STUDIES INTO THE COGNITIVE AND NEURAL BASIS OF CONGENITAL AMUSIA

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I, Diana Omigie, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

ABSTRACT

The majority of humans develop a facility with music effortlessly and in the absence of explicit training. However some individuals show a distinct lack of musical ability despite seeming to have otherwise normal cognitive functioning. Based on initial studies into congenital amusia, poor pitch discrimination ability and poor pitch memory have been ascribed a central role in the condition. However, the extent to which these play a causal role in the more global difficulties associated with the disorder remains unclear. Furthermore, with the disorder increasingly being conceived of as one of awareness rather than perception, an integrated account of the disorder in which the relative importance of observed impairments are clearly delineated is becoming essential. Critically, such an account would describe congenital amusia in those terms that are commonly used to account for how musical listening ability typically develops. Further, it would be based on the results of investigations using ecologically valid stimuli and methods. In a series of four experiments, this thesis seeks to contribute towards such an account. Firstly, using behavioural methods, the state of statistical learning processes known to be necessary for the internalisation of musical regularities in typical individuals is examined. Secondly, the thesis examines the state of musical anticipatory mechanisms, a corollary of such learning, which has been shown to play a critical role in the ability to recognize and discriminate melodies. Next, using electroencephalography recordings, the neural basis of abnormal melodic pitch processing in congenital amusia is studied, while in the final chapter, a social science technique is used to investigate the extent to which amusics show normal appreciation of music in everyday life. By combining findings from current and previous studies, this thesis will contribute towards a comprehensive description of congenital amusia based on findings from a number of different levels of inquiry.

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CHAPTER 1

INTRODUCTION

This chapter introduces the field of music cognition as a discipline, highlighting musical stimuli as a powerful tool with which to study the brain. It goes on to motivate the study of congenital amusia, a developmental disorder of musical listening, as a window into understanding how musical ability typically develops. An overview of previous findings in the literature is presented. Next, the main aims of the thesis are put forward. Finally, the different questions addressed are outlined.

1.1 MUSIC COGNITION AND DISORDERS OF MUSIC LISTENING

Music serves a variety of uses and functions in our every day lives. With the advent of music recording technology, the rise in digital media and the exponential growth in the use of personal electronic devices, it constitutes a highly ubiquitous stimulus that can be experienced in a variety of settings and put to use in an assortment of ways. However the endless fascination we have with music today is not new. Music has played a fundamental role in the lives of our ancestors for thousands of years and a human society without music remains to be discovered. Indeed, likely because of it universality and powerful affective properties, music has proved a rich source of debate among thinkers and philosophers, who ponder on its origins and adaptive value. Due to the nature of the problem, questions related to the evolutionary origins of music inevitably remain unresolved. However, in contrast, music's unique position as a powerful tool with which to probe different aspects of auditory perception and brain function is ever increasingly acknowledged by psychologists and cognitive neuroscientists alike.

Music presents an important stimulus with which to study the brain for a multitude of reasons. Firstly, the pitch, timbres and rhythms present in most music provide the opportunity to examine the perceptual mechanisms involved in processing spectral and temporal information as well as the combined interaction of the two. Secondly, as a dynamically changing stimulus, music allows the examination of processes involved in the integration of events in a sequence over time. Further, the ease and automaticity with which individuals recognize melodies has the potential to contribute to the study of how the brain compares new incoming stimuli with stored representations that may not have been experienced in years. Finally, music's inimitable ability to induce emotions, and the pleasure this gives its listeners, makes it a powerful and important stimulus with which to study the human affective system.

It is unanimous that the study of musical ability in typical individuals presents a potentially rich source of information about the organization of the brain and its function, but as pointed out by McCloskey (2001, p. 594), "*Complex systems often reveal their inner working more clearly when they are malfunctioning than when they are running smoothly*". Thus the quest to understand how the brain is organized for musical processing, and complex auditory processing more generally, may be argued to benefit even more from the study of individuals lacking musical abilities than those with normal musical ability. Indeed, given the long list of cognitive mechanisms and consequently interacting brain areas potentially implicated in the music listening process, incidents of musical ability being selectively affected in the seeming absence of other cognitive impairments provide a promising source of information regarding the neuro-architecture of music processing and auditory processing more generally.

In fact such cases abound in the literature. For over a hundred years, clinical neurologists have reported on patients who acquired musical deficits after incurring brain lesions (Critchley & Henson, 1977). These individuals have shown deficits in the tonal representation of melodic patterns (e.g. Peretz, 1993) and have reported music as no longer sounding musical, in key or emotional (e.g. Griffiths, Warren, Dean, & Howard, 2004). However, musical deficits do not exclusively arise as a result of acquired neurological insult. Indeed, also interesting, from a developmental point of view, are those individuals who show similar difficulties with music in the absence of any neurological history. In contrast to those who acquire musical difficulties, such individuals, who constitute the subject of this thesis, are unique in allowing researchers to investigate how musical ability typically develops as opposed to how or why it may be lost.

Individuals who report musical deficits despite having no neurological history have been referred to sporadically in the literature, over the last century, and with a number of different terminologies. However, recently, the term *congenital amusia* (amusia, hereafter) is most widely used (Peretz, Champod & Hyde, 2003). Following the coining of this term and the publication of a standardized battery with which to diagnose amusia in the general population, there has been an explosion in the amount of systematic research carried out into the condition. Importantly, this work has contributed to a number of interesting research questions such as the extent to which music processing is modular (e.g. Tillmann, Rusconi, Traube, Butterworth, Umilta, & Peretz, 2011), the particular anatomical substrates that may be critically involved in music listening (e.g. Hyde, Zatorre, Griffiths, Lerch, & Peretz, 2006), and the extent to which different auditory processing disorders share a common biological basis (e.g. Loui, Alsop & Schlaug, 2009).

In brief, this thesis aims to characterize amusia at a number of different levels of inquiry in order to contribute to a better understanding of the disorder. It is motivated by the different ways in which the study of amusia can contribute to our knowledge of the auditory system as well as how musical ability typically develops. In the following sections, details on how the disorder is diagnosed, along with an overview of previous literature is provided. The chapter then goes on to motivate the aims of the thesis in greater detail before outlining the specific questions addressed.

A common behavioural manifestation of amusia is poor singing, and indeed music production ability in amusia has received considerable interest in recent years, with interesting implications for the action perception network. However as music production ability is outside the scope of the current thesis, this literature is referred to only when it has direct implications for current findings and theorizing.

1.2 CONGENITAL AMUSIA

1.2.1 Diagnosis & Incidence

Before the term congenital amusia was coined, a number of other labels were used to describe the phenomenon whereby an individual is born with severe impairments in musical processing. Describing a young man with difficulty recognizing familiar melodies and discriminating two notes as far as an octave apart, Allen (1879), used the term *note deafness* to capture his patient's deficit. Geschwind (1984), reporting a similar case of musical difficulties, referred to his patient as having *dysmusia.* On appraising a sample of 1200 participants on their ability to compare musical phrases for a change in pitch, Fry (1948) proposed that 5% of the British population is *tone deaf,* while in a later large scale study, the term *dysmelodia* was used to describe those with the inability to detect anomalous pitches in melodies (Kalmus & Fry, 1980). These papers, spanning almost 100 years, verified the existence of individuals in the general population possessing impairment in the music domain despite otherwise normal cognitive functioning. However, it would be many years before the disorder would receive systematic evaluation.

The lack of a suitable tool with which to systematically identify these individuals is likely to be the reason that amusic individuals have only recently received research interest. To study a phenomenon it must first be operationally defined and the study of a congenital musical listening disorder warranted a tool able to categorically discriminate those with a real lack of musical aptitude or musicality from those with normal musical aptitude. Musical aptitude, simply put, may be conceived of as the potential for musical achievement, and indeed a range of behavioural tools have been used to appraise and quantify the levels of musical aptitude that may be found in the general public (Grison, 1972 [cited in Stewart, von Kriegstein, Warren & Griffiths, 2006]; Prior, Kinsella & Giese, 1990; Wertheim & Botez, 1961).

The first standardized battery used to do so, the Seashore Tests of Musical Ability, was published almost a century ago (Seashore, 1919). In contrast to the ongoing philosophy, Seashore proposed that there exist multiple measures of musical talent and consequently his tool included various distinct measures of music perception including the sense of pitch, the sense of intensity, the sense of time, the sense of consonance and dissonance, tonal memory, sense of rhythm and auditory imagery. Seashore's battery was consequently followed by Gordon's musical aptitude profile (Gordon, 1965), which not only measured sensitivity to variations in the pitch and temporal dimension but also interpretative ability and melodic and rhythmic creativity. Gordon's musical aptitude profile test survived for many years as a chief measure of musical ability however, in 2003, Peretz, Champod and Hyde (2003) proposed the tool that now currently serves as the established way to discriminate those with congenital musical deficits from those with normal musical aptitude. A modified version of this tool, assessed and validated in 86 children, has also recently been introduced for use in diagnosing amusia in children (Lebrun, Moreau, McNally-Gagnon, Mignault Goulet, & Peretz, 2012; Mignault Goulet, Moreau, Robitaille, & Peretz, 2012).

In its standard version, the Montreal Battery for the Evaluation of Amusia (MBEA) encompasses a range of subtests assessing musical processing in the temporal and the melodic domain. In the melodic domain, the MBEA comprises three individual subtests (*scale, contour and interval*) assessing responses to different types of pitch change. Sensitivity to the temporal structure in music is measured with the *rhythm* and *meter* subtests and finally a *memory* subtest is used to assess melody recognition ability. All subtests are comprised of the same 30 novel musical phrases, composed in the style of western tonal melody and lasting an average of 5.1 seconds. In each of the melodic tests, a particular manipulation is carried out on the same tone in 15 sequences: in the scale subtest the pitch is modified to be out of scale, in the interval subtest a pitch is altered to have a different interval size while maintaining the melodic contour, while in the contour subtest a pitch is changed to alter the pitch direction or contour whilst keeping pitch change size constant.

The MBEA is proposed to be a superior measure of musical deficits in the general public for a number of key conceptual reasons (Peretz et al., 2003). Firstly, in contrast to previous tools, which had the general aims of helping teachers evaluate the aptitude of their students and identify exceptional ones**,** the MBEA was designed with the sole aim of identifying listeners with impaired abilities. Secondly, in contrast to previous tools that test many aspects of musical perception at the same time, the MBEA, by testing different aspects of musical perception in isolation, allows a finer description of existing deficits. In a similar vein, the use of multiple distinct subtests to tests distinct aspects of musical listening is proposed to make it superior, in terms of validity and reliability, to the Distorted Tunes Test (DTT: as developed by Kalmus & Fry (1980)), which comprises only one test of musical ability.

Perhaps most critically, however, it is argued that the MBEA reflects current knowledge on music perception and cognition better than any of the previous tools as it is based on a model of monophonic music processing that is informed by neurological findings. The authors motivated the use of separate tests for the melodic and temporal dimension with reports of brain damaged patients in whom temporal processing is spared in the absence of melodic impairment (e.g. Ayotte, Peretz, Rousseau, Bard & Bojanowski, 2000; Peretz, 1990) and vice versa (Liegeois-Chauvel, Peretz, Babai, Laguitton & Chauvel, 1998; Mavlov, 1980). The use of different subtests for assessing interval and contour perception was motivated by the observation of selective lesions suggesting a serial organization of pitch contour and interval size (e.g. Liegeois-Chauvel et al., 1998; Peretz, 1990). Finally, the authors motivated the creation of different subtests for rhythm and meter perception with the explanation that the "*tendency to group events according to temporal proximity without regard to periodicity*" is distinct in the brain from "*the extraction of an underlying temporal regularity or beat*" (Peretz et al., 2003, p. 62).

