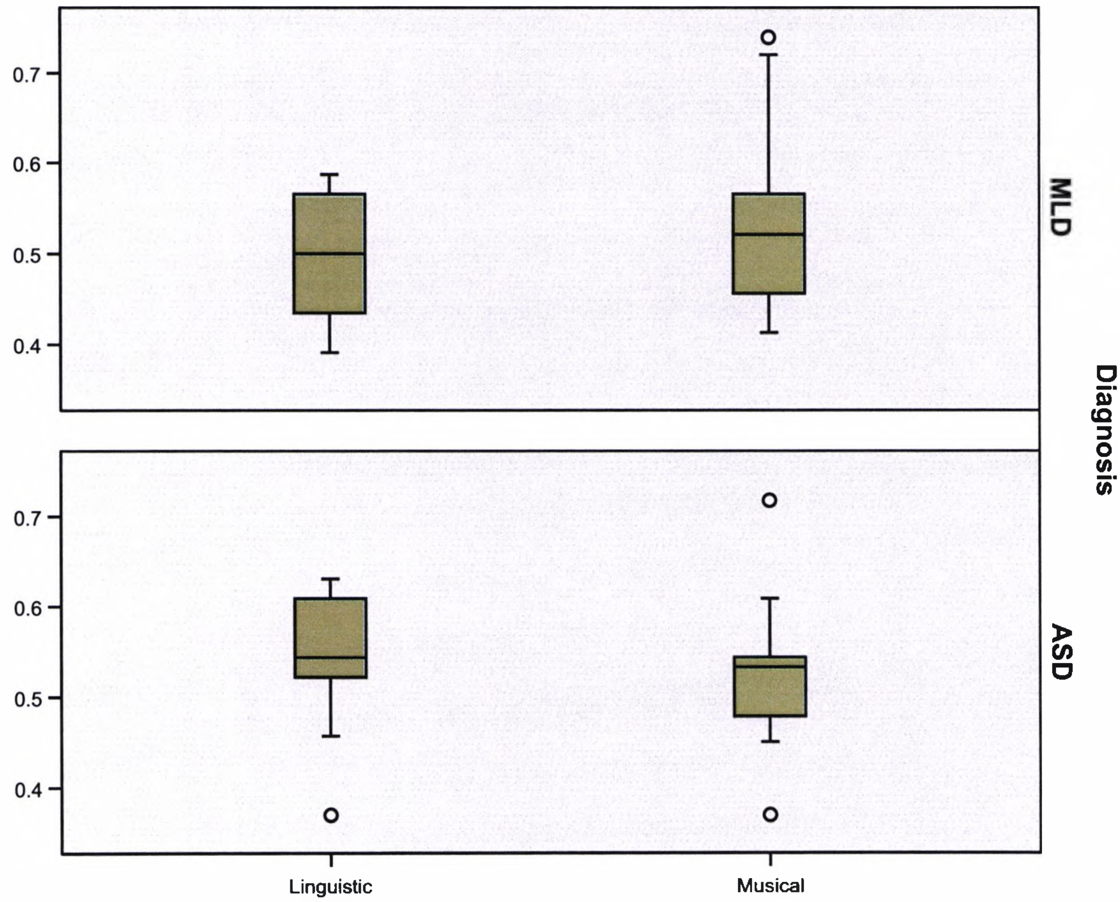
Order of presentation of the conditions (musical or linguistic) was initially counterbalanced. However, because some of the children were unable to complete the task, they were excluded from the final data analysis. Thus, of the participants who completed the whole task, 18 children received the linguistic task first while 15 children received the musical task first. As this could influence interpretation of the data, the performance across conditions was compared. This showed that there was no significant difference between scores for participants who completed the linguistic task first versus those who completed the musical task first, for either task. ($F=0.001$, $p=0.976$ for linguistic first; $F=0.389$, $p=0.537$ for musical first).

Participants

Participants were two girls and fifteen boys between the ages of twelve and sixteen (mean age=13.87) with a diagnosis of autism, and two girls and sixteen boys between the ages of thirteen and sixteen (mean age 14.11) without a diagnosis of autism, but with moderate learning difficulties (MLD). Two participants with autism were excluded from analysis because they were unable to perform the task as set. Thus the final sample of individuals with autism was two girls and thirteen boys between the ages of twelve and sixteen (mean age=13.86) Children were recruited from local schools with a special provision for pupils with autism spectrum disorders (ASD) or MLD, or dedicated specialist high schools throughout England. All children consented freely to participate in this experiment, and written permission was obtained from legal guardians in compliance with the ethical review board requirements of Goldsmiths College.

However, upon inspection, it was noted that several of the participants logged either very high or very low scores, thus the data was screened for outliers. Boxplots were made (Figure VI:3) which highlighted the outliers amongst both the MLD and ASD participants.

Figure VI:3: Outliers in Implicit Learning Task



As can be seen, two participants, one from each group performed at very high levels on the musical task. Two individuals from the ASD group performed at a very low level on the task. These four participants were thus removed from all further analysis.

Thus the final sample was matched in terms of age (F=2.901, p=0.100, ns) or non-verbal IQ (F=0.153, p=0.699, ns), however there is a highly significant difference between groups on a measure of verbal IQ, the BPVS (F=11.343, p=0.002) with the ASD group scoring worse than the MLD group. There is a non-significant difference between group scores on the TROG (F=2.247, p=0.147, ns). See Table VI:A for a summary of matching variables in this sample.

Table VI:A: Participants

Measure	Diagnosis	Mean	F	p
Age	ASD	13.45	2.901	0.100
	MLD	14.18		
Raven's Matrices	ASD	20.36	0.153	0.699
	MLD	22.65		
BPVS	ASD	53.45	11.343	0.002
	MLD	97.00		
TROG	ASD	12.18	2.247	0.147
	MLD	14.86		

Results

One point was awarded for each "correct" answer, and scores were then divided by the number of stimuli (the number of "questions") in order to produce a ratio. This ratio can then be compared against the chance ratio (0.50) in order to test whether participants succeeded on the task.

Means and standard deviations were calculated for linguistic and musical type stimuli, for both participants with ASD and those with MLD.

These statistics can be found in table VI:B, below and are also shown in Figure VI:4.

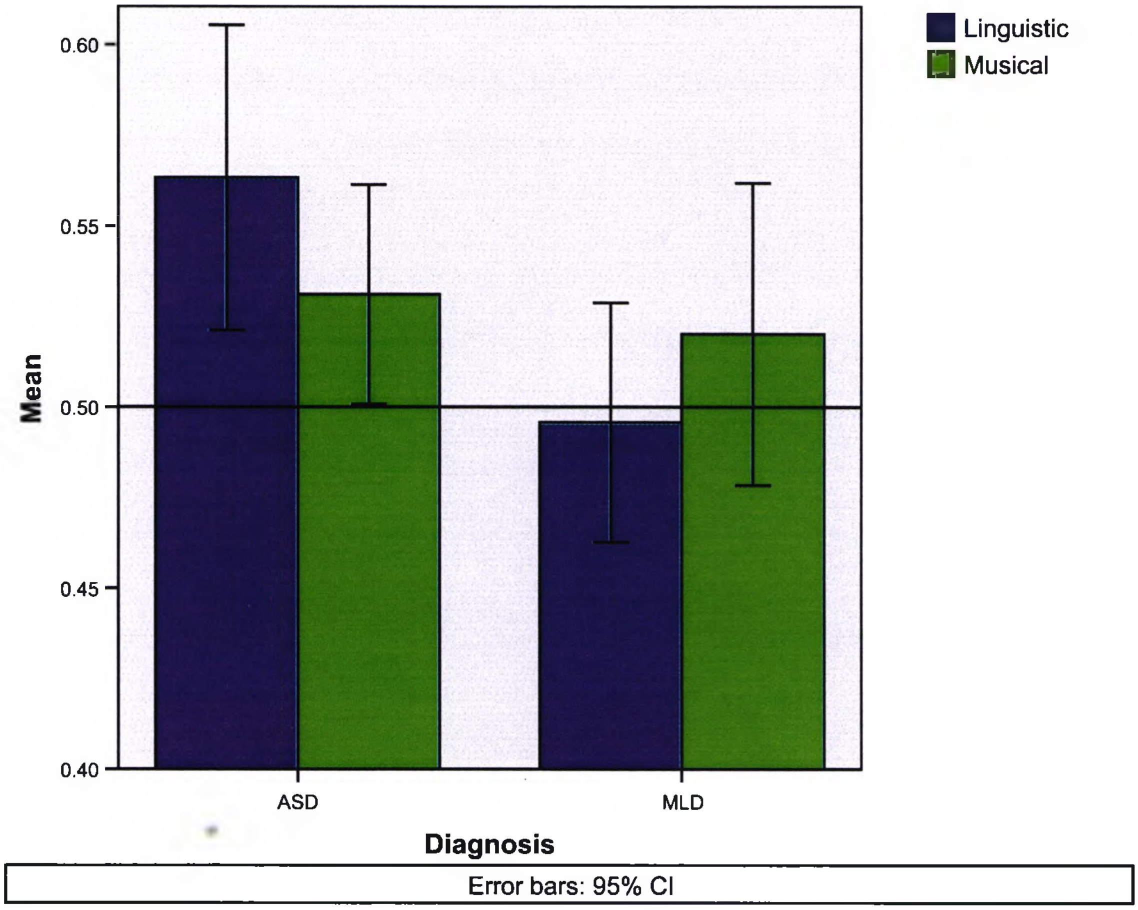
Table VI:B: Results of Implicit Learning Task

Participants	Linguistic Stimuli		Musical Stimuli	
	Mean	Standard Deviation	Mean	Standard Deviation
ASD	0.5632	0.06259	0.5310	0.04502
MLD	0.4957	0.06428	0.5210	0.08118

A planned repeated-measures analysis of variance (ANCOVA) with group (ASD/MLD) as the within group factor, diagnosis as the between-groups factor, and age, TROG scores, Raven's Matrices scores and BPVS scores as covariates, was then carried out on the data. This showed no significant main effect of stimulus type (F=0.010, p=0.920), and a significant main effect of diagnosis (F=7.938, p=0.011) with superior performance in the ASD group. There were no interaction effects.

However, performance on the task was low and this made the interpretation of the ANCOVA difficult to interpret. In order to explore absolute levels of performance on the task a one-sample t-test comparing the performance on the implicit learning task on linguistic and musical modalities with the chance score of 0.5, or 50% correct, showed that participants with ASD reliably scored better than chance on both modalities of the task (ASD: Linguistic: t=3.351, p=0.007; Musical: t=2.286, p=0.045), while participants with MLD did not score better than chance on either modality (MLD: Linguistic: t=-0.276, p=0.786; Musical: t=1.021, p=0.323). It did therefore appear that implicit learning in the autism group was superior to that of controls matched on age and non-verbal intelligence. See Figure VI:4 for graphical representation of the means and standard errors of musical and linguistic implicit learning tasks, by group.

Figure VI:4: Means for musical and linguistic implicit learning, by diagnostic group



Factors associated with task success and failure were then explored within groups.

Correlations carried out for the autism group are shown in Table VI:C below.

Table VI:C: Correlations of Background Data with Implicit Learning Task for ASD Participants

		Age	TROG	RavensRaw	BPVS	Linguistic	Musical
Age	Pearson Correlation	1	-.075	.039	.737(**)	.260	-.032
	Sig. (2-tailed)		.828	.909	.010	.440	.927
TROG	Pearson Correlation	-.075	1	.073	.023	.243	.058
	Sig. (2-tailed)	.828		.831	.947	.472	.866
RavensRaw	Pearson Correlation	.039	.073	1	.354	.118	-.158
	Sig. (2-tailed)	.909	.831		.286	.730	.642
BPVS	Pearson Correlation	.737(**)	.023	.354	1	.177	.365
	Sig. (2-tailed)	.010	.947	.286		.602	.269
Linguistic	Pearson Correlation	.260	.243	.118	.177	1	-.645(*)
	Sig. (2-tailed)	.440	.472	.730	.602		.032
Musical	Pearson Correlation	-.032	.058	-.158	.365	-.645(*)	1
	Sig. (2-tailed)	.927	.866	.642	.269	.032	

FigureFigure
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

In Table VI:C, it can be seen that, for the ASD participants, none of the background data correlate with the response on either the linguistic or musical implicit learning tasks. Age and IQ measures do not account for any of the variability in performance on the implicit learning task in the ASD group. The only significant correlation to be observed was between the two implicit learning conditions; the performance on the linguistic portion of the implicit learning task does correlate with performance on the musical portion. Most importantly, however, this correlation is quite strongly negative; that is, when performance on the linguistic portion of the task is high, performance on the musical portion of the task is low, and vice versa. This is an important finding that will be further explored in the Discussion.

Table VI:D: Correlations of Background Data with Implicit Learning Task for MLD Participants

		Age	TROG	RavensRaw	BPVS	Linguistic	Musical
Age	Pearson Correlation	1	-.305	-.251	-.190	-.209	.342
	Sig. (2-tailed)		.289	.331	.482	.420	.179
TROG	Pearson Correlation	-.305	1	.494	.862(**)	.166	-.163
	Sig. (2-tailed)	.289		.072	.000	.570	.578
RavensRaw	Pearson Correlation	-.251	.494	1	.640(**)	-.233	-.404
	Sig. (2-tailed)	.331	.072		.008	.368	.107
BPVS	Pearson Correlation	-.190	.862(**)	.640(**)	1	.093	-.473
	Sig. (2-tailed)	.482	.000	.008		.732	.064
Linguistic	Pearson Correlation	-.209	.166	-.233	.093	1	.242
	Sig. (2-tailed)	.420	.570	.368	.732		.350
Musical	Pearson Correlation	.342	-.163	-.404	-.473	.242	1
	Sig. (2-tailed)	.179	.578	.107	.064	.350	

** Correlation is significant at the 0.01 level (2-tailed).

In Table VI:D it can be seen that there were no correlations between background data and performance on the musical or implicit learning tasks for the MLD participants. In the case of the MLD participants, even performance on the implicit learning task in one modality did not correlate with performance in the other modality. This may be because the participants simply did not understand the task. However, this is surprising given that these participants were significantly more verbally able that the ASD participants who were able to perform above chance. Thus none of the factors tested here, such as age and IQ, can account for the variability in performance on the implicit learning task.