Finally, with regard to the incidence of the disorder in the population, amusia is commonly cited as having a prevalence of 4%. In the study that gave rise to this number (Kalmus & Fry, 1980), a normal musical listening group was compared to a group of self proclaimed tone deaf individuals in terms of their ability to identify the pitch errors in popular melodies. Observing that the normal musical listening group never made more than three misses, this cut off was applied to a large cohort comprised of 604 individuals leading to the conclusion that 4% of individuals in the population have a congenital musical disability. However it is worth noting that a recent study has criticized the validity of this figure as it is based on a test (the DTT) that is supposedly lacking in established psychometric properties (Henry & McAuley, 2010). Henry and McAuley further point out that while the psychometric properties of the MBEA are better established than those of the DTT, the use of a cut off of 2 standard deviations (SD) to determine who is amusic or not is fairly arbitrary.

1.2.2 What is missing in music listening?

In the first documented case of amusia, diagnosed using the MBEA, Peretz and colleagues described in great detail "*the most clear-cut case*" from an advert soliciting the participation of musically impaired members of the public (Peretz et al., 2002, p. 185). Speaking against the notion that her difficulties existed because her family life was not sufficiently musically enriched, Monica had attended music lessons during childhood and her siblings had no such difficulties with music. Comprehensive testing established that Monica had no psychiatric or neurological history and no audiological anomalies while magnetic resonance imaging (MRI) revealed no obvious cortical atrophy or pathology in the primary or secondary auditory cortices. Further, Monica performed above average in standard intelligence tests and showed normal working memory.

However, despite being able to identify the voices of well-known speakers, Monica had very poor recognition of highly familiar music that was readily recognized by women of her age and education and she performed at chance level (below 3 SD of the mean obtained from control subjects) in the contour and interval subtests as well as the scale subtest of the MBEA. Further, when required to respond to pitch changes inserted in a five-tone sequence, (making a 'yes' response if she detected a pitch change at the fourth tone and a 'no' if no difference was detected), Monica's performance yielded very large thresholds. Specifically, Monica failed to detect pitch variations smaller than 2 semitones. This high value sat in stark contrast to the normal performance of typical humans who can detect intervals as small as a quarter of a semitone (Olsho, Schoon, Sakai, Turpin, & Sperduto, 1982).

A follow-up study seeking to document the behaviour of a group of amusic individuals in detail confirmed the behaviours seen in Monica (Ayotte, Peretz, & Hyde, 2002). Via announcements in the media, (radio, newspapers, etc), individuals in the general population who felt they were musically handicapped were sought out. Even before undergoing MBEA testing, these individuals filled in a questionnaire with which the researchers were able to examine how close they were to the reported cases of Geschwind (1984) and Allen (1878). From 100 interviewees, it was surmised that 22 exhibited real musical deficits in the lab. Eleven of these, who fit several criteria including university level education, music lessons during childhood, history of musical failure and no previous neurological history, agreed to take part in further testing. Self-report indicated that they were unable to identify wrong notes in a melody or to sing in tune.

Results from MBEA testing confirmed that the 11 participants performed 3 SD below the mean of a control group (comprised of 20 individuals matched for age, gender, education and musical background) and failed in at least 2 of the 3 pitch subtests. Further, in contrast to controls, amusic individuals were shown to perform at chance when required to detect wrong notes in an anomalous pitch detection task modeled after that used by Kalmus and Fry (1980). Diagnosed amusics were also found to have difficulty discriminating between consonant and dissonant versions of real classical music (in which the pitch of the notes of the leading voice had been shifted by one semitone upward or downward). Presented with the opportunity to make pleasantness judgments using a scale of 1 to 10, these individuals tended to report the majority of music excerpts as weakly pleasant (Ayotte et al., 2002). Finally, a similar pattern of high thresholds to that seen in Monica was observed when fine-grained pitch perception was measured in a group of diagnosed individuals (Hyde & Peretz, 2004). Requiring participants to monitor a sequence of five monotonic piano notes for a possible change in pitch at the fourth note, the authors reported that while amusic individuals were unable to detect a pitch change of a semitone or less, controls were able to detect pitch intervals as small as a quarter of a semitone.

1.2.3 A disorder of pitch processing?

Further experimental research sought to characterize amusia in terms of its potential underlying deficits. The first of these studies focused on examining the striking impairments in pitch change detection exhibited by amusic individuals in the initial exploratory studies. Pitch in language can be used to transmit important information about the identity of a speaker as well as the emotion and the meaning of a phrase through intonation. In tonal languages, it can also be used to transmit the meaning of a word. However, in music, pitch is even more fundamental than in language and the ability to discriminate pitch intervals is essential for normal music processing.

With the aim of isolating the stage and extent of pitch processing impairments in amusia, Foxton, Dean, Gee, Peretz & Griffiths (2004) carried out tests examining pitch processing from the level of simple pitch difference detection to the level of complex pattern perception. In one condition from a set of pitch change detection tasks, participants were presented with two pairs of sounds, one of which consisted of two identical tones and the other of two different tones, and were given the task of determining whether the first or second pair contained a pitch change. In a second condition from the set of pitch change detection tasks, the pair of sounds presented constituted a steady state tone and a frequency glide, also either going upwards or downwards, and here again the participants' task was to determine which sound contained a pitch change. In a set of pitch direction discrimination tasks, participants were required to decide whether the first or second of a pair of glides went up, while finally, in a set of pitch sequence tasks, participants had to decide whether pitch contours in tone sequences were the same or different.

The results of these tests confirmed that amusic individuals possess larger thresholds than matched controls for the detection of pitch change and discrimination of pitch direction. However results were striking in showing that, while still elevated, amusics' thresholds were considerably smaller (below a semitone) than in the previous tasks used to assess pitch change. Critically, this pattern of results has since pervaded the literature with similar reports made by Tillmann, Schulze & Foxton (2009) and also by Liu, Patel, Fourcin & Stewart (2010). Interestingly, data from Liu and colleagues (2010) suggested that amusic individuals show problems mainly with the discrimination of pitch direction as opposed to pitch change detection. Specifically, while all but one of the amusic individuals tested had thresholds below one semitone for the simple detection of a pitch difference, half of them had thresholds close to or exceeding one semitone in the pitch direction discrimination task.

Pitch discrimination deficits thus present a reasonable candidate for explaining the difficulties amusic individuals show with music, however several recent studies suggest that pitch memory deficits may also play a role. In one of these, Williamson, McDonald, Deutsch, Griffiths and Stewart (2010) used a standard tone comparison task in which participants were required to compare two tones separated by time intervals of varying length. Williamson and colleagues showed that individuals with amusia are able to hold pitches in memory for less time than controls. In an earlier test of pitch memory, Tillmann and colleagues (2009) showed that while amusics had no difficulty discriminating word lists, they were impaired in the memorizing of pitch and timbre sequences. Further supporting this, Williamson and Stewart (2010) used an adaptive tracking paradigm to demonstrate that individuals with amusia are able to hold fewer pitches in memory than typical individuals. Although both groups showed equivalent performance in a digit span task, amusics had an average *tone span* of 4 compared to a tone span of 7 in controls. Importantly both studies showed that this deficit was not simply due to an insensitivity to pitch change as all intervals were either individually calibrated according to detection thresholds (Tillman et al., 2009) or were supra-threshold for the discrimination of pitch direction (Williamson & Stewart, 2010).

1.2.4 Music specific or music relevant?

The domain specificity of brain function is a matter of great interest in cognitive neuroscience and results from studies into amusia have recently been used as evidence for and against the notion that distinct classes of auditory stimuli are processed by distinct networks in the brain. In line with the theory that different parts of the brain are organized to carry out distinct functions (Fodor, 1983), Peretz and Coltheart (2003) suggested that dissociations between disorders of language and music processing, such as is seen in cases of aphasias and amusias, provide support for the notion of music processing being modular in nature. However, a competing hypothesis to the notion of a distinct module for music processing is that music processing shares mechanisms and resources with other types of auditory stimuli including language. The Shared Syntactic Integration Resource Hypothesis (SSIRH: Slevc, Rosenberg, & Patel, 2009) proposes that music and language exploit the same limited processing resources for integrating unfolding events into syntactic structures - a view which is supported by neuro-imaging studies showing that many of the neural correlates of musical and language processing are shared (Maess, Koelsch, Gunter, & Friederici, 2001; Patel, Gibson, Ratner, Besson, & Holcomb, 1998).

In part to contribute to the knowledge regarding whether perceptual mechanisms involved in music processing are shared with other domains, and in part to better characterize the deficits observable in amusia, a series of studies have sought to investigate the extent to which pitch processing deficits in amusia transfer to speech processing (Ayotte et al., 2002; Liu et al., 2010; Patel, Foxton & Griffiths, 2005). In one of the initial exploratory studies into amusia (Ayotte et al., 2002), participants were required to judge whether heard sentences were questions or statements or alternatively to say on which word the stress fell. Interestingly, and providing support for the notion that pitch deficits in amusia may be music specific, amusic participants performed as controls on this task. Indeed it was only when the linguistic information was removed from the speech stimuli that amusic participants showed a deficit relative to controls, leading the authors to conclude in favour of the modularity of music processing (Ayotte et al., 2002; Peretz et al., 2002).

Patel, Foxton and Griffiths (2005) reproduced these findings of preserved pitch processing in speech stimuli. However, they suggested that differences in strategies rather than differences in the way pitch is processed in music versus speech could account for the observed dissociation. The authors pointed out that in speech, observed pitch changes may be associated with a speech sound, making it unnecessary to encode the entire tone sequence for comparison with the next. In contrast, the absence of any such labeling tool in music means that the comparison of tone analogs creates a heavier load on memory processing than the comparison of speech sequences.

Later, Liu and colleagues (2010) contributed to the outstanding issue by testing a cohort of amusics and controls on intervals that were smaller than previously used but still within the range of natural speech. Participants provided same - different judgments when presented with statement - question pairs as well as tone analogs of these spoken utterances. Results confirmed that amusics were similarly impaired in the processing of speech and tone stimuli, especially when pitch excursions were small, and further demonstrated that performance in discrimination of pitch contour in speech correlated with psychophysically measured pitch discrimination thresholds. However, it is worthy of note that while the notion that amusics' pitch deficit extend to speech has received further support (Tillmann et al., 2011), it would appear that amusics, nevertheless, have better pitch discrimination thresholds with speech material than with the musical counterpart, in contrast to controls for whom this is generally the opposite. Using stimuli in which the only acoustic difference between so-called speech and music stimuli were the presence or absence of formants, Tillmann and colleagues (2011) showed that the more severe the deficit seen in an amusic individual, the more the speech context conferred an advantage. The authors proposed this may be related to amusic participants using the extra information in the specific energy distribution of the sound spectrum.