Children with ASD had marginally lower TROG-2 scores suggesting that their current level of receptive grammar was slightly poorer than that of controls. However, on the language as well as on the music condition participants with ASD outperformed MLD participants. This suggests that implicit learning is not implicated in language acquisition difficulties in autism and will be further discussed.

Discussion

The most important finding to emerge from this study was that the participants with ASD performed at significantly higher levels on the task than controls matched on non-verbal intelligence and chronological age. Furthermore, control participants, whose current levels of receptive vocabulary and grammar were higher than those with ASD, evidence poorer performance on a task testing mechanisms implicated in language acquisition. There is no evidence that there were any impairments in the ASD group on this task, suggesting that implicit learning is not implicated in their difficulties in acquiring language.

The robustness of implicit learning in the autism group was further evidenced by the fact that there is no difference in the performance of the ASD participants on the two modalities: music and language. It is reasonable to expect, since participants with autism appear to orient to and prefer musical over linguistic stimuli, and because of the deficit in language-learning, but not music-learning evidenced by ASD individuals, that these participants would perform better on the musical portion of the task than they would on the linguistic portion of the task. Some discussion has taken place in the literature about whether language and music are modular, that is, self-contained abilities represented distinctly in the brain, or whether they are subserved by shared mechanisms. The fact that ASD participants did as well in both modalities, and the significant correlations found with the ASD group between performance on both linguistic and musical portions of this task argue for the sharing of mechanisms between music and language in the brain. This conclusion, however, is forestalled by the significant *negative* correlation between the ASD group's performances on the linguistic and musical portions of the task. This finding directly challenges theories that postulate a shared mechanism of processing between linguistic and musical input. If, however, the modular view is correct, this would explain how, when one participant does well on the linguistic task, he correspondingly does poorly on the musical task. Given this negative correlation, it could be that *either* the linguistic module *or* the musical module can be developed in individuals with ASD, although more data would be required to draw any such conclusion. At least in these ASD participants, increased implicit grammar learning in the linguistic modality is associated with decreased implicit grammar learning in the musical modality to the exclusion of all else. Measures of IQ were not correlated; even measures of receptive grammar ability did not correlate with performance on this implicit learning task.

The concept of modularity is an important one in the study of autism. At least one report has linked modularity with reports of savant syndrome (Smith & Tsimpli, 1995), while a whole debate about the modularity of Theory of Mind abilities in individuals with ASD has been discussed in recent literature (see, for example, Baron-Cohen, 1998). It has been said that autism itself is the study of distinct modules of ability (Coltheart & Langdon, 1998). For this reason it is important to pursue this issue of modularity between language, which is a known topic of trouble, and music which is hypothesized to be a relative strength. If the modularity hypothesis is valid, then attempts to remediate language through music therapy may be misguided, however more hope for such cross-modal education may be due if the modularity hypothesis is not correct. Further work should more explicitly address the relevance of this issue on therapy.

Another important question to consider is why MLD participants performed worse than ASD participants on this task of implicit learning. This is especially interesting considering that their cognitive profile specifies no particular deficits that might result from a deficit in implicit learning (such as language delay). This difference between the performance of MLD and ASD participants may come down to speed-of-processing. Speed-of-processing is the cognitive mechanism that is proposed to cause many cases of undifferentiated mental retardation – it is an overall deficit in the cognitive processes at the root of mental retardation. In autism, however, speed-of-processing is not thought to be a problem (Anderson, 2008). Low-IQ in autism is thought to be due to cascade effects from problems in top-down processing. Thus these participants with MLD have a speed-of-processing deficit that may not allow them to learn (even implicitly) quickly enough for them to succeed on this fast-paced learning task. Participants with ASD, however, are not thought to be handicapped in this manner, and thus immediately have an advantage over the MLD participants when approaching this task.

The question must also be asked, why do individuals with ASD have trouble acquiring language but no problems acquiring musical grammars? It may be, as some research has found, that there is little problem for individuals with ASD to acquire linguistic grammar, but that the deficit in language learning lies elsewhere, in semantics or pragmatics (Tager-Flusberg, Paul &

Lord, 2005). Whatever the reason, it is clear that speed-of-processing, on its own, does not account for the rapid acquisition and cognition of musically-related stimuli as compared to linguistic stimuli.

Performance on these implicit learning tasks has been generally low. The atypically high performance of the two participants on the musical tasks indicates that these participants evidenced implicit learning at a much higher level than did their peers. The two participants with atypically low performance may also have been demonstrating increased implicit learning. Chance alone would predict performance of 50%, and any significant deviation from this indicates that there is some systematic deviation from "just guessing." In these cases, the under-performing participants may have known *something*, they were just unclear about what they knew or how to use it.

This is in contrast to the participants who scored more or less at chance. The MLD group did not score significantly differently from a fifty percent on this task of implicit learning in either modality. This indicates that these participants with moderate learning difficulties did not evidence implicit learning of the grammatical stimuli. It is unclear why the task proved too difficult for the MLD participants. As discussed above, learning difficulties do not generally impair implicit learning. Indeed moderate learning disabilities have not, in the past, posed a problem to implicit learning paradigms (Vinter & Detable, 2003). However, it is difficult to "equate" learning difficulties, and more importantly the task used here is not identical to that used in this particular literature. However, whilst this task was too difficult for the MLD participants, the ASD participants performed significantly above chance.

It is unclear whether this ability to quickly and efficiently implicitly learn about music is completely spared in individuals with autism. Only comparison with a chronological-age-matched typically developing control group could determine whether their ability is spared only relative to the learning impairment these participants with ASD have, or whether this ability is typical for their age. This comparison is the next step in this research. However, from the data presented here it can be concluded that these participants with ASD are endowed with at least as much facility with implicit learning in music as their mental age allows.

The choice of group against whom to compare the ASD group was crucially important in this experiment. The hypothesis in this task was two-tailed: participants with ASD could show a deficit in this language-learning task relative to controls because of impaired implicit learning mechanisms, or there could be a sparing of implicit learning (more specifically for the music condition) which would lead to participants with ASD performing well on this task. Because participants with ASD were reasonably hypothesized to perform poorly at least on the pseudo-language condition, it was not thought prudent to attempt to compare them with typically-developing age-matched controls, as this would disadvantage them in this experiment. Instead, a group matched for chronological age and non-verbal IQ was chosen as a more appropriate match for the ASD group. Having this group as a comparison would help to determine if the deficits posited to be shown by the ASD group were due to mental age, or whether they were ASD-specific deficits, perhaps due to specific cognitive deficits.

Results have now shown, however, that no implicit learning deficit is present in individuals with ASD on either the pseudo-language or musical conditions, and in fact that the MLD comparison group performed poorly on the task. Thus, for their mental age, the children with ASD performed quite well, evidencing at least sparing, or perhaps enhancement, on this task of artificial grammar learning. In order to determine whether it is a sparing or an enhancement, however, it will be necessary to compare the performance of these children with ASD with that of typically developing age-matched control children. The next step will be to carry out a full developmental study to ascertain the developmental trajectory in typical development and identify the factors that led to failure in the MLD participants, as well as identifying factors that led to success for the ASD participants.

Not all participants scored within the "normal" range for their group, and some had to be removed from analysis because of aberrant performance, both good and bad. In each of the ASD and MLD groups, one participant far outperformed the other participants on the musical task, and was a statistical outlier. Furthermore, in the ASD group one participant performed significantly worse on the musical task, and one participant performed significantly worse on the linguistic task such that they were also statistical outliers. These participants were removed from all further analysis, however it is worth taking a moment to consider their significance.

Implicit learning tasks are naturally difficult for participants to perform, because it seems as though there was no learning, and therefore the participants feel as though they are "just guessing". If participants were indeed "just guessing" one would expect performance to be at chance.

However, with these outliers especially, performance was most notably different from chance.

The atypically high performance of the two participants on the musical tasks indicates that these participants evidenced implicit learning at a much higher level than did their peers. The two participants with atypically low performance may also have been demonstrating increased implicit learning. Chance alone would predict performance of 50%, and any significant deviation from this indicates that there is some systematic deviation from "just guessing." In these cases, the under-performing participants showed systematic deficits with regards to implicit learning for artificial grammars.

Without further study it is difficult to say why these participants performed poorly on this task. Given the tendency for individuals with ASD to have temporal processing abnormalities, and the temporal binding aspect of this task, it is a good first hypothesis that these two participants might be showing such temporal processing abnormalities. However, neither participant showed temporal processing deficits on any other experiment in this study, including the explicitly temporal aspect of the chord processing task (chapter five), or either rhythm task (chapter four). In fact, their performance in all of the other tasks, and on background tasks such as BPVS and RPM is quite typical. Indeed, they even show evidence of having learned implicitly in the chord processing task, which requires use of the grammatical rules of Western Tonal Music. Thus it remains unclear why they are distinguished on this task.

The primary challenge in this task was not that implicit learning should be in evidence at all, but rather that it be in evidence quickly and employed immediately, without extra repetition or time for processing. The chord processing task (chapter five) already allows participants to demonstrate that they have, in their daily lives, made use of implicit learning and understood the rules of Western Tonal Music that dictate what is discordant. This implicit learning task is an online task which taxes the implicit learning mechanism. It could be that these participants have a deficit which handicaps their implicit learning mechanism, requiring increased training through exposure for a grammar to be implicitly learned. Further research will examine whether these are aberrant results, or whether a subgroup exists in autism which shows this implicit learning deficit.

Apart from these statistical outliers, the group with ASD performed statistically above chance on this task of implicit learning. These findings add further support to the growing literature suggesting that many or most aspects of music perception are spared in ASD. Language difficulties are characteristic in autism, however these likely reflect a weakened drive to communicate which is manifest in atypical early joint attention behaviours, and not an inability to implicitly learn the grammatical rules associated with language. Interest in music, and music cognition do not rest on early communicative behaviours, however, as music can be experienced and pursued independently, and this may be a major factor explaining these and related findings of unexpectedly good performance in studies of musical cognition in ASD.

Conclusion

In this test of statistical learning, participants with ASD demonstrated that they were able to learn implicitly about both musical and pseudolinguistic stimuli in a quick-paced task. Participants with MLD were not able to perform above chance on the same task. In ASD participants, significant correlations between scores on the linguistic and musical tasks indicate that these functions may share mechanisms in the brain, rather than being modular as some researchers have argued (Peretz, 2006).

This result furthers the search for musicality in individuals with ASD. It has been established in experiment five that participants with autism learn musical grammar implicitly, but this experiment shows that they implicitly learn that grammar quickly and efficiently and are able to use the implicit knowledge they have acquired. This is important for musicality; acquiring essential information about music naturally and effortlessly allows the infant (and eventually the young adult) to gain the facility with music to become an expert listener and from there to begin to learn more explicitly about music.

VII. Discussion: Reviewing the findings from the studies presented in the context of a hypothesised deficit in music in ASD.

Abstract:

Many historic and even some modern accounts of autism could be called "deficit" accounts, choosing to focus on the *dis*abilities of individuals with ASD rather than their abilities. However, recent evidence indicates that individuals with ASD can and do develop *abilities* in cognitive functioning that equal (sparings) or even rival (enhancements) those of their typically developing peers. This chapter evaluates the claim that music is one of these areas of special sparing or enhancement for many individuals with ASD, in concert with the evidence available in the literature, and the evidence of those studies presented in this thesis. Organized along the structure of Lerdahl and Jackendoff's (2006) structure of music, the evidence summarized here leads to one inevitable conclusion: the development of high levels of musicality does take place in individuals with ASD. Each piece of evidence, from the timbre and tempo studies, through the rhythm and finally implicit learning studies, is evaluated with reference to relevant theories of ASD in

the literature. Suggestions for future research are also discussed.

Autism is a disorder of development. As such, those developmental milestones that pass, often quietly and unnoticed in typically developing children, have a distinct tendency to pass *by* children with ASD. Children thus quickly become delayed, detained, set back and slowed down. It is difficult to see the strengths of a child amidst the disorder and delay.

In line with this bias, the original hypotheses presented here and elsewhere with respect to the cognitive functioning of individuals with ASD predicted many deficits, but findings have shown that in all areas of musical functioning here tested, as well as in previous studies testing pitch intervals chords and contours (Heaton, 2003; Mottron et al. 2003; Mottron, Peretz & Menard, 2000; Heaton, Pring & Hermelin, 1999) participants with autism did as well or better than matched comparison participants. Development in autism is very uneven; evidence showing an uneven cognitive profile including visuo-spatial peaks, memory peaks (and troughs) converges with this evidence indicating a sparing of musical processing in individuals with ASD.

Keeping in mind evidence from musical autistic savants, evidence from pitch and tonality perception research, and evidence from studies probing emotional understanding of music in individuals with autism, (Heaton, Hermelin & Pring, 1999; Heaton, Allen, Williams, Cummins & Happé, 2008; Allen, Hill & Heaton, in press) can it be concluded that there is no apparent reason that individuals with autism could not develop musical ability?

Musical ability is difficult to describe or quantify. However, it is a common assumption that everyone (save for members of some clinical populations such as congenital amusics, or the congenitally deaf) has the ability not only to listen to, but to make music. Indeed, there is even evidence that amusics and congenitally deaf people can gain some enjoyment from music (McDonald & Stewart, 2008; Nakata, Trehub, Mitani & Kanda, 2006). In many countries it is common practice that music tuition be provided in school and many children learn play the recorder, or xylophone, or sing in choirs. Basic musical ability might thus be defined as the ability to encode musical structures thereby allowing rudimentary manipulation of musical materials. This is synonymous with the term "musicality".

The Oxford Dictionary, defines 'musicality' as the state of being fond of, or skilled in, music. It is important the "being fond of music" is encompassed in definitions of musicality. Skills for music only normally develop when children have access to intruments and tuition, and sadly, this is not true for all children. If, as is often suggested, musicality is a universal musical trait, musicality must extend beyond those fortunate few who are formally trained as musicians.

In the literature, the word 'musicality' is used to refer to an aptitude, skill or *talent* for music (Hallam, 2006). Indeed, in the West, measurement of an individual's 'musicality' almost exclusively refers to their ability to make music (Hallam, 2006). The ability to make music already presupposes the ability to listen to music, and thus in the West, the bar for 'musicality,' is set rather high. Thus it is possible that an individual who can listen to and process music well enough is still thought to be unmusical (as is the situation with Temple Grandin). Musicality, in the context of this thesis, is defined as the ability to process and represent musical information. As previously suggested, musicality is believed to be a universal trait and this study seeks to question whether individuals with autism, like typical people, are pre-wired with 'musicality,' and possess the potential to develop musically, or whether, like Temple Grandin, they are innately unmusical.

Musicality

Lerdahl and Jackendoff (2006) have made a useful model of musical structure, based on both observations of music, and on neuropsychological science. They argue that music can be fundamentally split into two components: rhythm and pitch. Rhythm is further segmented into grouping structure and metrical structure, while pitch is further segmented into tonality and pitch space. On top of these deep structures, these authors place the musical surface, which incorporates timbre, duration, intensity and pitch. In this analysis, Lerdahl and Jackendoff (2006) are arguing for a structure of music not unlike the structure of language formulated by Chomsky (2003).

It is a useful model, and it is grounded in neuroscience. For example, pitch and rhythm are dissociable in the human brain, as discussed by Peretz (2006). They are also dissociable in music, as some percussive traditions produce music in which pitch plays a minimal or no role, while some chanting traditions produce music in which rhythm or metrical structure are inconsequential (Lerdahl & Jackendoff, 2006). Furthermore, thinking of timbre, for example, as a surface structure is useful, as it does not directly alter the form of the music (pitch or rhythm) or it's musical "meaning" (harmony, tonality etc.) but does contribute to the form and affective quality (melodies played on the oboe have a different affective quality to when they are played on the flute) of the heard music.

Given this model of music, then, what is known about music cognition in autism? Prior to this work, a great deal was known about pitch processing in individuals with ASD (Heaton, Davis & Happé, 2008; Heaton, 2005; Altgassen, Kliegel & Williams, 2005; Heaton, 2003; Bonnel, Mottron, Peretz, Trudel, Gallun & Bonnel, 2003; Mottron, Peretz, Belleville & Rouleau, 1999; Heaton, Pring & Hermelin, 1999; Heaton, Hermelin & Pring, 1998). This includes a significant body of work regarding tonality as well as work involving absolute and relative pitch abilities (Foxton et al. 2003; Mottron, Peretz & Ménard, 2000; Heaton, Williams, Cummins & Happé, 2008). The other deep structure, rhythm, had as yet been little studied in people with ASD, although some studies have touched on this this (O'Connell, 1974; Thaut, 1988; Jarvinen-Pasley, Wallace, Ramus, Happé & Heaton, 2008). However, these studies are very constrained; Thaut (1988) used a very small sample with uncontrolled simuli. Jarvinen-Pasley, et al. (2008) studied speech rhythm rather than musical rhythm, so prior to this study, little was known about the rhythmic abilities of individuals with autism. As for the surface structures, timbre, duration (tempo) and intensity have not been specifically studied in people with autism. The experiments described in this thesis sought to fill some of the gaps in the investigation of musical processing in individuals with ASD.

Surface Structures

Timbre

Timbre is often described as having the quality of a colour. In actuality, timbre is a complex quality of sound that includes attack, spectrum and ending of a sound, and functionally can be operationalized as the quality that makes two instruments, each playing the same note, still sound different to one another.

At the very least, it is certain that individuals with ASD differentiate timbre at some level. Auditory hypersensitivity is widely reported in autism and the findings suggest that individuals with these difficulties strongly differentiate between different qualities of sounds, for example, those made by refrigerators and vacuum cleaners. However, it is not clear to what extent this hypersensitivity might help or hinder processing of more subtle differences in timbre, such as that between the instruments in a Western orchestra. Without the ability to process timbre, a significant portion of the surface structure of music would be inaccessible. Whilst individuals with timbral deficits might retain the ability to appreciate deeper musical structure, for example in a Bach fugue, colouristic aspects would be lost and musical perception would be somewhat impoverished. Thus the experiment presented in chapter three sought to investigate the ability of people with ASD to process timbres.

The hypothesis with respect to this ability could reasonably go either way: hypersensitivity to sound in individuals with autism spectrum disorders could indicate an increased sensitivity to timbre, or a decreased sensitivity to timbre. There is no previous work regarding timbre and ASD. However, previous work on pitch perception and autism may be relevant. Some studies into pitch perception in autism (Heaton, Hermelin & Pring 1998; Heaton, 2003) revealed pitch processing and memory capabilities relative to typically developing controls, whereas other work has shown that superior processing of pitch is characteristic of only a sub-group of individuals (Heaton, Williams, Cummins & Happé, 2008). However, the finding that is of most importance when considering musical ability in autism, is that in none of the studies that have been carried out have children with autism showed inferior pitch processing in relation to control group performance. Thus is evident that participants with autism are sensitive to pitch, an important aspect deep structure. Timbre is, however, a surface structure, and it is unclear whether this pattern will hold.

In experiment one, which tested timbre perception, participants with ASD were not equally as good as age and intelligence matched children, but were in fact superior. The experiment tested participants' ability to detect whether both of a pair of melodies were timbrally similar or dissimilar (as determined by Grey's (1976) multidimensional scaling of timbres). Signal detection analysis, is a very stringent technique that enables the user to quantify the ability of the participants to discern between signal and noise. It takes into account all the different types of answers that can be given: hit, miss, false alarm and correct rejection. In this way, signal detection analysis enables the user to determine whether the participants had any response biases, and how sensitive participants were when detecting signal among the noise. When the data from experiment one was analysed using signal detection, the results showed that participants with ASD were more sensitive to timbral differences than their MLD peers. In addition to this generally enhanced sensitivity to timbral qualities, the participants with autism also demonstrated a different pattern of performance to their matched controls. On the same and unrelated conditions, participants with ASD performed indistinguishably from their MLD peers, however on the related condition, when the timbres were similar (according to Grey's (1977) multidimensional scaling of timbre) participants with autism were significantly more able to detect the differences between timbres than were MLD participants. This shows that the ASD participants were conducting a much more fine-grained auditory analysis of the heard material without ASD. Thus the findings from the study showed that with regards to the musical surface structure of timbre, individuals with ASD are more, not less sensitive, than their MLD peers.

This result is interesting with respect to the Enhanced Perceptual Functioning (EPF) model of Mottron et al. (2006). Timbre is a perceptual facet of the musical stimulus which is processed more ably by individuals with autism than by their age- and IQ-matched peers. Such a finding is consistent with EPF theory that predicts enhanced processing of lower-order perceptual aspects of stimuli in autism. However, researchers have also speculated that spectro-temporally complex stimuli will be harder for persons with ASD to process (Samson, Mottron, Jemel, Belin & Ciocca, 2006) and this is not supported by the findings from experiment one. Spectro-temporal complexity is a qualifier that certainly applies to timbre. It describes a stimulus that acts on many levels of spectra (be they light, or sound etc.) and which unfolds over time. Timbre, consists of the surrounding harmonics of the fundamental frequency so is a spectrally complex stimulus by definition. It is also temporally complex in encompassing several phases which unfold over a span of time: attack, spectrum and ending of a sound. According to the hypothesis of Samson et al. (2006), individuals with autism are better at processing spectro-temporally simple stimuli than spectro-temporally complex ones. This is thought to explain why certain hypersensitivities to perceptual phenomena (such as hyperacusis) characterise autism.

In experiment one reported in chapter three, participants with autism displayed no deficits in processing the spectro-temporally complex timbres presented. Indeed the signal detection analysis revealed increased sensitivity to these stimuli. Thus in this experiment, this Samson et al. (2006) hypothesis was not upheld.

Another popular theory of autism, the Enhanced Perceptual Functioning (EPF) theory, was upheld in the results of experiment 1, however. Just as results showed, EPF theory would predict that the ASD population would show sparing at the least (enhancement more likely) for perception of timbre. The modern incarnation of weak central coherence (WCC) theory, which predicts a cognitive style more focused on local elements (of which timbre is arguably one) also predicts this enhancement.

This investigation of timbre in children with autism is fundamental to our understanding of musicality in the ASD population. Timbre is affectively rich and may be one of the components of music that draw children with autism to listen. Anecdotal reports indicate that children with ASD are interested in and seek out objects, for example vacuum cleaners and motor engines, with variable timbres. Sometimes these objects become the focus of repetitive and restricted behaviours. However, whilst such behaviour serves no useful function, a similar tendency applied to musical instruments may be much more productive in enabling the child to learn about music. So what happens when the object in question is an orchestral instrument? Might the resulting obsession itself result in musical savant syndrome? In order to address this question, future studies should investigate the timbre perception and preferences of musical savants.

Tonality and Tempo

Tonality is the organization of all the tones in a piece (and all the harmonies) in relation to the tonic, or the key of the piece. This has been investigated in individuals with autism in one study testing the theory of Weak Central Coherence (Heaton, Williams, Cummins and Happe, 2007). However, the findings from this study failed to find a weak global or strong local bias in the autism group and therefore failed to support WCC. These researchers found that participants with autism were answering “globally” – that is, they were more likely to answer that a melody sounded “good” when its ending was consistent with the overall tonality of the piece, than when it was just consistent within the last two notes (a local “goodness”). This indicates that individuals with autism, like typically developing controls, can recognize the tonality of a piece of music.

The fourth experiment described in this thesis adopted a similar method to that carried out by Heaton, Williams, Cummins and Happé (2007), but extended it by manipulating the speed at which stimuli were presented.

In their (2007) study, Heaton, Williams, Cummins and Happé varied the tempo of some of their melodies. Half of the melodies were in a moderate tempo, and half in a slow tempo. In that study, the investigators found no differences in response of either group between the two tempi. In the experiment reported here, three tempi were used (crotchet = 70, 100, 130 respectively) in order to access a finer grained level of tempo processing. The hypothesis was therefore that participants with autism would, specifically, have difficulty processing melodies the slower they were presented.

The reason behind this hypothesis is two fold. Firstly, it has been hypothesized that individuals with autism suffer from what has been called a "social timing impairment", which is related to the function of clock genes in the brain (Nicholas, Rudrasingham, Nash, Kirov, Owen & Wimpory, 2007; Wimpory, Nicholas & Nash, 2002). It has been shown that clock genes are present with variants at a significant level in the autism population. These clock genes have been shown, in other mammals, to be responsible for sleep (which is anomalous in autism), memory (which is also known to be anomalous in autism) and timing (Nicholas et al,, 2007). Whilst this hypothesis rests largely on observed difficulties is social turn-taking in autism, it may nevertheless translate into tempo and timing impairments in musical processing.

Secondly, in much the same way as it becomes more difficult to remember words that are longer simply because they take up more time to pronounce (Baddeley, Thomson & Buchanan, 1975), so also melodies that take longer to present – because their tempo is slower – may be more difficult to process. WCC has been proposed to be characteristic of verbal-semantic processing in autism (Happé, 1999) but few researchers have considered the possibility that it may be the case that abnormalities in processing strings of auditory stimuli at variable speeds are the core deficit resulting in WCC with auditory information. Melodies presented slowly make increased demands on working memory and if this was a difficulty in autism, increasing difficulties would be observed when melodies were presented more slowly.

In experiment four, an effect of temporal manipulation was observed and it was in the direction hypothesized. However, there was no interaction effect and both the ASD and MLD groups performed at lower levels as the tempo of presentation was decreased. Whilst paradigms of the type used in experiment four have been widely tested with adults (e.g. Tillman, Janata, Birk & Barucha, 2008) little is known about how development-linked increases in working memory influence performance on chord priming tasks such as the one employed here. A future goal is to test typical children using this paradigm in order to determine whether findings of decreased performance at slow speeds is specifically characteristic of children with low IQ, or is characteristic of children as a whole. If it is the case that ASD and MLD children show specific deficits in processing fast music, this does not necessarily mean that musicality will be globally impaired. Indeed, recent findings (Allen, Hill & Heaton, 2008) show that a sub-group of adults with autism do not like slow music, but continue to enjoy music played at fast and moderate speeds.

It may also be the case that the clock gene abnormalities, which feature heavily in the social timing hypothesis of Wimpory, Nicholas and Nash (2002), and which are manifest in other species as abnormalities in timing, do not serve this function in humans. It may be that the deficits in timing and circadian rhythm are not translatable into deficits in voluntary uses of timing abilities. It may be that individuals with ASD do have an overall timing deficit, but that the MLD comparison group recruited here also have an overall timing deficit and that the two are indifferentiable. In order to tease apart these potential explanations, in the first instance ASD participants should be compared against age-matched typically developing controls, about whom we can be reasonably sure there is no cause to suspect a timing deficit. In this experiment, the participants with MLD showed an uncharacteristic motor impairment which may well be linked to an internal timing deficit.

Future inquiries into temporal processing in ASD would also do well to more explicitly test tempo perception, and to test it more finely. The present experiment used three tempi each thirty beats per minute quicker than the next. However, in future, it would be advisable to use a wider range of tempi. In addition, rather than varying tempo in the course of testing another hypothesis, future studies should be designed so that they explicitly test processing of temporal information in a musical context, and potentially in a non-musical (social?) context as well.

Despite its limitations, however, this experiment into tonality and tempo did replicate the finding that participants with ASD have an intact sense of tonality, relative to children matched on age and intelligence. Thus deficits in this area of musical functioning is clearly not characteristic of autism. Like their MLD comparison participants, they correctly identified globally and locally related items as "good", and globally and locally unrelated items as "bad". Targets that were related at one, but not both levels were more difficult to categorise, although it is important to note that the autistic participants did not make increased numbers of local choices as would have been predicted by WCC theory. Furthermore, this experiment challenged hypotheses based on proposed deficits in clock genes. Whilst temporal processing deficits may well be characteristic of some individuals with ASD, it did not appear that for musical stimuli, these clearly distinguish ASD and MLD. Sensitivity to timing in social interactions, and timing in the auditory domains of music and language will clearly recruit different neural mechanisms and much more research is required to disentangle these findings. Findings showing spared musical processing in individuals who show language and social timing disabilities may help inform future research.