Finally, in addition to assessing sensitivity to prosody in speech, the investigation of tonal language processing in individuals with amusia has provided an important natural experiment with which to investigate whether pitch discrimination problems transfer into the speech domain. Indeed two interesting questions may be asked with regard to tonal language processing. The first concerns the extent to which being affected by amusia affects the ability to learn tonal languages while the second concerns the extent to which speaking a tonal language can protect against the occurrence of amusia. With regard to the first, the domain generality of pitch processing has found support in data showing that the amusic individuals (who normally speak non-tonal languages) are less able to process and learn tonal languages (Nguyen, Tillmann, Gosselin & Peretz, 2009; Tillmann, Burnham, Nguyen, Grimault, Gosselin, & Peretz, 2011). With regard to the second, it would appear that despite the huge importance of pitch information in their language, speakers of tonal languages are nevertheless not exempt from a congenital musical listening disorder (Jiang, Hamm, Lim, Kirk, & Yang, 2010; Nan, Sun & Peretz, 2010).

Nan and colleagues (2010) demonstrated that Mandarin speakers diagnosed with amusia can possess lexical tone agnosia and in other studies comparing Mandarin amusics with matched controls, amusics' impairments in identifying and discriminating mandarin tones have been confirmed (Jiang et al., 2010; Liu, Jiang, Thompson, Xu, Yang, & Stewart, 2012). Recently, the finding that mandarin Chinese amusics have greater difficulty recognizing pitch direction in discrete compared with gliding pitches, for both speech and non-speech stimuli, has been proposed to explain why amusics may have greater difficulty with music than speech perception, where continuously changing pitch movements are more common (Liu, Xu, Patel, Francart & Jiang, 2012).

Notwithstanding the idiosyncrancies that may arise from strategies developed over a lifetime, studies of speech processing in congenitally amusic speakers of both tonal and non-tonal languages provide considerable evidence that music shares processing mechanisms with language stimuli. However, other non-auditory mechanisms have also been implicated as sharing neural functions with music listening. For instance, empirical evidence suggests that the representation of pitch may be spatial in nature with listeners associating high-pitched tones with responses that are high in vertical space and low-pitched ones with those that are low in vertical space. To test the hypothesis that musical and visuo-spatial stimuli are represented in a similar way, Douglas and Bilkey (2007) used a complex visuo-spatial cognition task to test the ability of amusics to mentally transform 3D images. In the Shepard Metzler mental rotation task, a participant is required to determine whether a pair of 2D schematics of a 3D object can be fitted into alignment with the other by rotation. The authors hypothesized that if indeed music and visuo-spatial processing share a common framework then amusics should be impaired in this task. While they reported results suggesting this was the case, two groups have failed to replicate this finding. In particular, Tillmann, Jolicoeur, Ishihara, Gosselin, Betrand, Rossetti, & Peretz (2010) showed that amusics had no deficits in visuo-spatial attention while Williamson, Cocchini, & Stewart (2011) failed to see any sign of visuo-spatial deficits despite carrying out additional tests including the Corsi block task, testing spatial location memory and the Visual patterns tests, testing memory for 2D visual arrays.

In sum, while deficits in amusia may not reliably be associated with deficits in visuo-spatial processing, the weight of evidence from experimental investigations suggest that amusics' deficit in pitch processing is music relevant but not necessarily music specific (Liu et al., 2010; Nan et al., 2010; Nguyen et al., 2009; Patel et al., 2005; Tillmann et al., 2011). This is important in its implications for the notion of the modularity of music processing.

1.2.5 Biological basis: Structural imaging and twin/family studies

Recent research efforts have demonstrated that the increasing competence that musicians achieve with musical stimuli following rigorous training is accompanied by significant changes in a range of brain areas including auditory, motor, somato-sensory and visuo-spatial cortices (see Jancke, 2009 for review). In turn, evidence that amusic individuals differ significantly from controls in their ability to process musical stimuli motivates the study of the way in which the brains of these individuals may differ from those of typical individuals. In other words, one might expect the impairments shown by amusic individuals to be accompanied by structural and/ or functional differences in the areas of the brain known to be involved in music processing.

Voxel based morphometry (VBM), a technique which may be used to search the whole brain for differences in the concentration of brain tissue, has proved highly successful in identifying abnormalities in the brain structure of those with a number of developmental disorders. The first attempt to study the structural neural correlates of the musical impairments present in amusic individuals made use of this technique (Hyde et al., 2006). To avoid reporting false positive results from an initial study that suffered from limited power, a dual sample approach was taken whereby analysis of this initial data collected from a Canadian cohort was used to generate hypotheses that could then be tested with an independent cohort from the UK. Results of an initial group comparison at each voxel, were used to determine which, if any, brain regions differed in terms of grey and white matter. This revealed a reduced white matter concentration in the *pars orbitalis* of the right *inferior frontal gyrus* (IFG). A correlation analysis was run to determine which areas, if any, were related to performance on the MBEA and revealed that white matter concentration in this area positively correlated with performance in the melodic key violation test and the memory test. A final interesting observation was that of an increased grey matter concentration in the amusics in the same areas that had shown reduced white matter.

A second study was carried out in order to further investigate these findings (Hyde, Lerch, Zatorre, Griffiths, Evans & Peretz, 2007). Results of this study were consistent with the initial VBM study in confirming the presence of abnormalities in the cortical thickness of the right IFG. The sensitivity of the cortical thickness analysis used in this study also allowed the identification of anomalies in the right auditory cortex of amusics. Further regression analyses were able to confirm the importance of these regions by showing a correlation between their thickness and global scores on the MBEA. The authors explained their findings by suggesting that the grey matter increase may be due to abnormal neuronal migration that in turn compromises the normal development of the fronto-temporal pathway.

Interestingly, these patterns of abnormal neuronal migration have also been seen in other disorders with a presumed genetic basis lending support to the notion that congenital amusia has genetic origins. Indeed, this notion is further supported by twin and family studies showing that musical pitch encoding is heritable (Drayna, Manichaikul, de Lange, Snieder & Spector, 2001; Peretz, Cummings, & Dubé, 2007). Drayna and colleagues required monozygotic and dizygotic twins to detect anomalous pitches in popular melodies in the DTT and using genetic model fitting, showed that the significant influence of shared genes was greater than the influence of shared environment in the heritability of musical pitch recognition. Peretz and colleagues (2007) recruited the family members of a group of amusics and the family members of a group of controls and required them to take a shortened version of the MBEA, the anomalous pitch detection task (in which incongruous pitches were either out of key or out of tune) and a control time condition task in which the incongruous note was delayed by a short period of time. Participants were required to indicate the presence or absence of an incongruity using a *yes* or *no* button. The results of this study also provided convincing evidence that amusia has a heritable component by showing that 39% of first degree relatives of amusic individuals (siblings and children) are affected compared to only 3% of first degree relatives in control families.

1.2.6. A disorder of awareness: Functional imaging studies

While structural imaging as well as twin and family studies provide substantial evidence that amusia has a biological basis, these methods are limited in their capacity to contribute towards a mechanistic account of the disorder. Functional imaging methods and electrophysiological techniques are of great use here in their capacity to reveal how the amusic and non-amusic brain differ in function when processing incoming pitch information.

The first study to assess pitch processing in amusia using functional magnetic resonance imaging (fMRI) (Hyde, Zatorre & Peretz, 2011), confirmed the role of areas previously implicated by structural imaging studies (Hyde et al., 2006). Specifically, this study was able to reveal a global functional brain difference between controls and amusics in the pars orbitalis of the right IFG, in response to the changing pitch sequence, with controls showing an increase in the activation of this area and amusics showing a decrease. In contrast, both the amusic and control auditory areas showed a positive linear increase in blood-oxygen-level-dependent (BOLD) response as a function of increasing pitch distance between successive tones. This pattern of results led the authors to conclude that the main functional problems in amusia lay outside the auditory cortex and in higher areas important for the attentive monitoring of pitch sequences.

Interestingly, converging evidence for this notion is increasingly found in the results of electrophysiology studies conducted with the aim of providing a functional account of the disorder. The first evoked related potential (ERP) study into congenital amusia was designed to search for neural correlates of the elevated pitch detection thresholds reported in relation to the disorder (Peretz, Brattico & Tervaniemi, 2005). Amusic and control participants were presented with isochronous five tone sequences and asked to monitor the fourth note of each sequence for a change in pitch. The authors reported an altered pattern of activity in the amusic brain in response to pitch change. Specifically large pitch changes elicited an abnormally large P3, as well as an N2 wave not seen in controls while small pitch changes, which amusics were also unable to report, failed to produce a P3 component. In a second ERP, (Moreau, Jolicoeur, & Peretz, 2009) study in which participants simply watched a silent movie and were not required to actively monitor the sequence, the passive response of the amusic brain to pitch deviations in a tone stream was examined. In support of the notion that the dysfunction in amusia lies beyond the auditory areas, here the authors observed that, even though it was slightly smaller in amusics, no significant difference existed between amusic and control groups in terms of the measured Mismatch negativity (MMN) waveform, a negative going deflection classically observed after an infrequent change in a repetitive series of standard sounds (Naatanen, 1992).

The third and most recently published study investigating musical pitch processing in amusia differed from the preceding two in that ERP responses to out of tune and out of key notes inserted in novel melodies were examined (Peretz, Brattico, Jarvenpaa, & Tervaniemi, 2009). Here again, results were taken as support for the notion that problems in amusia may be related to a deficit in conscious perception of pitch change. Specifically, results showed that the amusic brain, like that of controls, elicits an early negativity (termed the N200) to out of tune notes while failing to elicit the late positive component (the P600) that is commonly associated with conscious processing when seen in typical individuals.

1.2.7 Uses and functions in everyday life: Engagement and Appreciation.

The majority of studies into amusia have sought to clarify the nature of the difficulties experienced by amusics, however also of interest is the extent to which amusics' impairments affect their ability to enjoy music. Previous literature has shown that people with acquired amusias may demonstrate dissociations in music perception and appreciation (Griffiths et al., 2004; Peretz, Gagnon, & Bouchard, 1998). For instance, one individual with acquired amusia, patient I.R, routinely reports enjoying music, despite being unable to recognize melodies once familiar to her or to distinguish dissonance from consonance. Similarly, anecdotal reports from individuals with congenital amusia suggest that some individuals are able to appreciate music despite their difficulties perceiving it (Stewart, 2008).

In terms of empirical findings concerning processing of music's affective properties in amusia, intact recognition of emotion in music has been reported in the presence of severely degraded perception (Ayotte et al. 2002). However recognizing emotion in music and appreciating music are arguably distinct phenomena (Juslin & Vastfjall, 2008). Using a set of questionnaires, McDonald and Stewart (2008) systematically addressed the question of how individuals with amusia use and engage with music in comparison to matched controls. Results from this study showed that in general, amusics report incorporating it into their lives less broadly than controls and are less likely to use music for psychological functions such as evoking nostalgic memories, inducing a good mood, providing comfort, etc. However, the study also revealed that a subgroup of amusic individuals was comparable to controls in the extent to which they reported using and engaging with music. Noting that the only factors differentiating this music-appreciating amusic subgroup from non-appreciators was difference in age, they raised the possibility that younger amusics are more likely to listen to music for reasons not intrinsic to the music and suggested a role of impression management in accounting for the observed behaviours.