Intensity

Beside tempo (duration) and timbre, intensity is the final surface structure mentioned by Lerdahl and Jackendoff (2006). Intensity refers to the perceived loudness of an auditory stimulus. It was not specifically tested in this study, but it has been long studied in individuals with autism, who present with certain hypersensitivities to sensory stimuli. Hyperacusis is one such hypersensitivity, and this refers to over-sensitivity to certain sounds and certain intensity levels. This propensity to over-react to loud sounds was noted by Kanner himself in the first report of autism (1943) and later led several researchers to hypothesize that there is a primary deficiency in the capacity of the individual with autism to modulate sound input (Kootz, Marinelli & Cohen, 1982; Lincoln, Courchesne, Harms & Allen, 1995). Indeed, in their (1995) study, Lincoln, Courchesne, Harms and Allen found a neurophysiological correlate of this deficiency when they studied event-related potentials known to be reactive, in the TD population, to intensity of auditory stimulus and found no such reactivity in the ASD sample they studied. Thus intensity is potentially a problem for individuals with ASD.

The design of these studies, which were fully portable for use in a child's school or home environment, precluded examining the perception of musical intensity in this study. What is interesting is that so many of the parents of children with ASD, but not the parents of MLD children, reported some hyper-sensitivity to certain sounds. This observation is in line with the reports of hyperacusis in the ASD population (Rosenhall, Nordin, Sandström, Ahlsén & Gillberg, 1999). Future studies, however should continue this line of research into perception of auditory intensity, perhaps focusing on the idiomatic use of intensity in music (e.g. to create suspense) and whether individuals with ASD are able to perceive and use this kind of information in online music processing. For this type of research, a sound-proof laboratory testing space would be required, along with equipment that can be finely calibrated to deliver specific intensities of sound.

Deep Structures

Rhythm

Currently very little is known bout how individuals with autism processing rhythm in music. Rhythm is one of the two deep structures of music outlined by (Jackendoff & Lerdahl, 2006) but to date, fewer than a handful of studies had examined rhythm perception or production in autism. O'Connor and Marshall (1974) noted that a young boy with autism initially had trouble playing piano pieces in rhythm, but that instruction remedied this problem. Thaut (1988) studied the musical improvisations of a group of children with autism, and recorded that they scored well on a measure of rhythm in comparison to their typically developing peers. Rhythmic entrainment as it relates to music therapy has become a topic of interest in recent years, with several investigators reporting positive results (Orr, Myles & Carlson, 1998; Rider & Eagle, 1986). And Jarvinen-Pasley, Wallace, Ramus, Happe and Heaton, (2008) investigated rhythm perception in speech stimuli in autism and found enhanced identification of specific rhythmic patterns in individuals with autism. Apart from these studies, which themselves only treat musical rhythm peripherally, the literature is largely silent on the subject of rhythmic abilities in autism.

Two studies investigating rhythm were described in chapter four, and neither showed deficits in ASD participants in comparison to controls. Indeed participants with ASD did, in fact, score higher than their MLD comparison participants on a measure of reproduction (clapping) of rhythms.

However, these results were quite difficult to interpret, as the two groups also showed a significant difference on a measure of motor dexterity,and one task (experiment two, rhythm reproduction) involved motor ability. Motor control problems have been described in ASD (Ming, Brimacombe & Wagner, 1997) and the pegboard task, a test of manual dexterity, was included in order to partial out such difficulties in the autism group. However, it was surprising that motor deficits were observed in the MLD participants, none of whom (in the final sample) were diagnosed with disorders associated with motor abnormalities.

Given this pattern of motor problems in the MLD group, it was unsurprising that the participants in the ASD group were better able to complete the rhythm clapping task than their MLD comparison group who possessed poorer motor skills. This entanglement makes these results difficult to interpret. When motor skills were parceled out of the equation, however, results indicated that participants with ASD still outperformed those with MLD on this task of rhythm reproduction. Future studies should more closely match for motor control abilities in order to further investigate this finding.

Peformance on experiment three, which tested rhythm perception and cognition was far less reliant on motor skills so provided a better comparison of the groups. In line with the social timing deficit hypothesis of autism (Wimpory, Nicholas & Nash, 2002), it was again hypothesized that individuals with autism would show impairment in rhythm perception and cognition. The analysis of the data from experiment three showed that participants with ASD performed identically on the rhythm perception and cognition task as compared to the MLD participants. Signal detection also shows that participants with ASD were more sensitive to the differences between same and different rhythms. Thus while the rhythm reproduction task is difficult to interpret due to group differences in manual dexterity, findings from the rhythm perception and cognition task can be taken as evidence that participants with ASD possess at least spared, if not enhanced cognition of rhythms relative to their MLD comparison participants.

Interestingly, however, the performance on the rhythm reproduction task did correlate highly with performance on the rhythm perception and cognition task but only for MLD participants. This suggests that different mechanisms might underpin performance on the two tasks in the two groups.

Deficits in musical processing in MLD groups have not previously been reported but these findings suggests that motor problems do not simply limit the ability to clap back rhythms but are strongly associated with deficits in perceiving rhythms as well. A further investigation of this should form the basis of a future research study. It will also be important to compare the ASD group performance across the two tasks, with groups of typically developing children matched on chronological rather than mental age. It may be the case that typical children will also show very different patterns of performance across the two tasks.

With respect to theories of cognition in ASD, these rhythm results are anomalous. There are two (related) theories of autism that deal with temporal sequence cognition, into which category these rhythm tasks fall. Both of these hypotheses (the social timing deficit hypothesis of Wimpory, Nash and Nicholas (2001) and the temporal binding deficit hypothesis of Brock, Brown, Boucher, and Rippon (2002)) predict poor timing sense (and thus, poor rhythm) in individuals with ASD.

Future directions with these experiments would include comparing the ASD sample, which has been shown to outperform an age- and IQ-matched control sample, to a typically developing control sample of average IQ. The present results allow for the interpretation that individuals with ASD are better than would be expected for their level of intellectual ability, on rhythm tasks (recall the "Talented" category in Treffert's (1989) classification).

It was noteworthy, in experiment two that when the children made errors in reproducing rhythms, it appeared that this was often because they could not recall the entire rhythm from start to finish. For example, when clapping back the most complex rhythms, participants would often get the beginning correct, evidencing a primacy effect described by Thorndike (1922). They also sometimes displayed a recency effect, by correctly clapping the end of the sequence, but forgetting the material in the middle of the long and complicated rhythmic patterns. This pattern is predicted by findings from memory research. Many studies into memory have been carried out with individuals with autism, although the findings have frequently produced contradictory results. Findings showing enhanced memory skills in savants with autism may then be surprising, although, interest in an area of activity is likely to motivate increased information processing and result in increased memory performance.

As music is one of those stimulus types that captures the attention of many people with ASD (Blackstock 1978; Lepisto et al. 2006; Kellerman, Fan & Gorman, 2005; Dawson et al., 1998) it is plausible to suggest that memory for musical materials will be spared or superior in autism. Indeed, Sloboda, Hermelin & O'Connor (1985) reported on a severely disabled autistic man who was able to memorize large pieces of music after only a few hearings. After careful manipulations, Sloboda et al. (1985) were able to show that the memory of this musical savant was confined to tonal music and did not transfer into atonal music (which has a structure with which he was much less familiar). This experiment was not designed to test such differences, but in future this potential strength in individuals with ASD, who do not have savant musical abilities, should be given careful consideration.

Pitch

The bulk of research into the musical abilities of individuals with ASD has looked at pitch processing abilities. This research has been reviewed elsewhere in this thesis (PG. 37-42), and will not be redescribed here. However, with regards to musicality, there are several issues that must be commented upon.

First, almost all studies into pitch or tonality processing in autism indicate that individuals with ASD have an ability commensurate with or surpassing that of control populations. Heightened auditory perception has been recruited to explain this difference, in the EPF model (Mottron, Dawson, Soulières, Hubert & Burack, 2006).

Indeed, in their (2005) review, Ross, Gore and Marks note that absolute pitch is not a unitary phenomenon. Instead, they propose that there are two types of AP: that which appears to be restricted to music, which they call Heightened Tonal Memory (HTM); and AP which transcends music and allows the possessor to encode the pitch of almost any auditory signal, which they call Ability to Perceptually Encode (APE). Recent evidence has indicated that individuals with autism are much more likely to be APE processors. Heaton, Davis and Happé (2008), and Järvinen-Pasley and Heaton (2007) both show that individuals with autism have excellent perception of pitch in complex speech sounds as well as in musical contexts.

Interestingly, the periodotopic pathway mechanism that is proposed by Ross, Gore and Marks (2005) to account for "true" AP (APE), and which individuals with autism are almost certainly using to process pitch, is also proposed to be the pathway that processes timbre. The findings from the timbre experiment were consistent with reports of increased sensitivity to pitch in autism and both can be explained by the enhanced perceptual functioning (EPF) model of autism, which proposes increased access to low-level representation of stimuli. Given these results with respect to pitch, the EPF model of autism should be investigated with the model of Ross, Gore and Marks (2005) in mind.

Another finding in the pitch literature is that enhanced pitch perception, observed in several studies of autistic participant, is unrelated to the degree of musical training the individuals has received (Heaton, 2003; Bonnel, Mottron, Peretz, Trudel, Gallun & Bonnel, 2003; Mottron, Peretz, Belleville & Rouleau, 1999; Heaton, Pring & Hermelin, 1999). For example, in a recent case study, highly trained musicians showed poorer pitch naming skills than an autistic man who had undergone very limited musical training (Heaton, Davis & Happe, 2008). Similar findings emerged from a study comparing autistic and control children. Here a sub-group of autistic children whose formal musical training was extremely limited performed at extremely high levels on pitch discrimination and memory tasks (Heaton et al., 2008). It was noted that this sub-group of children had poor language skills, and this may have been one reason for why they had not been provided with individual music lessons. The question thus arises as to what, if any, is the contribution of heightened pitch abilities to musicality. It is often implied that pitch processing ability is what "makes or breaks" musicality; having a "good ear" for pitch implies natural talent. It is certainly very common for children who are told that they cannot sing in tune, to lose heart and give up on musical activity. In those studies mentioned above, individuals with autism all had a good ear..

It is clear that individuals with autism possess an enhanced capacity to process pitch. It remains unclear why this enhanced ability exists particularly in individuals with autism, and what mechanisms can explain the existence of this ability. Recent findings suggest that AP is more prevalent in the congentially blind (Gaab, Schulze, Ozdemir & Schlaug,2006) and it appears that this is not a result of factors that predispose AP in typical populations. This parallels findings from autism (Heaton, Williams, Cummins & Happé, 2008) and should be further investigated. Future directions include a search for the mechanisms of AP ability in autism, possibly as they pertain to the work of Ross, Gore and Marks (2005), and the relevance this ability has on the development of musicality in individuals with autism, including savants. Further, it is important to continue to examine how children with autism who are not savants (and who do not have AP) can learn about and enjoy music. Future research in the area of pitch perception in autism should perhaps concentrate on the abilities of such children.

Learning Structures

Implicit Learning of Music

The final study presented here was a study probing the learning of musical relationships. Central to Jackendoff and Lerdahl (2006) model is the notion that the structure of music is much like the structure of language and research motivated by developmental theories has shown that the learning of musical structures is related to the learning of linguistic structures (Trehub & Trainor, 1993; Fitch, 2006; McMullen & Saffran, 2004). Thus experiment five investigated implicit learning for both pseudolanguage and for music in participants with ASD and MLD. Reber (1967) developed the artifical grammar learning (AGL) paradigm for use with language. He showed that if participants were exposed to language-like stimuli that were related to one another in a predictable and consistent way (grammatically), participants could unconsciously learn these associations and subsequently recognize other strings made from the same grammar. Since Reber's seminal work, several investigators have used this paradigm (with appropriate modifications) successfully on individuals of all ages and ability levels. Of note are those studies that looked at individuals both with and without learning difficulties (Gebauer & Mackintosh, 2007; Don, Schellenberg, Reber, DiGirolamo & Wang, 2003), and showed that implicit learning is not affected by general intellectual functioning. However, at least one study has found that implicit learning can be affected in developmental disorders characterised by deficits in mechanisms undepinning implicit learning (Vicari, Verucci & Carlesimo, 2007). Implicit learning for Language or music has not yet been tested in individuals with ASD (Although some research has been done into implicit learning in general in ASD (Barnes et al., 2008; Klinger, Klinger & Pohlig, 2007).

There have been investigations into implicit learning in modalities other than language in typical populations. These include studies using symbols (Manza & Reber, 1991) and, notably, music (Kuhn & Dienes, 2005; Tillmann & McAdams, 2004; Dienes & Longuet-Higgins, 2004; Bigand, Perruchet & Boyer, 1998). These investigations confirmed that implicit learning is a robust construct, and that the AGL paradigm is a useful one, as participants are able to evidence implicit learning of material in all of these modalities.

In experiment five the AGL paradigm was used with participants who were young (12-16 years old), learning disabled and with a diagnosis of autism. Furthermore, rather than presenting stimuli on a page for individual study (as in Reber's classic AGL studies), participants were asked to quietly attend to the stimuli as they were read or played aurally. This procedure was adopted because it better reflected the conditions under which individuals learn about music and language. Despite the difference between experiment five and the original AGL experiments, it was hypothesized that the robustness of the paradigm would allow implicit learning to be evidenced even under these circumstances.

With regards to performance on the task itself, it was hypothesized that participants with ASD might not perform as well on the linguistic condition of the task as on the musical condition. Delays in language acquisition in early life are part of the diagnostic criteria for autism, and problems in communication are diagnostic of all disorders on the autism spectrum. Indeed, whilst our autism and MLD group were matched on age and non-verbal intelligence, language scores were significantly lower for the autism group, suggesting that their current language level was inferior to that of the participants with MLD. Whilst much is to be learned about the language delay in autism, recent work shows that the strongest predictor of language acquisition in autism is the extent that joint attention develops in the first years of life (Luyster, Kadlec, Carter & Tager-Flusberg, 2008). However, even in typical development joint attention develops well after the period that highly focused attention to people is observed. Widely used diagnostic measures, like the ADOS (Lord et al., 1989) directly test the extent that children suspected of having autism make eye contact and orientate to the clinician, so reduced attention to others is a common feature of autism.

This hypothesis, provides the rationale for the prediction that participants with autism may not attend to the pseudo-linguistic stimuli presented in this experiment and thus will show poorer implicit learning for linguistic stimuli. However, as has been noted, they do attend to musical stimuli, and it is hypothesised that they will perform at higher levels on the music condition of the experiment. This hypothesis presumes modularity between linguistic and musical abilities in the brain as well as functional modularity. However, this assumption was testable as correlations carried out on the data from the two experimental conditions could provide information on whether performance levels were similar.

The findings from the experiment supported the second hypothesis. Participants with ASD performed at higher levels on both conditions than MLD participants who appeared to show a global deficit in implicit learning. The finding showing implicit grammatical learning for both musical and pseudolinguistic stimuli in the ASD group, was contrary to the initial hypothesis. This result demonstrates that children with ASD can learn the grammar of language just as easily (or, in fact, more easily) than age- and IQ-matched controls. However, language scores were poorer for the ASD than the MLD group and this suggests that difficulties in acquiring language in autism do not result from deficits in implicit learning mechanisms.

The significant correlation across conditions, observed in the ASD group, raise questions about the domain-specificity account of grammar learning. There has long been a debate raging over whether shared brain mechanisms subserve music and language or whether each is modular (for a recent discussion see Patel, 2003). Whilst the correlation observed in the autism group better supports a shared mechanisms explanation, the study should be replicated with typical children who show normal onset of language. In this experiment it was shown that the learning of a grammar in one modality was correlated with the learning of a grammar in the other modality. This indicates that there is some sharing of the load for learning.

Whilst this study has shown that implicit learning is intact for both music and for language in participants with ASD, it is somewhat puzzling that functioning in the musical modality appears to be preserved, while language does not. There does not appear to be an association between the present language level of children with ASD (which, it is assumed, is a product of learning) and their implicit learning mechanisms. This indicates that the deficit in language not because of language acquisition mechanisms (i.e. Implicit learning) but because of social and communicative impairments. Music, on the other hand, appears not to be affected by social and communicative impairments in the slightest in these participants, as they do not impact at all on music learning.

However only functional imaging work or EEG could truly address this question of shared mechanisms. Studies in which individuals with autism are presented with music and speech stimuli whilst undergoing scanning are currently being planned.

But why did the MLD participants find it so difficult to complete this task? It should be noted that such an AGL paradigm has been used with individuals who are lower-functioning than those in the present MLD sample.

However, this task was different to those studies in that participants were asked to listen to the stimuli (rather than study them on a page) and were asked to listen to the exemplars then again to judge them. This was not a self-directed task, but rather attention is required throughout the experiment (or the participant will miss something). These factors may have contributed to the surprisingly low score of the MLD participants on this task.

An interesting point is that the implicit learning scores for these MLD participants were not correlated with any of the background data collected, not even with their scores on language tasks (TROG and BPVS). This may indicate that the task does not provide an analogue for the conditions under which handicapped children learn language future studies should address this question.

In future, it is further suggested that older (adult) and higher-functioning (typical NVIQ) individuals with autism should be tested with this paradigm. As matched control groups would not then include individuals with learning difficulties, The paradigm appears to be fairly robust, in that it has been successfully used in past studies and the participants with ASD performed at levels that were significantly above chance (i.e. Barnes et al., 2008; Klinger, Lee, Bush, Klinger & Crump, 2001). This experiment has extended these findings to AGL paradigms with both musical and linguistic stimuli, upon which participants with ASD are unimpaired.

This question of implicit learning for music and language is essential to the study of musical behaviour in autism. Musical savants, if not diagnosed with autism (i.e. Leslie Lemke, a musical savant with cerebral palsy in: Treffert, 1989) often present with autism or autistic-like traits, and so neatly show the dissociation that can be present between abilities in language and abilities in musical performance. It is imperative that it is determined how these savants – and indeed every musical person with autism – can so ably learn the musical grammars of their culture, and yet apparently fail to learn with the same fluency the linguistic grammars of their culture.

Or, indeed, it may be that grammar – linguistic or musical – is not the problem for individuals with autism. Some researchers have suggested that the language problem in autism is not one of grammar or syntax (or, for that matter, vocabulary) but rather is pragmatic in nature (Bartak, Rutter, & Cox, 1975; Pierce & Bartolucci, 1977; Tager-Flusberg, 1981). In this case, it may be that individuals with autism have greater facility for music than speech because of the lack of pragmatic elements in musi and the deeply social nature of language learning. Still, none of these conclusions can be reached without further research.

Of further interest with regards to this question is the new formulation of the Enhanced Perceptual Function model of Mottron and colleagues (as formulated in Mottron, 2008). In this new model, Mottron identifies four hypotheses about how individuals with autism develop musicality, or indeed any savant talent. Hypothesis one states that individuals with autism demonstrate enhanced pattern recognition (which is no longer limited to lower-level stimuli, but includes higher-level aspects of stimuli) which results in acquisition of human codes. Codes are those aspects of culture that are characterized by their temporo-spatial redundancy, composed of repeated units where patterns are phenomenally similar across occurrences. Enhanced perception encourages orientation towards human codes and enables integration of rules into coherent wholes. It is quite like implicit learning. This hypothesis goes toward explaining, in the first instance, why savant skills are so often apparent in a small circumscribed set of ability areas (i.e. music, art/drawing, calendar calculating etc.) Secondly, this hypothesis provides some insights into the findings from experiments four and five showing a correlation across music and language conditions in the autism group. Both language and music represent examples of domains characteristics by what Mottron refers to as human "codes."

The second hypothesis proposed by Mottron (2008) states that enhanced perception makes detection of within-code and between-code isomorphisms easier. This is significant because isomorphisms are those aspects of codes that repeat, making them easier to understand and to apply to wider situations. Learning the regularities and patterns, the grammars, the isomorphisms of music is what a musician does for the first long years of their training, which enables them to manipulate the individual units of music to create new and known pieces of music.

The findings from the ASD group, suggesting shared mechanisms for processing both linguistic and musical grammars, are relevant with respect to this hypothesis. Between-code isomorphisms are those regularities that apply to more than one domain; in this case, those regularities that are common to both linguistic and to musical grammars can actually be detected more easily (and presumably used more easily) by individuals with ASD. This might account for the fact that individuals with ASD were better able to succeed on this task, as they may have garnered more, useful information in training trials.

The third hypothesis specifically bears upon the performance of individuals with savant syndrome, but is relevant for this discussion into musicality in ASD. The hypothesis states that savant operations make extended use of pattern completion through a process of redintegration. Redintegration (Schweickert, 1993) is the process whereby one completes a cue identification to part of a larger configuration previously encountered. This means that expertise, or frequency of experience improves redintegration because greater frequency of experience creates a larger database of configurations previously encountered. This experiment does not deal with individuals who have expertise with regards to playing music – the participants with ASD had not undergone formal training or possess savant skills, but development of musicality does require expertise with regards to listening. This means that one would expect these participants with autism to use redintegration when dealing with heard auditory information including music.

Finally, in his fourth hypothesis, Mottron (2008) makes clear that pattern completion is not a *purely* local process, but occurs, in parallel, at the level of the entire isomorphism. This last hypothesis is a caveat to those who are familiar with earlier versions of the Enhanced Perceptual Functions theory, as this was based largely on low-level perception. In the original formulation of EPF (Mottron & Burack, 2001), pitch perception (for example) was considered an area of enhanced functioning of the auditory perception domain. A small, circumscribed area of the auditory cortex, and an early-level (A2 or A3) area of cortex, was presumed to control this function. However, findings from studies of typical populations implicate association cortex in AP

(Zatorre, 2003) and once higher-order "association" cortex is evoked, EPF theory fell out of its depth and its explanatory power disappeared. In this new (Mottron, 2008) elaboration of EPF, pitch perception is still well accounted-for, but the involvement of the association cortex can be accommodated. It is within these higher-order brain areas and at much higher-order perceptual and cognitive levels that the detection of within-code and between-code isomorphisms can take place, and the redintegration occurs. This is in line with current neurobiological theorizing: The further up each perceptual pathway one travels (be that up the visual, auditory, somatosensory or other) more and more connections (neural processes) are recruited. It is these connections that allow for processing of complex stimuli such as musical and linguistic grammar (Tettamanti & Weniger, 2006), and this is precisely what Mottron (2008) is getting at when he makes his fourth hypothesis.

Mottron (2008) concludes by summing up his main tenet: enhanced (not purely local) perception, combined with the expertise effect may account for the increased incidence of savant syndrome among persons with autism. However, let us push that further and propose that enhanced perception (which is evident in pitch, and now, timbre processing (Chapter 3) in the musical domain combined with listening expertise may account for the increased learning of musical materials in individuals with autism. Absent from the EPF theory is any account of affective experiences that motivate engagement and whilst the findings in this thesis are broadly consistent with EPF theory, the question of why children with autism find music salient is not addressed.

The final point to be raised about this experiment 5 is the "problem" of the inverse correlation between performance on the linguistic portion of this task and that on the musical portion of the task by the ASD participants. The better they did on the musical portion, the worse they did on the linguistic portion. It is difficult to explain this finding on the basis of the assumed shared mechanisms underlying both language and music, if they are subserved by the same mechanisms in the brain, then we would expect for performance in one to predict performance in the other. However the introduction of the concept of modularity allows an easy explanation. If music and language are subserved by entirely separate and autonomous functions in the brain, then there is no need for indices of music and language cognition to correlate. This argument is not so easy as it may appear; the modularity (or lack thereof) of language and music has been discussed for decades with excellent arguments on either side. One finding of an inverse correlation is not sufficient to "prove" the case, although this finding does support the idea of modularity.

It is possible, however, that this finding points to an enduring difference between individuals with ASD and those with typical development. It is clear that music cognition is either spared or enhanced in individuals with ASD, while language is a particular difficulty for many of them. It may be that in individuals with ASD, music and language are modular, the function of the one (language) being affected without the correlation of the other. Just because this is true of ASD individuals, however, it is not necessarily true of the TD population. This atypical modularity might even be a defining feature of ASD. One could envision children with ASD that do not use the rules and strategies that they use to understand music to understand other auditory input, such as spoken language. Without the transfer of these grouping strategies, implicitly learned grammars, and relationships between elements, this modular child with ASD would have extra difficulty decoding the puzzle of spoken language during infancy, thus language acquisition would be delayed (if it developed at all). Meanwhile, the TD child whose amodular language/music brain gets "smarter" whenever any auditory input is given, allowing it to make leaps and bounds ahead of its ASD peers. The evidence presented here does not, again, "prove" such a hypothesis, but it is consistent. What this finding shows is that children with ASD complete this task in such a way that modularity for music and language in their brain is implied. It remains unclear what further conclusions can be drawn.

Musicality and ASD

In all of the experiments presented here (and most of those in the literature reviewed here) participants with ASD show at least spared, if not enhanced ability to process musical structures, relative to carefully chosen comparison groups. If "musicality" is defined by the individual possessing "neural hardware" important for music processing, the individuals with ASD certainly fit this criterion. According to the findings from the studies presented in the thesis, there should be no reason why the individuals with ASD should not be able to hear, process and understand music. And indeed this fits in with the self-report of many higher-functioning individuals with autism. The study by Allen, Hill and Heaton (in press), that adults with autism listen to music for much the same reasons as typical people and report similar experiences in response to music as typical people.

Limitations of the study: Future Directions

There are some limitations of the experiments in this study that must be addressed, and that also lead into the directions this work can take in the future.

To begin with, a general comment that can apply to any (or all) of the experiments in this study. Because the hypothesis was that participants with autism would likely have deficits with respect to their performance on many of these tasks, it was decided at the outset that the use of a typically developing control group would be disadvantageous to the participants with ASD. The decision was made to match participants with ASD to a control group on the basis of non-verbal IQ scores (scores on Raven's Matrices). Even then, the control participants had higher VIQ scores (on BPVS) and there was a concern that the ASD participants might be handicapped by this. However, participants with ASD were not handicapped relative to this control group (which turned out to be populated with individuals with moderate (but non-specific) learning disabilities), in fact they performed similar to or better than the MLD control group on every task.

With this knowledge, it is time to compare the musical abilities of children with ASD with their unimpaired typically developing (but age-matched) peers, and future work is already planned in this regard.

The other generally applicable comment to be made concerns the breadth – and depth – of this study. Because so little work had previously investigated these areas of musical functioning in children with ASD, the decision was made at the conception of this study to focus on the breadth of topics to be studied. A perfectly adequate study could have treated any one of the five topics treated here – timbre, rhythm, tonality, tempo and implicit learning – and "drilled down" to their depths using ever more probing experiments. However, this "breadth"-style study allowed for a maximum of topics to be covered superficially in order to identify where the best prospects are with regards to abilities in ASD. Now, knowing that all five abilities studied are either preserved or particularly strong in ASD, more specific follow-up studies can be planned to probe the precise peaks and troughs associated with each ability. Some possible ideas for such studies follow in the remainder of this section.

The Timbre experiment (experiment 1, Chapter 3) rests on the assumption that Gray's multidimensional scaling of timbre is a useful one; so far, this appears to be the case, as differences were found between the slightly related and the unrelated conditions of the experiment. However it would be interesting to begin with a timbre space that is psychometrically tested and yet unfamiliar to participants, such as that of Samson, Zatorre, and Ramsay, (1997). Use of this multidimensional scaling of artificial timbres would help to further disentangle the fine timbre-perception abilities of individuals with ASD and their comparison populations. Whenver one attempts to digitize the sound of an instrument, the question must be asked: how faithfully did the sound on the computer approximate the sound of the instrument. In this study, it would appear that the approximation was decent, but a purer study would use timbres that have no real-world correlate, but which have been psychometrically scaled straight from the digital output.

Further, as an effect was found in this study of the ASD participants perceiving timbres more finely, future studies should ensure that the capacity is there to look at even more finely grained differences between timbres, in a way that is not possible with orchestral instruments. Further investigation of artificial timbres (such as those produced by engines, often fixated upon by youngsters with ASD) would also be an important development of research.