1.3. AIMS OF THESIS

As demonstrated above, studies into amusia have the potential to address questions that have relevance beyond the disorder itself. However, research remains incomplete in some respects and it is highly likely that the underlying deficits reported thus far are only a part of the story in accounting for the musical perceptual deficits seen in amusia. Specifically, the case may be made that studies investigating amusia using simple stimuli such as glides and tones need to be complemented with the use of more complex stimuli if findings from experimental research are to be generalisable to real music. It may also be argued that to continue to produce significant and widely impacting contributions, it is increasingly important for studies into the nature of amusia to investigate the condition at a number of different levels of inquiry that capture the complexity of the musical listening process. The main aim of the current thesis was to address these issues. By investigating the nature of the disorder from different perspectives and within a context of real world music listening it sought to contribute towards an integrated account of amusia. Further, by characterizing the condition with reference to what is known about typical musical development, it sought to not only inform further theorizing about the disorder but also to inform theorizing about what constitute critical mechanisms for normal musical ability.

1.4. THE KEY QUESTIONS

Four main questions, motivated by research into typical individuals, were addressed in this thesis. The first examined the extent to which individuals with amusia are able to internalize statistical regularities in tonal sequences. The second asked whether amusic individuals can form expectations about how real music will unfold and whether this is dependent on the way in which these expectations are probed, namely at an implicit or explicit level. Next, the third addressed whether the patterns of results shown at a behavioural level, regarding the formation of expectations, may also be seen in the electrophysiological signal. Finally, the last question addressed the issue of whether the deficits seen in amusic individuals have an impact on the levels of musical engagement these individuals show. These questions are now briefly introduced before receiving further treatment in the forthcoming chapters.

1.4.1. Statistical learning in amusia.

Just as it widely acknowledged that a pre-requisite of language comprehension is the prior acquisition of basic rules guiding the way language is structured, so also is it increasingly held that the development of musical competency in a listener relies on them internalizing the regularities of the given musical system (Tillmann, Bharucha, & Bigand, 2000). Based on empirical studies showing a correlation between the distributions of notes in a musical system and the tonal hierarchies present in that system, it has been proposed that the induction of statistical regularities in music play an important role in tonality learning (Krumhansl, 1990). Other studies suggesting that internalised regularities form the basis of tonal expectations provide further support for the notion that statistical learning mechanisms are highly important in the normal music listening process (Krumhansl, Toivanen, Eerola, Toiviainen, Jarvinen & Louhivuori, 2000; Oram & Cuddy, 1995; Tillmann & Poulin-Charronnat, 2010).

More generally, the ability to internalise the statistical structure within sequential input has been shown in a range of paradigms and across a range of sensory modalities (e.g. Conway & Christiansen, 2005). Neuro-imaging studies seeking to examine the correlates of statistical learning have shown recruitment of areas typically associated with implicit learning mechanisms, specifically, the hippocampus and the striatum although stimulus specific regions such as the lateral occipital cortex for visual objects have also been shown (Turk-Browne, Scholl, Chun & Johnson, 2009; Turk-Browne, Scholl, Johnson, & Chun, 2010, Durrant, Cairney & Lewis, 2012). In the auditory domain, aside from the hippocampus and striatum, interactions between right posterior temporal cortex and bilateral inferior parietal cortices, as well as areas around the temporoparietal junction (TPJ) and planum temporale have been associated with statistical learning of sequential input (Durrant et al, 2012; Furl, Kumar, Alter, Durrant, Shawe-Taylor, & Griffiths (2010).

Neuroimaging evidence concerning the likely structural basis for congenital amusia implicates some of the areas (specifically in the temporal lobe (e.g. Hyde & Peretz, 2006)) that have been suggested to be involved in statistical learning mechanisms of tones. Thus one might predict deficits in amusia for the statistical learning of this type of material. However, an additional hypothesis would be that statistical learning mechanisms may be compromised in congenital amusia just by virtue of the fact that individuals with the disorder show elevated thresholds for the discrimination of pitch. It is possible to distinguish between these possibilities by testing their ability to internalise regularities in tonal material containing either small intervals as may be found in the majority of musical systems or larger intervals, that are above the threshold for their discrimination. Initial theorizing accounted for the difficulties individuals with amusia show by suggesting that an insensitivity to small intervals, given their prevalence in Western music (Dowling & Harwood, 1986; Vos & Troost, 1989), would have downstream effects for the acquisition of higher order music features such as contour (Stewart et al., 2006) as well as the assimilation of musical scales which is central to the tonal encoding of pitch (Peretz & Hyde, 2003). This proposal however, remains to be tested and is an important outstanding issue, which the current thesis seeks to address,

1.4.2. Musical expectancy in amusia

Just as statistical learning is the proposed mechanism by which humans internalise the regularities in music (Tillmann, Bharucha, & Bigand, 2000), another process, seen as critically important in normal music cognition, and a presumed corollary of statistical learning processes, is musical expectancy. Specifically, the ability of a listener to anticipate how a piece of music will unfold has been proposed to contribute to the aesthetic and emotional aspects of musical listening (Huron, 2006; Juslin & Vastfjall, 2008) as well as to the ability of listeners to recognize and remember music (Schmuckler, 1997; Schulkind, Posner, & Rubin, 2003).

Research into the neural correlates of expectation formation in music, like in language, has typically made use of violation paradigms, whereby the neural response to an 'irregular' or unexpected event is contrasted with that to a regular or expected event (e.g. Koelsch, Gunter, Friederici, & Schröger, 2002; Koelsch, Gunter & Friederici, 2005). Due to the time resolution required, these studies have typically made use of EEG and MEG methodology and source reconstructions of the signature responses observed when these contrasts are made have suggested the role of bilateral inferior frontal and superior temporal gyrus in expectation formation (e.g. Maess, Koelsch & Gunter, 2001; Koelsch et. al, 2005). The role of these areas have received further support from an fMRI study showing focal activation of the pars orbitalis region of the inferior frontal cortex (Levitin & Menon, 2005). Here participants' neural activity when listening to classical music was contrasted to their neural activity when listening to its scrambled counterpart.

The difficulty amusic individuals show in identifying out of key notes would seem to suggest a difficulty with forming musical expectations. Combined with the anomalies they show in the inferior frontal cortices (Hyde et al, 2006, Hyde et al, 2007), one might predict impairments in forming musical expectations. However previous research showing that they may be processing aspects of melodic structure that they are not always able to report (Peretz et al, 2009, Hyde et al., 2011) would suggest a nuanced situation. By using both an implicit and explicit behavioural musical priming paradigm, the thesis aims to contribute to an understanding of not only whether amusic individuals are able to form musical expectations but also the extent to which these reach conscious awareness. Further by accompanying behavioural investigations with an electrophysiological one, the current thesis seeks to contribute towards a mechanistic account of the disorder.

1.4.3. The experience of music in everyday life in amusia

With the aim of placing musical listening in amusia in a wider context, the final study in this thesis evaluates the extent to which amusic individuals use and engage with music in everyday life. A previous questionnaire study was informative in showing that while the majority of amusics do not show any evidence of engaging with or appreciating music, a significant proportion nevertheless do so (McDonald & Stewart, 2008). This work was, however, limited in the level of detail it provided and did not afford the opportunity to probe individual instances of musical listening nor to observe how factors like situation and company affect enjoyment (North, Hargreaves, & Hargreaves, 2004). Previous studies on typical individuals however, have shown that this is possible to accomplish using a methodology known as Experience Sampling Methodology (ESM; Larson & Csikszentmihalyi, 1983). Collecting real world data on how individuals with amusia use and experience music as they go about their everyday lives provides a more ecologically valid approach to assessing their engagement and appreciation and further, has the potential to address an interesting question regarding the extent to which music appreciation is dissociable from perception and cognition.

CHAPTER 2

STATISTICAL LEARNING AND ACQUISITION OF MUSICAL KNOWLEDGE

Even in the absence of musical training, typical individuals display a sophisticated understanding of musical structure. Previous research has shown that they acquire this knowledge implicitly, through exposure to music's statistical regularities. To examine this critical mechanism for developing musical competence, the present study tested the ability of individuals with amusia to internalize statistical regularities - specifically, lower-order transitional probabilities. Participants were exposed to structured sequences and, in a subsequent test phase, were required to identify items that had been heard in the exposure phase, as distinct from foils comprising elements that had been present during exposure, but presented in a different temporal order. To examine specificity of any potential deficits to the musical domain, learning was examined with both tonal and linguistic materials. Critically, to explore the extent to which an insensitivity to small pitch changes is a limiting factor in the internalization of statistical regularities, structured tonal sequences either contained intervals that were 'supra-threshold' or 'sub-threshold' for perception. Amusic and control individuals showed comparable learning, for both tonal and linguistic material, even when the tonal stream included pitch intervals around one semitone. However analysis of binary confidence ratings revealed that amusic individuals have less confidence in their abilities and that their performance in learning tasks may not be contingent on explicit knowledge formation or level of awareness to the degree shown in typical individuals. The current findings suggest that the difficulties amusic individuals have with real-world music cannot be accounted for by an inability to internalize lower-order statistical regularities and importantly that insensitivity to pitch change is unlikely to be a limiting factor in the acquisition of musical knowledge.

2.1. INTRODUCTION

A growing body of work suggests that the musical knowledge that is possessed by most listeners is acquired via the internalization of statistical regularities (Jonaitis & Saffran, 2009; Smith, Nelson, Groskoph, & Appleton, 1994; Tillmann, Bharucha & Bigand, 2000; Tillmann & McAdams, 2004) and that this knowledge confers sensitivity to several aspects of musical structure that can be demonstrated in the lab using a range of musical tasks. These include making subjective ratings on goodness of fit, melodic expectation and goodness of completion (Brown, Butler & Jones, 1994; Cuddy & Badertscher 1987; Krumhansl & Keil, 1982; Schmuckler, 1989; Toiviainen & Krumhansl, 2003) as well as demonstrating sensitivity to musical tensions and relaxations in sequences of chords (Bigand & Parncutt, 1999; Bigand, Parncutt & Lerdahl, 1996).

One paradigm, originating in the language acquisition literature, has been particularly influential in demonstrating the ability of listeners to compute the statistical properties of their auditory environment. Saffran, Newport & Aslin (1996) demonstrated that adult listeners exposed to a nonsense speech language comprised of tri-syllabic units (henceforth, referred to as *words*, following Saffran (1996)) were able to discover boundaries between these units by computing the transitional probabilities between adjacent syllables. The authors showed that even though the speech stream was continuous, with no temporal cues between adjacent words, listeners in a later test phase were able to successfully discriminate between words in the language they had been exposed to versus foils containing the same syllables, which were arranged in a different order (so called *non-words*). Furthermore, in a separate experiment, the authors demonstrated that listeners were even able to discriminate between words and foils in which either the first or third syllable in a word from the language had been substituted with a different syllable (so called *part-words*). Importantly, the authors reported that the learning mechanism by which listeners carried out this sequence segmentation was not confined to linguistic materials. In an analogous study, Saffran, Johnson, Aslin and Newport (1999) presented participants with a continuous tone stream comprised of tone-triplet units (which the authors termed *tone words*) made up of musical notes from the octave above middle C and showed that after 21 minutes of exposure, listeners were able to distinguish the tone words they had been exposed to from both non-word and part-word foils.