Qualitative studies that probe the experience of timbre as described by individuals with and without ASD might be useful in order to identify and define any peculiarities of timbre processing (i.e. synaesthesia) that may enhance (or hinder) timbre processing in this special population. Epidemiological studies investigating the incidence and prevalence of hyperacusis (about which knowledge exists that it is present in the ASD population, but precious little else) and to what extent hyperacusis is attributable to peculiarities in processing timbre would be useful.

The first of the rhythm studies (Experiment 2, Chapter 4) was modeled on a classic study by Levitin and Bellugi (1998) who engaged children with William's Syndrome in a clapping call-response game. While it was chosen for its strengths, this paradigm has inherent flaws. First, it is a social task, a game in which participants are asked to collude. This was a great boon for those with Williams Syndrome who are often described as "hypersocial" (Jones et al., 2000) however this may be less so for a participant with ASD who has social problems. Secondly, since the experimenter is clapping each of the rhythms to the participant in question, each stimulus changes every time it is presented; no person can produce rhythms as truly as a machine.

Finally, the introduction of independent raters into this paradigm introduced variability in scoring procedures.

These limitations do not render the study invalid; conditions were the same for both samples of participants, and a true difference was seen. However now that a naturalistic task has been done and has shown that there is an effect present to be studied, future work should focus on tightening up this methodology. Perhaps using a less naturalistic task, such as listening to a computer-generated rhythm and pressing on a key pad in response, would allow for more direct comparison between exemplar and response. This manipulation would make the rhythm reproduction task less like making music and more like a psychology experiment, and perhaps higher-functioning participants would be required for such an experiment, but it would definitely allow access to a deeper understanding of this topic than can be got at with the more rudimentary experiment used here.

The rhythm perception task (Experiment 3, Chapter 4) did not suffer the limitations of the reproduction task, however that issue of motor dysfunction plagued both experiments. Future studies of rhythmic abilities in ASD should ensure a careful matching of participants on the basis of motor control.

The stimuli for both rhythm studies were relatively simple, often repeating sequences with few (or no) rests. Future plans include an examination of how complex the understanding of rhythm is in children with ASD. As the stimuli become more complex, the analysis can also become more fine-grained. The study of rhythm in typically developing populations is one of complex coupling systems of oscillators, and it would be interesting to investigate some of these dynamics in young people with ASD. A project examining interlimb coupling would be especially appropriate given the apraxia known to plague some individuals with ASD. In addition, research looking into the timekeeping abilities of individuals with ASD (for example, tapping a finger at a constant rate) would be instructive about any problems with the internal "clock."

Chapter five dealt with two different aspects of music cognition, and I will address them here separately. Firstly it investigated the understanding of tonal centre in individuals with autism, and demonstrated that these individuals did have a good understanding of the relationships between elements within the tonal space. This experiment was an elegant analogue of a verbal task, however it suffers a few limitations in the translation into music. First, it is somewhat unclear what constitutes a "global" or a "local" level in music. This limitation has been discussed in that chapter, and will not be reiterated here except to say that future tasks should keep in mind this limitation in their design. Second, it is also somewhat unclear what constitutes "goodness" and "badness" in music given that all tones relate to one degree or another in tonal space. The definition that was relied upon here spoke of close relation around a "tonal centre" as defining of "goodness", and this appeared to be agreed upon by the participants as they successfully carried out this task with this understanding. However, future tasks may want to probe how explicit is the understanding of tonality of these participants with ASD. Can they verbalize what makes two notes sound close together or far apart? And how do their verbal characterizations match music theory? It seems clear that there is an implicit understanding of tonality, but to what extent is this accessible to the person with ASD?

The second area of music cognition investigated in Experiment 4 (chapter 5) was tempo. The idea here was to discover whether different tempi (and thus by association, different processing times) would affect music cognition. As this manipulation was exploratory, the range of tempi used was not large, however. Future investigations should use a much wider range of tempi with wider variation between them – 30bpm (as used in this study) is apparently too small a range to detect any small group differences that might exist. It may well be that speed-of-processing is not an issue and that musical tempi are processed well by individuals with ASD. In this case, it will be interesting to discover how tempo is used by individuals with ASD in their processing of music. Does it "mean" the same thing to individuals with ASD when the music speeds up or slows down? Is there a preferred tempo of individuals with ASD, and how does that compare to the preferred tempo of typically developing individuals?

The final experiment (5, chapter 6) dealt with that structure that underlies all of this music cognition: implicit learning. It is likely that there would be no music cognition if implicit learning did not exist. Humans learn so much about musical structure just by being in the vicinity of a musical source, it is difficult to imagine the individual who does not soak it up like a sponge. In this experiment, individuals with ASD demonstrated that they can and do soak up musical knowledge and indeed that they do so better than their MLD peers. It is a limitation of the study that the MLD comparison group did not show evidence of implicit learning. This indicates that the task might have been too difficult to expect our participants to be able to accomplish it. In order to investigate the difference in implicit learning between the two groups (ASD and control) it would be best if both groups could perform the task successfully, thus future work should focus on piloting the stimuli carefully with the desired control group and adjusting difficulty accordingly. It is also worth noting that there are already known relationships between notes in a scale, so that if “C” is the tonic, E would be the major third, and G the major fifth (the two most related notes), while D, F, B and A would be less related to the tonic. The relationships between the nodes in the steady-state grammar are artificially specified and would have to be learned by the participant in addition to those “natural” rules of musical grammar. It is unknown what effect these two separate relationships have on this task, and it may be advisable to introduce a new manipulation – such as using notes in a whole-tone (atonal) scale instead of those in the standard diatonic scale – in future studies.

The results of experiment 5 (specifically that inversere correlation between performance on linguistic and musical versions of the implicit learning task in the ASD sample) allude to the age-old debate into the modularity of music and language. The implications of this finding have been discussed elsewhere in this chapter (pp. 222, 229) and in this work (pp 171-190), however it should not be forgotten when discussing the limitations and future directions of this study. This argument is of the utmost importance to modern understanding of the function of the human brain. While many arguments have been made on each side – with this result adding another to the side of modularity – there is still no clear conclusion. Considering the hypothesis put forward earlier in this chapter regarding modularity for ASD participants but not necessarily TD or MLD participants, it is clear that there is a need for further work in the field of autism research to engage this question.

The study of the musical abilities of individuals with autism spectrum disorders has just begun; some of the studies presented here have investigated several areas of music cognition for the first time in the ASD population. Because it is clear that individuals with ASD process some aspects of music differently (i.e. timbre), virtually any study that has been useful with typically developing participants may also be applied to the study of music cognition in ASD. Perusal of one of the latest copies of the academic journals, Music Perception offers some possibilities: one article examines "Automated Analysis of Body Movement in Emotionally Expressive Piano Performances" (Castellano, Mortillaro, Camurri, Volpe & Scherer, 2008) and yet another examines the same issue, but with respect to the conductor (Wöllner & Auhagen, 2008). It would be interesting to investigate the role of bodily (and facial) expression in both the autistic musician and in the listener/watcher. Since social expression and communication is a difficulty for individuals with ASD, it might be expected that musical expression and communication would suffer similarly, however this is purely conjecture. And since the emotional component of biological motion is less understood by individuals with ASD than TD individuals (Hubert et al., 2007), we might expect there to be some differences in the ASD participant's perception of a performer's expression which an eye-tracking study might illuminate. Another paper examines "Eye Movements and Music Reading: Where Do We Look Next?" (Madell & Hebert, 2008) which would lend itself to another fascinating eye-tracking study of how autistic musicians read music. Yet a third article deals with "Infants' Memory for Isolated Tones and the Effects of Interference" (Plantinga & Trainor, 2008) and leads one to wonder whether the infant with ASD is processing and learning musical material differently from the TD infant. This would be more difficult to test, given that the study would have to be prospective and diagnosis could only be retrospective, but it would not be impossible. And this is only one volume of one journal. There are literally hundreds (perhaps more) of questions that could be asked about music perception and cogntition in autism spectrum disorders. It is hoped that this study begins to point to some of these fascinating future directions.

Conclusions

It is clear that some individuals with autism spectrum disorders develop extraordinary musical talent. Music is one of the few domains in which the autism-linked savant syndrome develops. However, it has long been hypothesized that for music, the ASD population is dichotomous, that is individuals are or aren't savants. This is a surprising assumption and one that seem unlikely to be made about populations of individuals without ASD. Other researchers, most notably Huron (2001) have speculated that people with autism are unmotivated by, insensitive to,uninterested in and even untalented for music. However, an increasing body of work questions this assumption. This work has focused on absolute pitch perception (Heaton, Davis & Happé, 2008; Heaton, 2005; Altgassen, Kliegel & Williams, 2005; Heaton, 2003; Bonnel, Mottron, Peretz, Trudel, Gallun & Bonnel, 2003; Mottron, Peretz, Belleville & Rouleau, 1999; Heaton, Pring & Hermelin, 1999;

Heaton, Hermelin & Pring, 1998) and recognition of tonality (Foxton et al. 2003; Mottron, Peretz & Ménard, 2000; Heaton, Williams, Cummins & Happé, 2008) in individuals with autism, or by looking at the autistic perception of affect in music (Heaton, Hermelin & Pring, 1999; Heaton, Allen, Williams, Cummins & Happé, 2008; Allen & Heaton, In press).

This thesis presents work in which the musical abilities of typical, non-savant children with ASD are indubitable. In all of the experiments presented, the children with ASD outperformed or at least equaled the performance levels of age- and IQ-matched controls. In line with a popular perceptual theory of autism, Enhanced Perceptual Functioning (EPF) (Mottron & Burack 2001), individuals with ASD performed well on the timbre discrimination task, showing increased sensitivity to fine-grained differences in timbre relative to controls. Participants with ASD also showed spared performance on a test of reproduction of rhythm, and heightened performance on a test of receptive rhythm relative to controls. While the reproduction task might be related to motor control abilities (which were surprisingly better in the ASD group), this was not the case for the rhythm perception and increased sensitivity to rhythmic differences was observed in the ASD group. Both the ASD and their age- and IQ-matched controls had difficulty processing the global aspects of music when the tempo was slower, but their performance on that tempo task did not differ. Finally, whilst the task demands of the implicit learning task where high, participants with ASD performed significantly better than did their control group, evidencing the potential to implicitly learn musical structures. These findings, together with those from earlier studies outlined in this thesis lead to the conclusion that people with ASD develop musicality despite their "disorder".

There are still questions to be investigated, however. Future directions should aim at fleshing out the full nature of musical ability in individuals with ASD. Too often it is assumed that their difficulties in social communicative domains will generalise to all areas of life, and this may result in a lack of opportunities for developing musical skills. Research might then focus of evaluating the musical potential of moderate-to-high functioning individual with ASD and ascertaining how best they might develop this. Comparisons of trained individuals with autism and those called musical savants, would serve to enrich our understanding of music cognition in atypical populations.
The investigations into musicality in autism that have been presented here are necessarily preliminary as the work has never been attempted before and should be replicated in the future. As such, there are many manipulations that can be performed to further probe the spared and enhanced areas of musical functioning in moderate -to-high functioning individuals with ASD. By investigating younger or older participants, for example, the pattern of musical development can be elucidated. In addition, since it is now clear that ASD participants show spared or enhanced abilities relative to age- and IQ-matched controls, future work is planned to compare ASD participants to chronological age-matched controls without intellectual impairment. This comparison will allow us to fully determine the degree to which music cognition is spared in ASD.

This progression is reminiscent of the "levels" of savant syndrome described by Treffert (1989). Treffert described three levels of savant syndrome: splinter skills, talent, and prodigy. Those with splinter skills have an ability that is amazing relative to that individual's own developmental level. Talented savants are those whose ability is commensurate with others their own chronological age. Prodigious savants are those whose ability would be startling if it were present in anyone. In this set of experiments, the level described by the "splinter skills" category was tested, and participants with autism were found to have splinter skills in listening to music relative to their age- and IQ-matched controls. The next step is to compare participants with ASD with age-matched typically developing controls.

The experiments presented in this thesis are the first explicit attempts to investigate tempo, rhythm, timbre and implicit learning in ASD, and as such they are not exhaustive investigations. It is anticipated that the results found here will inspire future explorations. For example, now that it is known that participants with ASD can more finely discriminate synthetic musical timbres, it would be interesting to explore different kinds of timbres, such as live instruments, completely synthetic unfamiliar sounds such as "backwards" timbres, or the timbres of voices with speech sounds. Similarly, the results of the tempo task can be further explored by investigating slower and slower tempi, as well as very fast tempi. There are many manipulations one could make to the investigation of rhythm production and reception in ASD. Sorting out the contribution of motor deficits to the production, but especially to the reception of rhythm is an essential next step. Further, more fine-tuned investigation of rhythm production, for example in traditional tapping tasks, would help to elucidate whether the same strategy is being used by the ASD brain to effect the motor program required for sophisticated rhythm production. The implicit learning paradigm would most benefit from replication with an age-matched comparison sample. However, further investigations could include implicit learning for other modalities (such as visual symbols) (Zizak & Reber, 2006) and implicit learning for other musical structures, such as the atonal scale. This would be interesting in terms of Mottron's (2008) elaboration of EPF theory because abstract symbols and the atonal scale are modalities or "codes" in which participants would not be experienced. Thus implicit learning in these areas would not be influenced by prior grammar learning experiences. These manipulations, and others, will help to flesh out the finer nature of musicality in individuals with ASD.

It has often been asked, since nearly all of the circumstances are perfect for the average individual with autism to develop high musicality, why are there not a noticeable wealth of autistic musicians? Certainly, there are musical savants, but these are fairly rare. If they are so musical, why does the average person with autism not develop musical talent? There are many possible answers to this question, some of which are to do with the politics of education for the learning disabled, others of which touch upon the cognitive challenges that any one individual with autism faces that disadvantage that particular individual from pursuing music, and still others of which are down to the personality and motivations of any particular individual with autism. The fact may be that there is a wealth of autistic musicians. One study has found that autistic-like traits are found in abundance in members of orchestras (Langendorfer, 2008).

The question of musical ability in ASD has not been solved yet, however. Much more research needs to be done to elucidate the precise nature of musicality and musical talent in ASD. It is not only deficits and impairments that are to be found in the behaviour of individuals with autism spectrum disorders, but also extraordinary ability. Individuals with ASD definitely have this elusive quality "musicality", as this experiment has demonstrated.