Since these seminal paradigms, which focused on transitional probabilities between adjacent tone elements, were reported, other paradigms have sought to further examine listeners' sensitivity to transitional probabilities within sequences of harmonic elements (Jonaitis & Saffran, 2009), pitch intervals (Saffran & Griepentrog, 2001) and timbral elements (Tillmann & McAdams, 2004), the statistical learning of non-adjacent dependencies in tonal stimuli (Creel, Newport & Aslin, 2004; Gebhart, Newport & Aslin, 2009; Kuhn & Dienes, 2005) and the facilitative effect of musical information on language learning (Schön, Boyer, Moreno, Besson, Peretz, & Kolinsky, 2008). Taken together, results from these studies show that listeners require only a limited amount of exposure to internalise the statistical properties of a completely novel musical system.

The evidence that musical competencies arise largely from implicit learning of regularities in our musical environment suggests at least two testable hypotheses concerning the nature of musical deficits in amusia. One hypothesis may be that such individuals lack the learning mechanism that permits internalization of regularities from a structured sound stream. The disproportionate difficulties seen with music, as opposed to language, would predict that a faulty learning mechanism would be restricted to tonal, rather than linguistic material. A second hypothesis may be that the learning mechanism is intact, but a difficulty in detection and/or discrimination of small pitch changes is the limiting factor in building up knowledge of musical structure.

An influential hypothesis put forward regarding the origins of amusic individuals' difficulties is that poor fine-grained pitch discrimination results in a failure to internalize regularities in music (Peretz & Hyde, 2003). However, since then, several studies have demonstrated that amusic individuals show smaller pitch change detection and discrimination thresholds when probed using forced choice methods (Foxton et al., 2004; Liu et al., 2010; Tillmann et al., 2009). Thus it remains an outstanding question whether amusics can internalize the regularities in tonal material even when they contain small intervals. The main aim of the current study was to distinguish between two possibilities: namely, that amusics exhibit pervasive and lifelong difficulties with music because they have inadequate learning mechanisms for acquiring this knowledge, or that they have intact learning mechanisms, but that these are rendered less effective owing to an insensitivity to small pitch changes.

To this end, a group of amusic and control participants were tested on their ability to internalize the regularities present in structured linguistic and tonal materials given equal amounts of exposure. Following the paradigm used by Saffran and colleagues (1996, 1999), participants were exposed to streams made up of words comprised of either syllables or tones. Critically, only the statistical properties within the stream served as a reliable cue as to the location of word boundaries. In a subsequent test phase, participants were then required to demonstrate their knowledge of these word boundaries, by distinguishing between words they had heard in the exposure phase and non-words, which were comprised of identical syllables or tones but were arranged in a different temporal order. Two types of tonal material were used. In the first, intervals within the tone sequence exceeded psychophysically measured thresholds across the amusic group (*supra-threshold* condition) while in the second (*sub-threshold* condition) intervals within the tone sequence were smaller, including a semitone.

If general learning mechanisms are compromised in amusia, the prediction would be for inferior learning across all conditions in the amusic group. However, if learning mechanisms in amusia are compromised for tonal material only, the prediction would be for inferior learning for both tonal conditions in the amusic group but equivalent learning across both groups for the linguistic material. Finally, if learning mechanisms are intact but the learning of amusics is limited by a poor sensitivity to pitch change, the prediction would be for inferior learning for the sub-threshold tonal condition in the amusic group but equivalent learning in both groups for both the linguistic material and materials in the supra-threshold tonal condition. In addition to recording accuracy rates for the above tasks, binary confidence judgments were collected on a trial-to-trial basis for the sub-threshold tonal condition. Recent studies have suggested that amusia may be a disorder of awareness, rather than perception, i.e. such individuals can represent pitch changes adequately, but these representations do not reach conscious awareness, resulting in poor performance on tests which probe musical perception explicitly (Hyde et al., 2010; Peretz et al., 2009). Such a hypothesis would predict that even if amusics and controls show comparable learning, as indicated by equivalent accuracy in identifying words they have been previously exposed to, individuals with amusia may show a bias towards reporting low confidence compared to control individuals.

2.2. MATERIALS AND METHODS

2.2.1 Participants

A total of 24 participants (12 amusic, 12 control) took part in the study. All participants were recruited via an online assessment based on the scale and rhythm subtest of the MBEA: Peretz et al., 2003: www.delosis.com/listening/home.html). Each participant took the online test twice and if they consistently achieved a score of 22/30 or less, they were invited to come in to the lab where assessment could take place under controlled conditions. Each participant was administered four MBEA subtests (scale, contour, interval and rhythm subtests) in a sound attenuated booth in order to confirm the presence or absence of amusia. Previous research had shown that amusia is characterized by poor perception in the pitch-based subtests of the MBEA (scale, contour, interval) while only half of them typically show a deficit in the rhythm test (Peretz et al., 2003). Thus a composite score for the three pitch-based subtests was calculated, using 65 out of 90 as a cut off score, whereby individuals were classified as amusic if their composite score fell below this value (Liu et al., 2010; Peretz et al., 2003). The amusic and control sample were matched on age, gender, score on the National Adult Reading Test (NART: Nelson, 1982), Digit-span (Wechsler Adult Intelligence Scale, WAIS: Wechsler, 1997), number of years of formal education and number of years of musical education. In addition, two pitch threshold tasks were conducted. A pitch change detection task and a pitch direction discrimination task, both employing a two-alternative forced choice AxB adaptive tracking procedure with pure tones, were used to assess thresholds for the detection of a simple pitch change and the discrimination of pitch direction respectively (see Liu et al., 2010 for further details).

Table 2-1 provides background information on the two groups, while Table 2-2 provides mean scores on the MBEA subtests and pitch thresholds. In addition to performing significantly worse on 4 sub-tests of the MBEA, the cohort of amusic individuals differed significantly in their thresholds for the discrimination of pitch direction (Controls: $M = 0.18$, $SD = 0.08$, Range = 0.09 to 0.33; Amusics: $M = 1.05$, $SD = 1.07$, Range = 0.10 to 2.97). However the two groups did not differ significantly in thresholds for the detection of a pitch change with only one amusic individual having a threshold above one semitone (Controls: $M = 0.15$, $SD = 0.06$, Range = 0.08 to 0.26;

Amusics: *M* = 0.27, *SD* = 0.33, Range = 0.07 to 1.29). Figure 2-1 shows individual direction and discrimination threshold data plotted for control and amusic participants.

Table 2-1: *Descriptive statistics and results of t-tests comparing amusic and control participant characteristics; summary of the two groups in terms of their mean age, gender, years of musical training and education, NART and total digit span (forward and backward).*

Group	Age	Gender	Yrs. of musical training	Yrs. of education	NART	Digit span
Amusic						
M	52.83	5M	0.58	15.92	42.25	22.58
SD	9.65	7F	1.24	1.93	5.69	3.48
Control						
M	51.08	4M	1.10	16.08	44.55	21.17
SD	8.90	8F	1.82	2.71	3.31	3.27
t-tests						
t	0.46		-0.82	-0.17	-1.21	1.02
p	.65		.42	.86	.24	.35

M = mean, SD = standard deviation, t = test statistic of the independent samples t-test, p = probability value.

Table 2-2: *Descriptive statistics and results of t-tests comparing performance of amusic and control participants on subtests of the MBEA and psychophysically measured pitch thresholds.*

Group	MBEA scale	MBEA contour	MBEA interval	MBEA rhythm	Pitch composite	Detection threshold	Direction threshold
Amusic							
M	19.75	19.58	18.25	24.17	57.58	0.27	1.05
SD	2.26	2.61	2.01	3.13	5.70	0.33	1.07
Control							
M	27.33	27.42	27.33	28.5	82.08	0.15	0.18
SD	2.35	2.27	2.84	1.31	6.17	0.06	0.08
t-tests							
t	-8.06	-7.84	-9.05	-4.42	-10.11	1.24	2.79
p	< .001	< .001	< .001	< .001	< .001	.240	.020

M = mean, SD = standard deviation, t = test statistic of the independent samples t-test, p = probability value. The pitch composite score is the mean score based on the scale, contour and interval subtests of the MBEA.

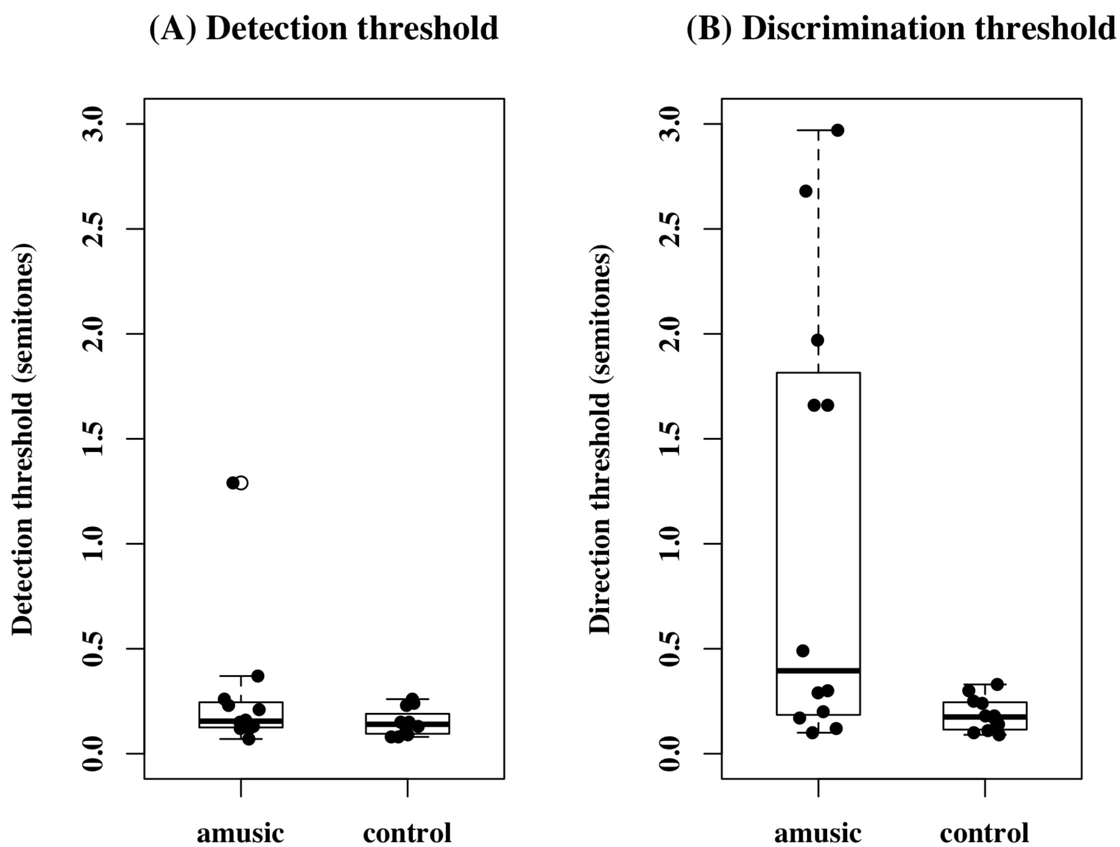

Figure 2-1: *Pitch detection and pitch direction discrimination thresholds in semitones for amusic and controls participants*.