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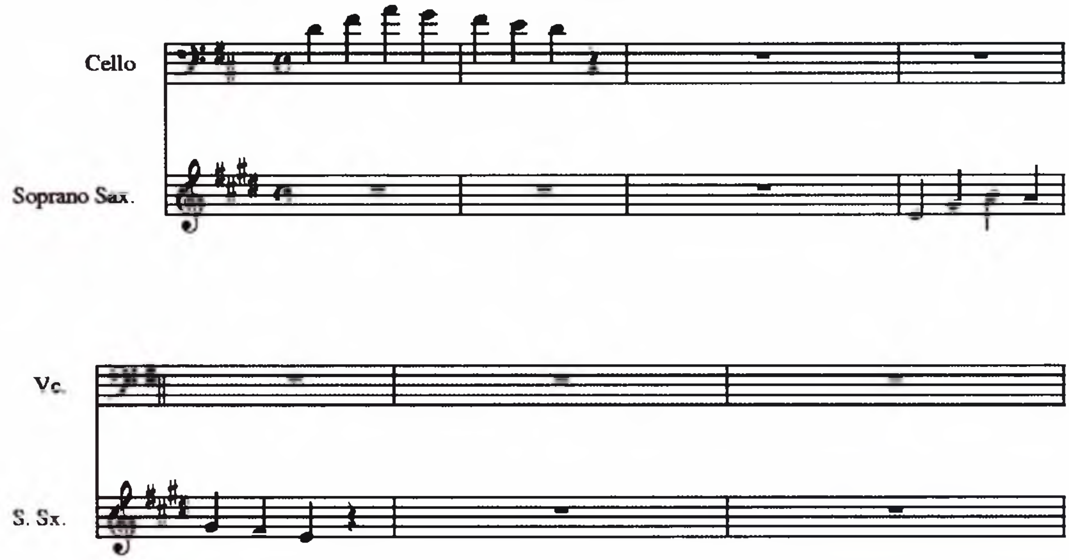
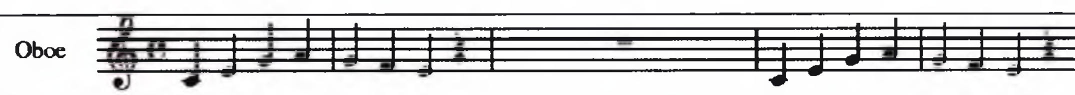
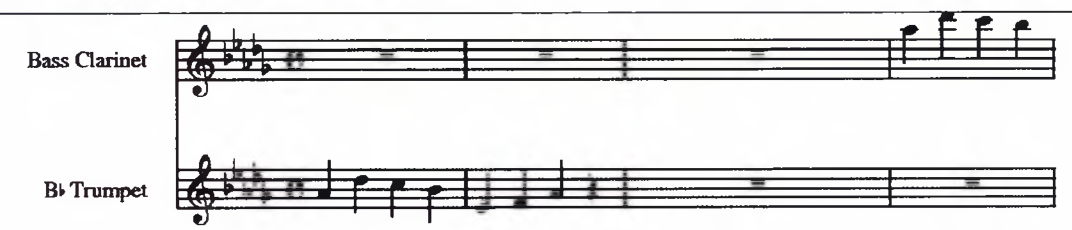
Appendix 1

Stimuli for Experiment 1 (Chapter 3), Timbre

1	
2	
3	

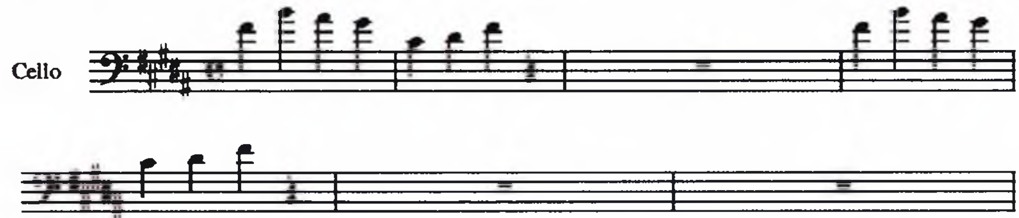
4	Bassoon Tenor Sax. Bsn. T. Sx.
5	Bassoon B♭ Trumpet Bsn. B♭ Tpt.
6	Oboe
7	Bass Clarinet B♭ Trumpet

8	 Horn in F Trombone Hn. Tbn.
9	 B♭ Trumpet
10	 Oboe Bassoon
11	 Horn in F B♭ Trumpet Hn. B♭ Tpt.

12

13

14



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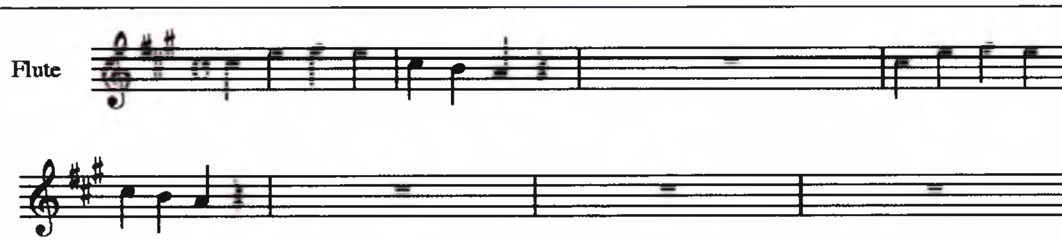
16

17



18


Bass Clarinet
Tenor Sax.
B.Cl.
T. Sx.

19


Trombone

20


Trombone

21


Flute
Cello
Fl.
Vc.

<table>
<tr><td>22</td><td>
</td></tr>
<tr><td>23</td><td>
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<tr><td>24</td><td>
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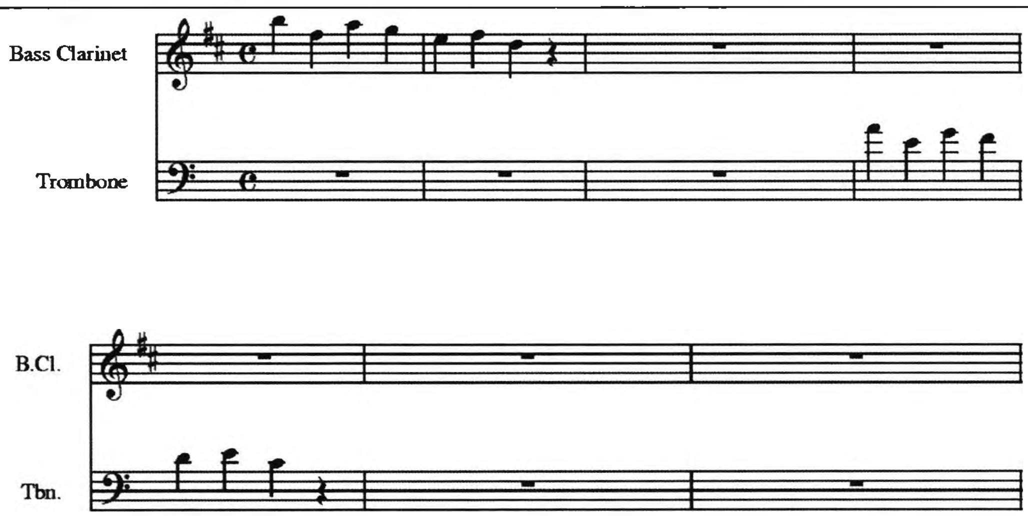
25	Flute Cello Fl. Vc.
26	Bassoon
27	Bass Clarinet Trombone B.Cl. Tbn.
28	B♭ Trumpet

29	 Bassoon Horn in F Bsn. Hn.
30	 B♭ Trumpet Tenor Sax. B♭ Tpt. T. Sx.
31	 Bass Clarinet
32	 Horn in F

33


Oboe
Trombone
Ob.
Tbn.

34


Bass Clarinet
Tenor Sax.
B.Cl.
T. Sx.

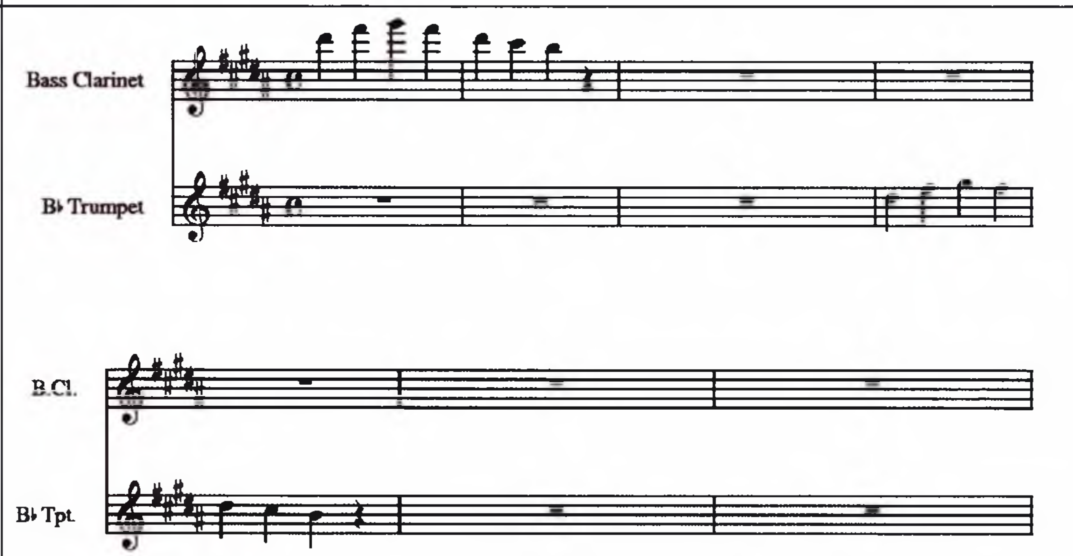
35


Bass Clarinet
Bassoon
B.Cl.
Bsn.

36


Soprano Sax.

37


Bass Clarinet
B♭ Trumpet
B.Cl.
B♭ Tpt.

38

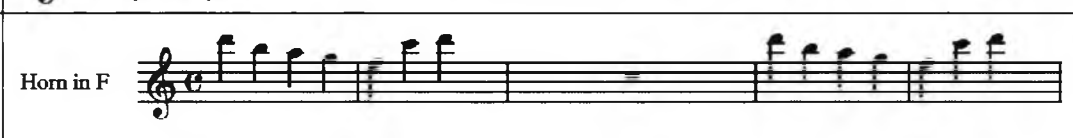
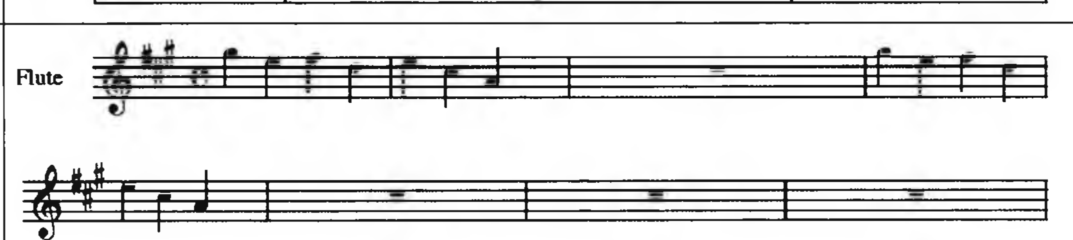

Flute
Soprano Sax.
Fl.
S. Sx.

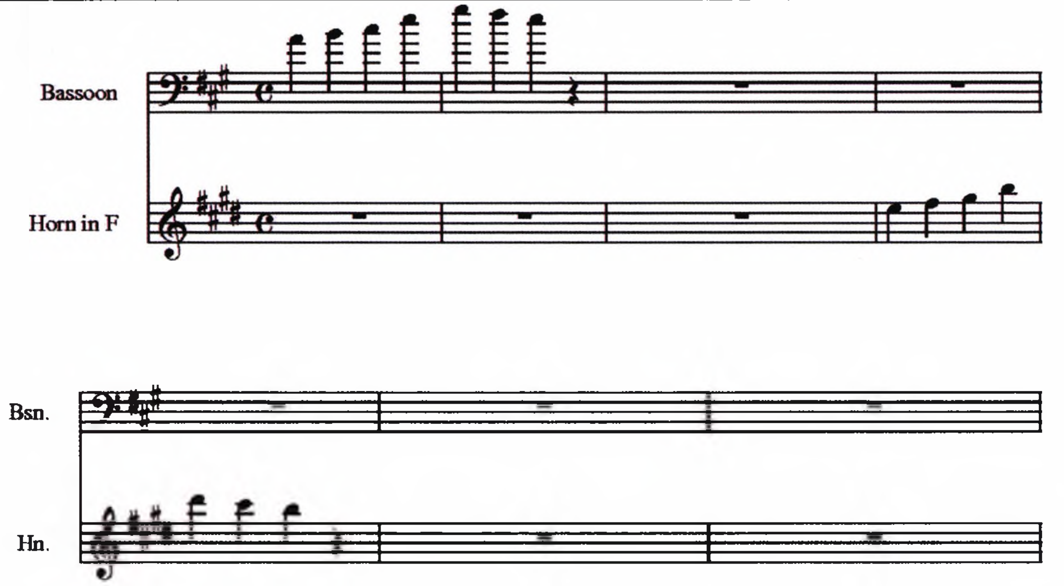
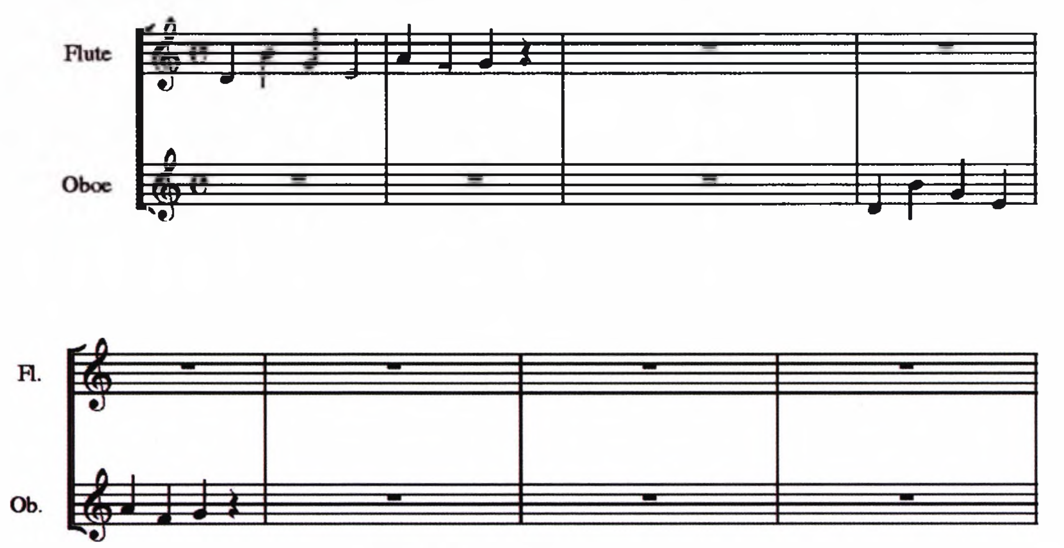
39

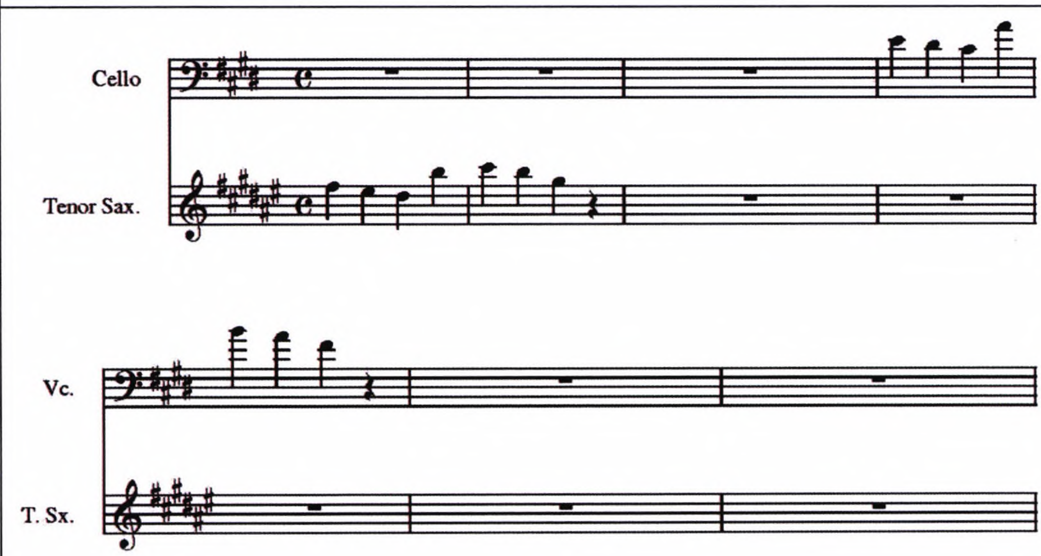

Oboe

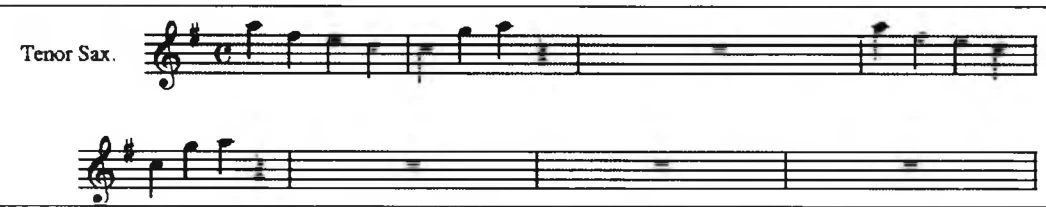
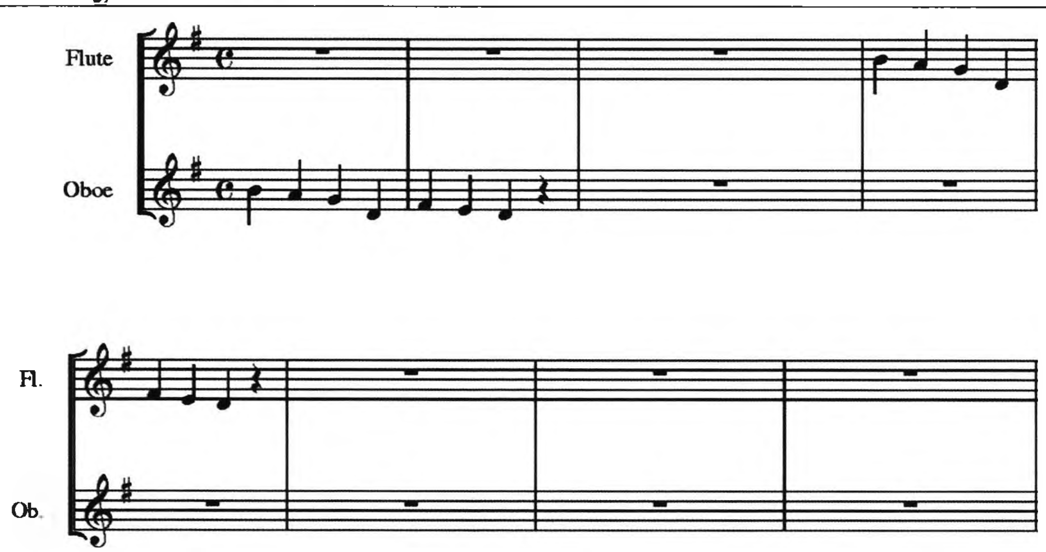
40


Tenor Sax.

41	
42	
43	
44	
45	
46	

47	Bassoon Horn in F Bsn. Hn.
48	Flute Oboe Fl. Ob.
49	Trombone

50	Soprano Sax. Tenor Sax. S. Sx. T. Sx.
51	Bassoon B♭ Trumpet Bsn. B♭ Tpt.
52	Cello Tenor Sax. Vc. T. Sx.

53	
54	
55	
56	
57	
58	

59	Horn in F Soprano Sax. Hn. S. Sx.
60	Horn in F Trombone Hn. Tbn.

Appendix 2

Rhythms used in Rhythm Reproduction task (Experiment 2, Chapter 4).

1) Percussion

2) Percussion

3) Percussion

4) Percussion

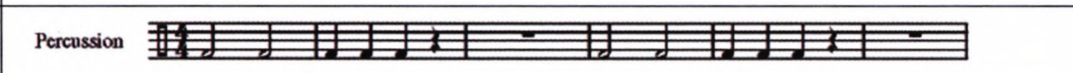
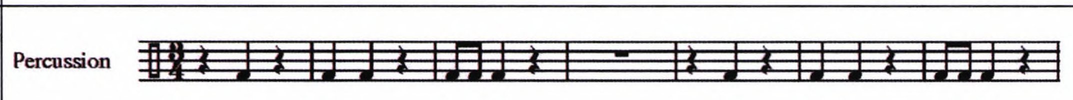
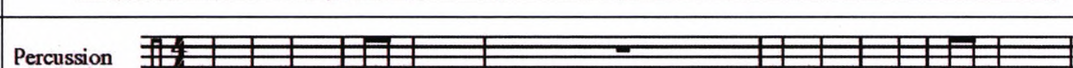
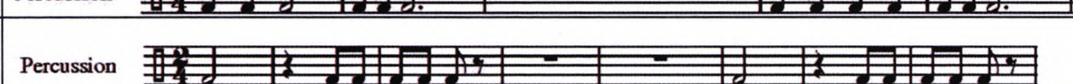
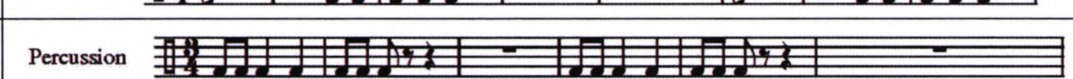
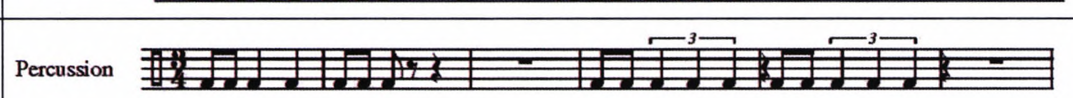
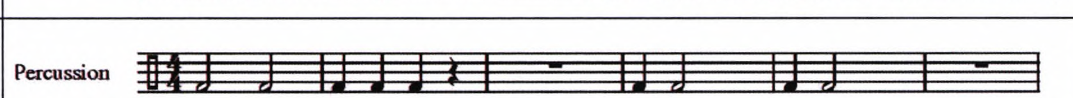
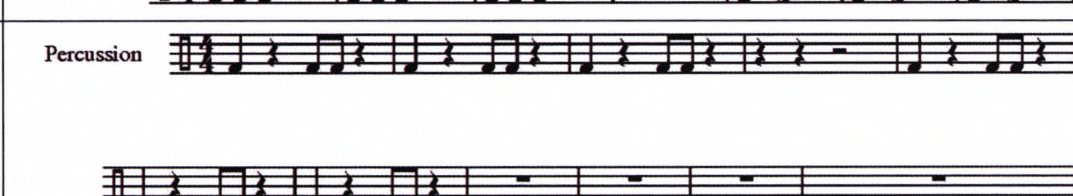
5) Percussion

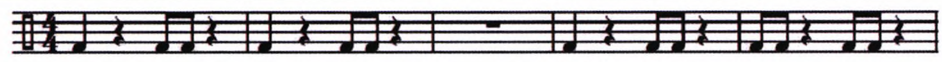
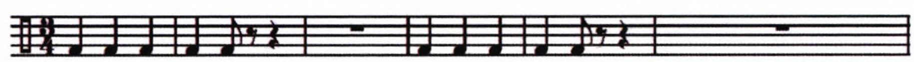
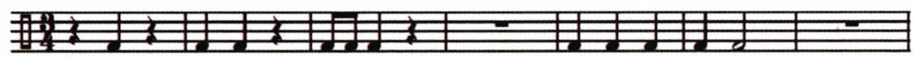
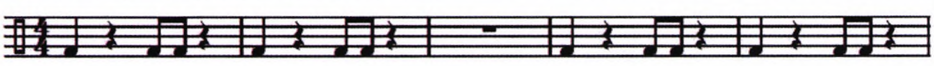
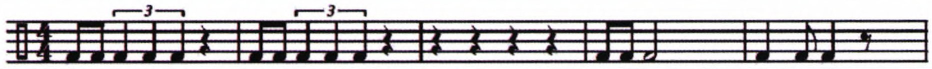
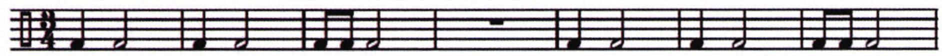
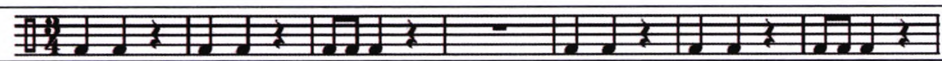
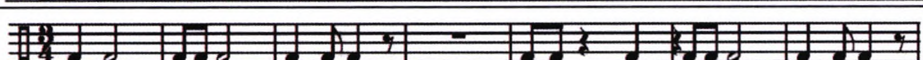
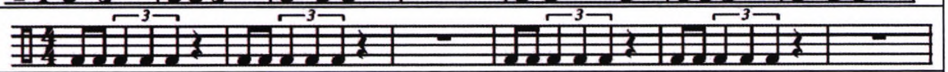
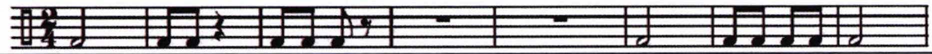
6) Percussion

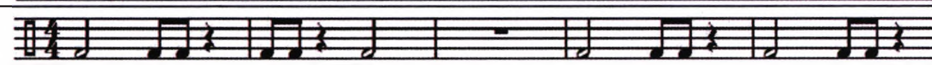
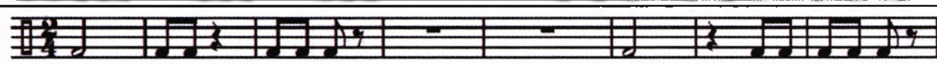
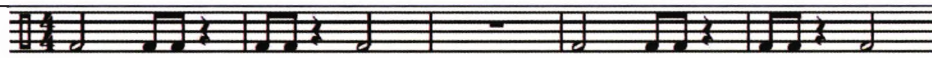
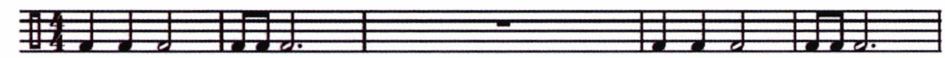
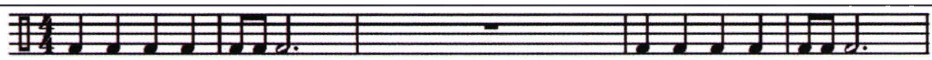
7) Percussion

Appendix 3

Rhythmic sequences for Rhythm Discrimination task (Experiment 3, Chapter 4), in order presented.

1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	

16	Percussion 
17	Percussion 
18	Percussion 
19	Percussion 
20	Percussion 
21	Percussion 
22	Percussion 
23	Percussion 
24	Percussion 
25	Percussion 
26	Percussion 
27	Percussion 
28	Percussion 
29	Percussion 
30	Percussion 
31	Percussion 
32	Percussion 
33	Percussion 
34	Percussion 
35	Percussion 
36	Percussion 
37	Percussion 
38	Percussion 

39	Percussion	
40	Percussion	
41	Percussion	
42	Percussion	
43	Percussion	
44	Percussion	
45	Percussion	
46	Percussion	
47	Percussion	
48	Percussion	

Appendix 4

Chord sequences used for each condition in the Chord Sequence and Tempo task (Chapter 5, Experiment 4), GRLR, GRLU, GULR and GULU.

GRLR 1

GRLR 2

GRLR 3

GRLR 4

GRLR 5

GRLR 6

GRLU

GRLU 1

GRLU 2

GRLU 3

GRLU 4

GRLU 5

GRLU 6

GULR

GULR 1

GULR 2

GULR 3

GULR 4

GULR 5

GULR 6

GULU

GULU 1

GULU 2

GULU 3

GULU 4

GULU 5

GULU 6