2.2.2. Stimuli

Stimuli for the three conditions (linguistic, supra-threshold tonal and sub-threshold tonal) were based on those used by Saffran and colleagues (1996, 1999). The linguistic sequences were created from 11 syllables obtained by pairing the consonants *p, t, b* and *d* with the vowels *a, i* and *u.* Syllabic sounds were excised from the recorded speech of a native English speaker who was required to read aloud a string of words in which the required syllables were inserted. The syllable sounds were constrained to a single monotone pitch using Praat software (Boersma, 2001). Subsequently, the syllable sounds were stretched or compressed (as necessary) to a fixed duration of 280 ms using Audacity software (http://audacity.sourceforge.net/).

Following Saffran and colleagues (1999), the sub-threshold sequences were constructed from 11 tones drawn from the chromatic scale beginning at C4 (261.3 Hz). As in Saffran and colleagues (1999), all the tones from C4 to B4 were used, excluding A#. The supra-threshold sequences were constructed from a novel scale with unfamiliar interval sizes, obtained by dividing the two-octave span from C4 (261.3 Hz) into 11 evenly log-spaced divisions. Thus, the 11 tones in the sub-threshold condition were generated using the formula: Frequency (Hz) = 261.63 * 2 ^ n/12, with *n* referring to the number of steps along the chromatic scale (0 to 9, 11) while the 11 tones in the supra-threshold condition followed the formula: Frequency (Hz) = 261.63 * 4 ^ n/11, where *n* was the number of equal sized steps along the new scale (0 to 10). Consequently, the tones used in the sub-threshold tonal condition were 261.63, 277.18, 293.66, 311.13, 329.63, 349.23, 369.99, 392.00, 415.30, 440 and 493.88 Hz while those used in the supra-threshold tonal condition were 261.63, 296.77, 336.63, 381.84, 433.13, 491.31, 557.29, 632.14, 717.05, 813.36 and 922.60 Hz. All tones were sine tones generated in Matlab (http://www.mathworks.com/products/matlab) with a duration of 330 ms and an envelope rise and fall time of 10 ms on either side.

2.2.2.1 Language construction

For all conditions (linguistic, supra-threshold tonal, sub-threshold tonal), two languages analogous in statistical structure were prepared to ensure that any potential learning could not be accounted for by idiosyncratic aspects of one language in particular. Both languages were comprised of the same elements that had been arranged to make different words, and differed only in the transitional probabilities between elements of the words. For half the participants of each group, language 1 was used in the listening phase, and words from language 2 were used as the non-word foils during the test phase, while the opposite was the case for the remaining participants.

Each language comprised six words. In language 1 of the linguistic condition, the six words used were *babupu, bupada, dutaba, patubi, pidabu* and *tutibu* while in language 2, they were *batida, bitada, dutupi, tipuba, tipabu* and *tapuba*. In the sub-threshold tonal condition, language 1 comprised of six tone words taken from the chromatic scale beginning at C4; ADB, DFE, GG#A, FCF#, D#ED and CC#D whilst language 2 comprised of a different set of six tone words from the chromatic scale beginning at C4; AC#E, F#G#E, GCD#, C#BA, C#FD, G#BA. To create tone words that were analogous in structure across the two tonal conditions, words in the supra-threshold condition were created by substituting frequencies in the sub-threshold words with frequencies from the novel scale that corresponded in terms of the number of steps from C4. Tone words in the two conditions were identical in pattern and differed only in the actual frequencies, and consequently the size of interval occurring between adjacent tones (Figure 2-2).

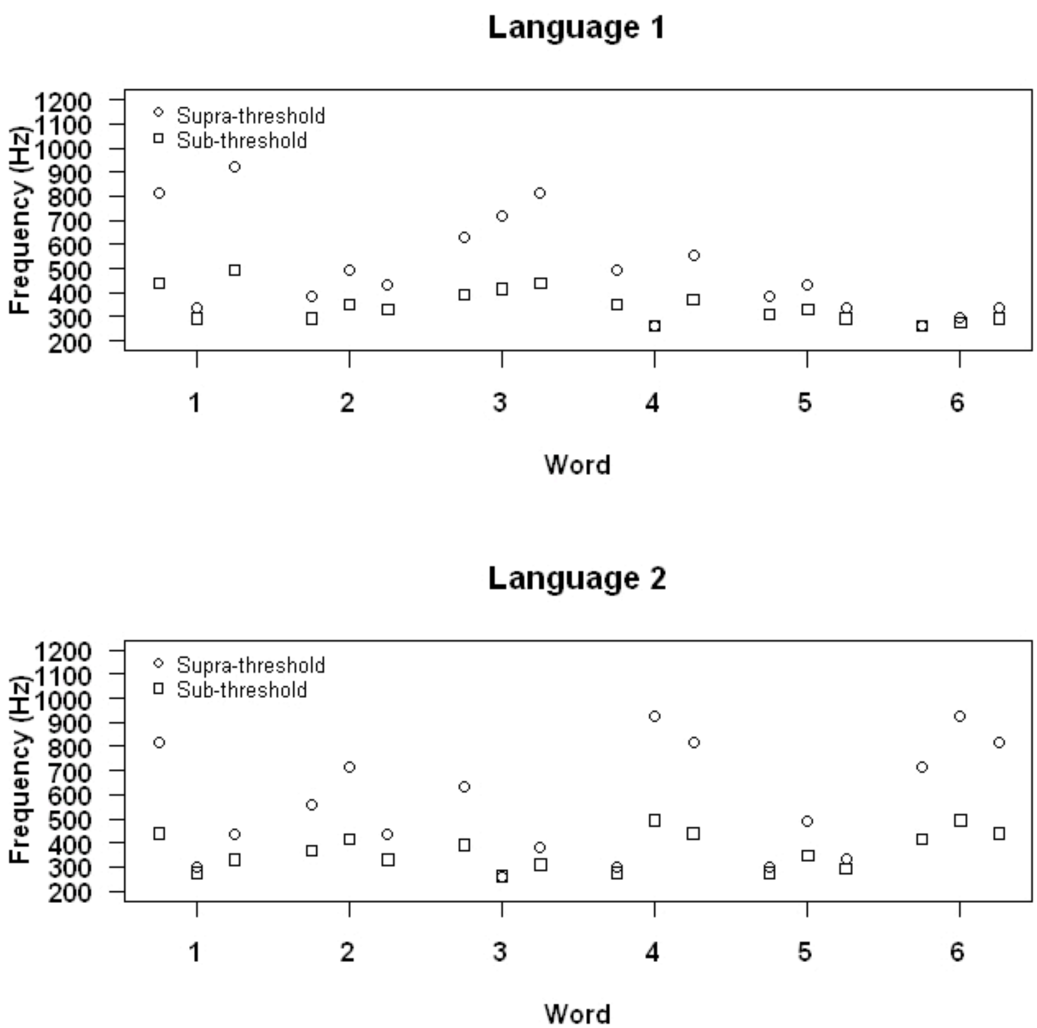

Figure 2-2: *Tone words used in language 1 and language 2 for the sub-threshold and supra-threshold tonal conditions. For the sub-threshold conditions, these correspond to ADB, DFE, GG#A, FCF#, D#ED and CC#D in language 1 and AC#E, F#G#E, GCD#, C#BA, C#FD, G#BA in language 2. For the supra-threshold conditions, these correspond*

to tone triplets composed using a novel scale obtained by dividing the two-octave span from C4 (261.3 Hz) into 11 evenly log-spaced divisions.

2.2.2.2. Sequence concatenation

To create each sequence, the six words from the given language were concatenated in random order to create six different blocks containing 18 words each. Concatenation adhered to two strict conditions; that a word could not follow itself and that there were no silent gaps between words. The six blocks created in this way were then further concatenated to create sequences consisting of 432 words (72 tokens of each word). As the sequences in the tonal conditions consisted of units with a duration of 330 ms, these lasted approximately seven minutes. The sequences in the linguistic condition, consisting of syllable sounds of 280 ms length, were approximately six minutes long.

2.2.3 Procedure

Participants gave written consent to participate in the experiments, which were approved by the Ethics Committee at Goldsmiths, University of London. All experiments were conducted in a sound-attenuated booth. Sounds for the listening and test phase were presented through an external sound card (Edirol UA-4FX USB Audio Capture) at a fixed intensity level of 73 dB using Sennheiser headphones HD 202. Programs for stimulus presentation and the collection of data were written in Matlab (http://www.mathworks.com/products/matlab).

As languages in the sub-threshold and supra-threshold tonal conditions comprised analogous words (but over a different frequency range), it was important to eliminate any potential carryover effects between the conditions. This was achieved by splitting each group in two such that one half of each group was exposed to language 1 of the linguistic condition, language 2 of the supra-threshold tonal condition and language 1 of the sub-threshold tonal condition while the other half of each group was exposed to language 2 of the linguistic condition, language 1 of the supra-threshold tonal condition and language 2 of the sub-threshold condition.

Testing took place over two sessions. In the first session, participants were run on the supra-threshold tonal condition and on the linguistic condition. The order in which the conditions were presented to participants was counterbalanced for both the amusic and control groups. The linguistic and tonal conditions were separated by a period of about 40 minutes in which participants carried out a completely unrelated experiment (comprising a mental rotation task) as part of a separate study. The second testing session, in which participants were run on the sub-threshold tonal condition, took place on a different day on average seven months later. Note the delay between the testing sessions was not an intentional part of the design but reflected logistical factors relating to participant availability.

Exposure lasted approximately 21 minutes in total for the tonal conditions and 18 minutes for the linguistic condition. Instructions for all three conditions were identical for the listening phase. Participants were told that they would hear a stream of sounds. They were asked to avoid analyzing the stream but also to refrain from blocking out the sounds as they would be tested on what they had heard afterwards. They were then presented with three blocks of one of the sound sequences described previously with the opportunity for a short break between blocks.

Immediately after the exposure phase, the testing phase commenced, starting with three practice trials. Participants were then presented with 36 trials. Each trial comprised two words; one of which they had heard during exposure and another which had the same constituent parts, but which had not appeared in combination during the exposure phase. For all three conditions, the 36 trials were created by exhaustively pairing the six words from both languages such that on each trial participants exposed to opposing languages were expected to select opposing items. Within a trial, words were presented with a 750 ms inter-stimulus interval and there was an inter-trial interval of five seconds during which the participant was required to make their response.

On each trial of the test phase for the conditions run in the first session (the linguistic condition and the supra-threshold tonal condition), the participant’s task was to indicate, using the computer keyboard, which triplet (the first or the second) in the pair they had heard during the exposure phase. In the second session (the sub-threshold tonal condition), participants were additionally required to indicate whether or not they were confident about their decision by responding *confident* or *not confident* immediately after. As this condition required participants to make two responses (compared to one in the previous conditions), responses in this session were entered into the computer by the author so as to avoid inputting error. Two different random orders of the test trials were generated for each condition and following Saffran and colleagues (1999) each participant was randomly assigned to one of the two different random orders in each condition.

2.3. RESULTS

2.3.1. Evidence of Learning: performance during the test phase

Figure 2-3 shows scores for all individuals, by group, across all three conditions. Separate Shapiro-Wilks tests run on the scores from each group for each condition showed that in all cases the assumption of normality was met (all $p>.05$). As shown in Table 2-3, single-sample t-tests (all two-tailed) revealed an overall performance that was significantly greater than chance for both groups across all conditions. Independent sample t-tests revealed no significant differences between the scores of individuals assigned to alternative orders of the test trials in any of the three conditions (all $p > .05$) so data were treated similarly regardless of this factor.

Individual participants' performance were entered into a preliminary 2 x 2 x 3 repeated measures ANOVA with condition (linguistic, supra-threshold tonal, sub-threshold tonal) as a within subject factor and group (amusic, control) and language set (1, 2) as between subject factors. The aim of this initial analysis was to observe any effect of the set of languages to which participants were allocated. There were no significant main effects of language set, group or condition (Language set: $F(1, 20) = 0.03$, $p = .87$, Group: $F(1, 20) = 0.55$, $p = .47$; Condition: $F(2, 40) = 2.48$, $p = .10$), nor were there any significant interactions (all $p > .05$).

Table 2-3: *Results for one sample t-tests against chance performance for amusic individuals and controls across all three conditions*.

		Condition		
		Linguistic	Supra-threshold tonal	Sub-threshold tonal
Amusic	*M*	21.50	23.33	24.33
	SD	3.32	3.70	4.68
	t	3.66	4.99	3.89
	p	.004	<.001	.003
Control	*M*	20.67	23.08	23.25
	SD	3.96	4.52	5.48
	t	2.33	3.89	3.32
	p	.040	.003	.007

M = mean, SD = standard deviation, t = test statistic of the independent samples t-test, p = probability value.

Given that performance was not differentially affected according to the precise set of languages a participant had been allocated to, scores were collapsed across this factor to increase the power of the main analysis. A 2 x 3 repeated measures ANOVA with group (amusic, control) as a between-subjects factor and condition (linguistic, supra-threshold, sub-threshold) as a within-subjects factor was carried out in order to re-assess the main effects of group and condition. No difference was found between control and amusic subjects: $F(1, 22) = 0.60$, $p = .45$, or across conditions: $F(2,44) = 2.39$, $p = .10$. Nor was there a significant interaction between group and condition, suggesting that both groups performed equally well on all conditions: $F(2, 44) = .05$, $p = .95$. Having employed a within-subjects design, further analysis investigated the possibility that repeated testing on the same individuals resulted in order effects during the first session, where the linguistic condition and the supra-threshold tonal condition conditions were carried within an hour of each other. However, an independent samples *t*-test indicated that participants who carried out the linguistic condition first did not perform any better in the supra-threshold tonal condition ($M = 22.92$) compared with those who carried out the supra-threshold tonal condition first ($M = 23.50$, $t(22) = 0.35$, $p = .73$).

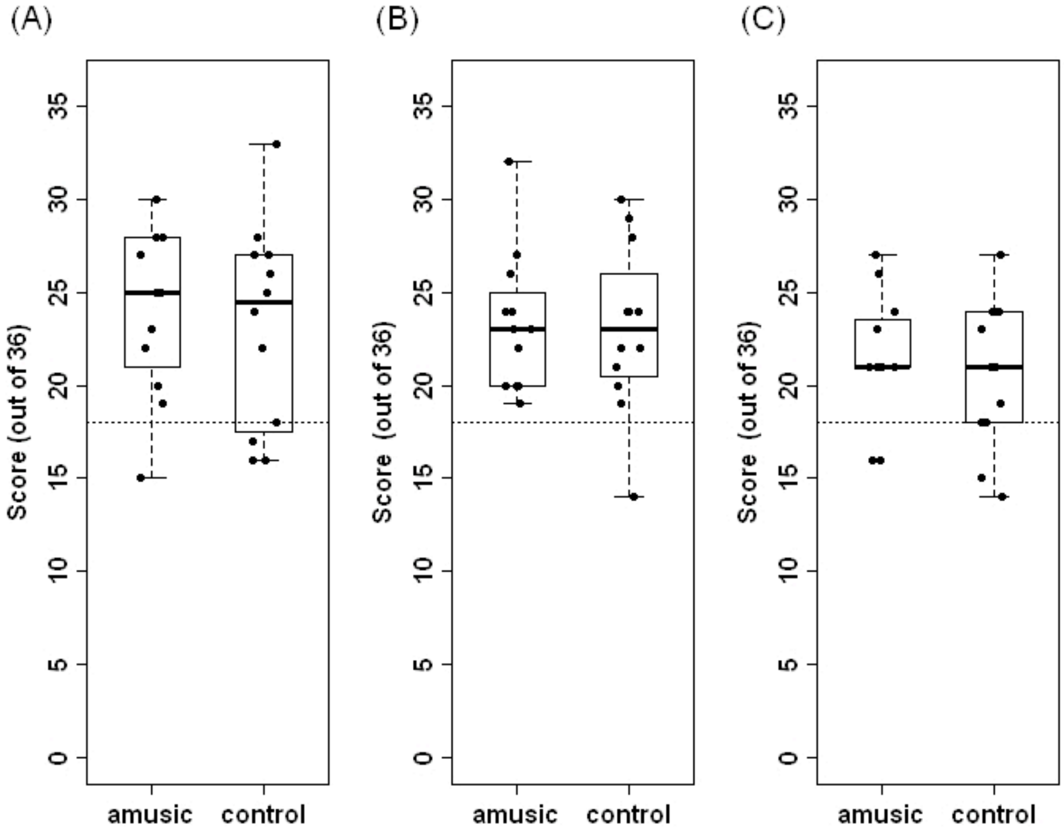

Figure 2-3: *Boxplots showing performance on the linguistic (A) supra-threshold tonal (B) and sub-threshold tonal (C) conditions for amusic and control participants. Black dots represent an individual. Median performance is represented by the solid black bar. Chance performance is represented by the dotted line.*

Finally, of key interest was whether participants' performance on the two tonal conditions could be accounted for by psychophysically measured pitch detection and pitch discrimination thresholds. Results from correlation analyses with each of the groups treated separately (Table 2-4), showed no significant relationship between learning and perceptual thresholds.

Table 2-4: *Results of Pearson correlations between the overall performance of both groups in the two tonal conditions and psychophysically measured pitch direction and discrimination thresholds.*

			Supra-threshold	Sub-threshold
Amusic	Pitch detection	*r*	-.35	-.24
		p	.26	.46
	Pitch direction	*r*	.01	-.36
		p	.99	.25
Control	Pitch detection	*r*	-.04	-.29
		p	.90	.35
	Pitch direction	*r*	-.49	-.20
		p	.11	.53

r = test statistic of the Pearson's product moment correlation, p = probability value

2.3.2. *Confidence Judgments*

The next stage of analysis evaluated confidence ratings given on a trial-by-trial basis using Signal Detection Theory (SDT: Green & Swets, 1966).

SDT is a useful model for separating an individual's biases from their sensitivity to a signal. In a given psychological task, individuals might be required to indicate whether a signal is either present or absent. In basic SDT, a *hit* refers to when the stimulus is present and the listener reports that it is present while a *false alarm* refers to when a stimulus is absent and the listener reports that it is present. As listeners may have a bias to report either absent or present more frequently, a measure of their sensitivity to the presence of the signal regardless of their bias is a useful measure of their performance. In SDT, this is known as *d'*, and is computed as z (hit rate) - z (false alarm rate).

In addition to measuring sensitivity to a signal, a *d'* may be a useful measure of a subject's ability to discriminate between their incorrect and correct trials (Kunimoto, Miller & Pashler, 2001; Tunney & Shanks, 2003). Specifically it may be used to measure a participant's ability to determine when they have made a correct or incorrect response regardless of their proclivity to say they are confident or not in their decisions. In this case, in which *d*' is computed using confidence ratings, a hit is considered to be a correct response with high confidence, whereas a false alarm is considered an incorrect response with high confidence. From hit and false alarm rates, computed by expressing the number of hits and false alarms as a proportion of correct and incorrect responses respectively, two key variables may be extracted for each participant: their *awareness* or ability to judge whether a correct or an incorrect response had been made (the discriminability index, *d'*) and their tendency to favour one response (confident versus not confident) over the other (the response bias, *c*). As in basic SDT, the former, *d',* is computed as *d'* = z (hit rate) - z (false alarm rate), while the latter, c, is computed as c = -0.5 [z (hit rate) + z (false alarm rate)] (Macmillan & Creelman, 2001). Importantly, a higher d' denotes greater awareness compared with a lower one and a d' value significantly greater than zero indicates presence of explicit knowledge. A negative value *c* denotes a liberal response bias (more likely to report confident), and a positive *c* value denotes a conservative response bias (less likely to report confident).

Table 2-5 shows means and standard deviations of the hit rates, false alarm rates, *d'* and *c* for both groups. Although the control group had a higher mean *d',* an independent sample *t*-test revealed no difference between the groups in their ability to discriminate correct responses from incorrect ones ($t(22) = -0.40$, $p = .70$). Further, neither group had a mean *d'* significantly greater than zero (amusics: $t(11) = 0.74$, $p = .48$; controls: $t(11) = 1.61$, $p = .14$) suggesting that knowledge acquired was largely implicit and failed to reach full conscious awareness in both groups (Dienes & Scott, 2005; Tunney & Shanks, 2003). The next analysis examined whether there were any differences in response biases (*c*) between the two groups using an independent samples *t*-test. This revealed that the amusic group exhibited significantly greater conservatism than the control group when judging their performance ($t(22) = 3.15$, $p < .01$). In order words, amusic individuals were less likely than controls to give a confident response.

Finally, using correlation analyses, it was investigated whether either awareness level (*d'*) or the response bias (*c*) predicted participants performance, as defined by the number of correct responses out of 36 in the test phase. No relationship was seen between the response bias and performance in either the amusic ($r = -\ .46$, $p = .13$) or the control group ($r = -\ .07$, $p =. 84$). However, results shown in Figure 2-4 revealed that while controls who had a greater level of awareness were also more accurate in the test phase (r = .62, p = .03), there was no such relationship in the amusic group (r = .27, p = .40).

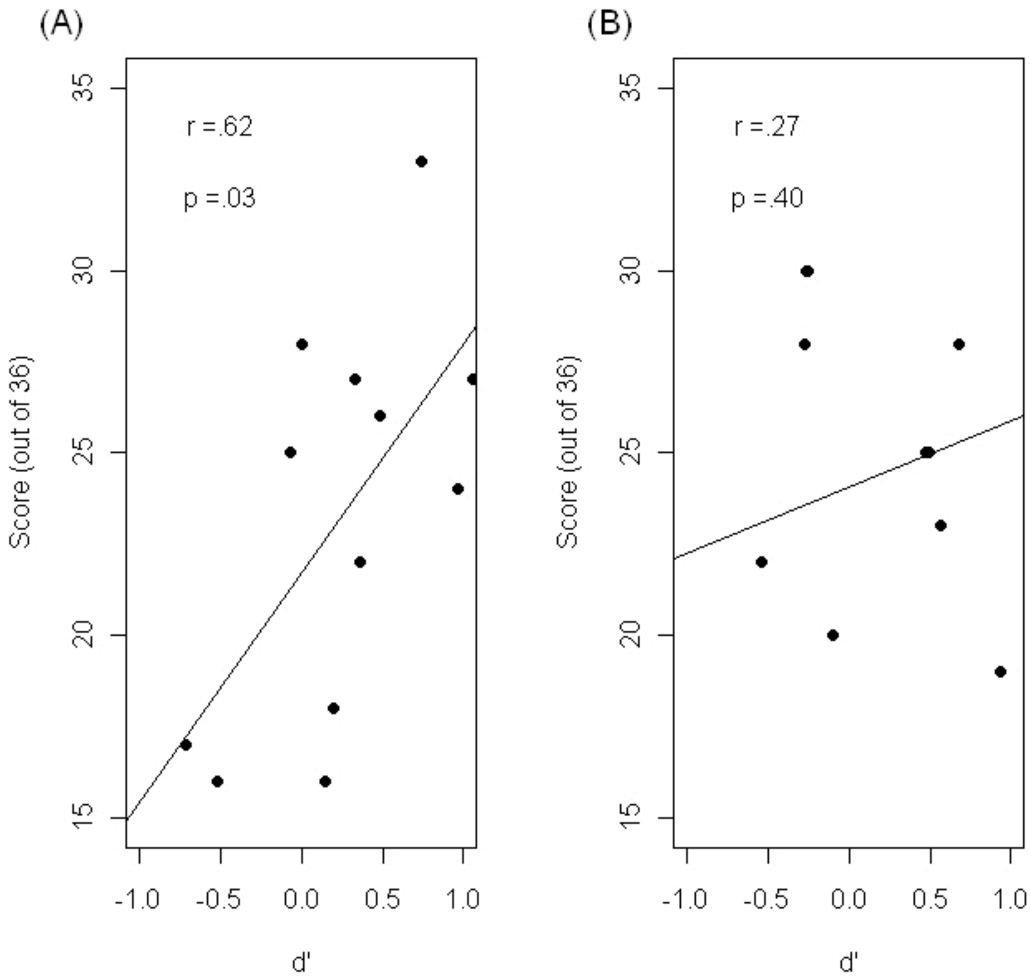

Figure 2-4: *Scatter plot showing the significant correlation between d' and performance for the control group (A) and the null correlation in the amusic group (B).*

Table 2-5: *Mean hit rates, false alarm rates and d' and c values for amusic and control participants.*

		p(H)	p(FA)	*d'*	*c*
Amusic	*M*	.40	.34	.15	.47
	SD	.29	.23	.70	.81
Control	*M*	.70	.63	.25	-.48
	SD	.21	.27	.54	.65

M = mean, SD = standard deviation.

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2.4. DISCUSSION

Based on the starting point that typical individuals' facility in perceiving music is built upon long term schematic knowledge gained incidentally over a life-time of exposure to the statistical properties of one's own musical culture (Tillmann et al., 2000) the present study aimed to test as well as to distinguish between two possibilities: firstly, that amusics exhibit pervasive and lifelong difficulties with music because they have inadequate learning mechanisms, or secondly, that while they have intact learning mechanisms, they are rendered less effective owing to an insensitivity to small pitch changes.

A cohort of amusic individuals and matched controls were given equal opportunity to learn the regularities present within novel tonal and linguistic materials. Two types of tonal materials were used, spanning one and two octaves respectively, in order to determine whether the use of small intervals could explain any potential lack of learning in the amusic group. The condition making use of linguistic materials was carried out to test the possibility that any potential learning deficits were not specific to music. In all conditions, participants were exposed to structured sequences made up of discrete words (tri-syllabic or tone triplets) that were concatenated in such a manner that the only cues to where words began and ended were the transitional probabilities between adjacent syllables/tones. Following an exposure phase, participants heard pairs of words and identified which word had been present in the exposure phase.

Results showed equivalent learning for both groups across all three conditions. The current study is limited in assessing sensitivity to only one type of regularity (first order transitional probabilities), however these preliminary findings nevertheless raise the possibility that the difficulties in real-world music perception in amusia are not simply due to a faulty learning mechanism, or even one that is compromised by pitch insensitivity. The finding that learning was equivalently good for both tonal conditions is particularly important because it had been suggested that with the prevalence of small intervals in Western music (Dowling & Harwood, 1986; Vos & Troost, 1989), an insensitivity to such small intervals would have downstream effects for the acquisition of higher order music features such as contour (Stewart et al., 2006) and the assimilation of musical scales which is central to the tonal encoding of pitch (Peretz & Hyde, 2003).

Results from the current study suggest that elevated pitch discrimination thresholds may not necessarily limit the ability to internalise the regularities in an auditory sequence and in doing so, calls for a re-examination of the notion that amusia arises from an insensitivity to pitch that culminates in a failure to acquire musical knowledge. (Foxton et al., 2004; Hyde & Peretz, 2004; Peretz et al., 2002).

Instead, the current results support the notion that performance in amusia is highly dependent on the way in which knowledge is probed. Neuro-imaging studies have demonstrated that individuals with amusia unconsciously process pitch deviations which they are unable to report explicitly (Hyde et al., 2010; Peretz et al., 2009) and in the present study, the analysis of response biases revealed that individuals with amusia, though no less accurate than controls were less confident about their decisions. While the groups did not differ from each other in terms of their levels of awareness (i.e. their ability to judge whether a correct or incorrect response had been made), a positive association was observed between awareness and performance in the control group that was not observed in the amusic group. The presence of this relationship in controls is not surprising as increasing awareness indicates an increasing tendency towards explicit knowledge acquisition and it is reasonable for performance in a learning task to correlate with levels of awareness (when unconscious) or explicit knowledge (when conscious). In contrast, the absence of this association in the amusic sample suggests a degree of dissociation whereby the level of awareness demonstrated by an individual does not predict their level of performance. What this finding suggests is that, in contrast to controls for whom performance in learning tasks may be largely contingent on awareness

(Shanks & St. John, 1994), at least some individuals with amusia are able to perform well in the absence of any ability to discriminate when they are making a correct response from when they are making an incorrect one. Interestingly, a dissociation between performance and explicit knowledge has been frequently reported in the neuropsychological literature, for instance with amnesic patients who often show preserved memory in priming tasks while lacking any explicit memory for the same information (Graf, Squire & Mandler, 1984; Knowlton, Ramus & Squire, 1992; Reber, Martinez, Weintraub, 2003).

In sum, the present study provides preliminary evidence that while individuals with amusia may lack confidence in their ability and display different patterns of awareness compared with typical individuals, they may nevertheless possess an important mechanism for building knowledge of musical structure. Importantly, though there is room for further work using other paradigms that test other forms of statistical regularities, the current study shows that amusic individuals are not necessarily limited in the acquisition of regularities in tonal material by their perceptual abilities, as had previously been suggested. The next chapter sought to investigate whether evidence could be found that amusic individuals are able to use the knowledge they have potentially acquired over a lifetime of listening to form expectations as to how music will unfold in a given piece. Importantly, by using analogous tasks examining levels of explicit and implicit knowledge separately, the study provided a systematic test of the notion that amusia should be considered a disorder of awareness.

CHAPTER 3

DO AMUSIC INDIVIDUALS FORM MUSICAL EXPECTATIONS?

In general, auditory perception involves not only hearing a series of sounds but also making predictions about future ones. For typical listeners, these predictions are formed on the basis of long-term schematic knowledge, gained over a lifetime of exposure to the auditory environment. Based on the previous finding that amusics show normal internalization of the regularities present in music-like stimuli, the current study had two aims; to test whether amusic individuals can use acquired knowledge to form expectations as to how music will unfold, and further to investigate the extent to which failure to do so is as a result of the way in which knowledge is probed. Two versions of a melodic priming paradigm were used to probe participants' abilities to form melodic pitch expectations, in an implicit and an explicit manner respectively. In the implicit version (Experiment 1), participants made speeded, forced-choice discriminations concerning the timbre of a cued target note. In the explicit version (Experiment 2), participants used a 1-7 rating scale to indicate the degree to which the pitch of the cued target note was expected or unexpected. Target notes were chosen to have high or low information content (IC) in the context of the melody, based on the predictions of a computational model of melodic expectation. Analysis of the data from the implicit task revealed a melodic priming effect in both amusic and control participants whereby both groups showed faster responses to low IC than high IC notes rendered in the same timbre as the context. However, analysis of the data from the explicit task revealed that amusic participants were significantly worse than controls at using explicit ratings to differentiate between high and low IC events in a melodic context. Taken together, findings demonstrate that amusic individuals track melodic pitch probabilities at an implicit level despite an impairment, relative to controls, when required to make explicit judgments in this regard. These findings thus provide substantial support for the notion that amusia should be considered a disorder of conscious awareness rather than perception.

3.1. INTRODUCTION

The previous chapter demonstrated that amusic individuals possess some of the fundamental mechanisms required to build knowledge of musical structure. The experiments reported in the current chapter sought to investigate whether there is evidence that they have not only been able to acquire this knowledge but are actually able to use it to make predictions as to how music will unfold. Critically, it sought to examine the extent to which predictions of how music will unfold are accessible to conscious awareness.

Expectations have been described as a form of mental or corporeal belief that some event or class of events is likely to happen in the future (Olsen, Roese, & Zanna, 1996). They are an important part of music cognition, proposed to account for the aesthetic and emotional aspects of musical listening (Huron, 2006; Juslin & Vastfjall, 2008) as well to explain how listeners recognize and remember music (Schmuckler, 1997; Schulkind, Posner & Rubin, 2003). The notion that individuals use previously acquired knowledge to generate expectations is increasingly well supported, with empirical evidence showing that even newly acquired tone structures subsequently influence pitch expectations (Krumhansl, Toivanen, Eerola, Toiviainen, Jarvinen & Louhivuori, 2000; Oram & Cuddy, 1995; Tillmann & Poulin-Charronnat, 2010). For instance, Tillmann and Poulin-Charronnat (2010) demonstrated that participants exposed to structured tone sequences showed a processing advantage for grammatical tones relative to ungrammatical ones in a subsequent task in which they were required to make speeded judgments regarding the intonation (in tune-ness) of target tones in new sequences.

The influence of long-term exposure to music's statistical regularities on listeners' expectations is also in clear evidence when real musical stimuli are used (Bigand & Poulin-Charronnat, 2006; Brown, et al., 1994; Cuddy & Badertscher, 1987; Krumhansl & Keil, 1982; Schmuckler, 1989; Smith et al., 1994; Toiviainen & Krumhansl, 2003). For instance, listeners rate small intervals as more expected than large ones, reflecting the relative frequency with which they occur in melodies (Huron, 2006) and, further, when required to give subjective ratings of how well each of a set of notes fits a musical pattern, listeners produce rating profiles that reflect the tonal hierarchy present in western music whereby some notes are more stable than others within a key (Cuddy & Badertscher, 1987).Critically for the present study is the influential notion that listeners internalize the patterns of occurrence and co-occurrence of musical events in music to acquire a sophisticated knowledge of musical structure over a lifetime of listening (Tillmann et al., 2000). This notion has inspired a computational model of melodic expectation, based on information theory and statistical learning (Pearce, 2005; Pearce, Ruiz, Kapasi, Wiggins & Bhattarcharya, 2010; Pearce & Wiggins, 2006). This model encodes past experience and then predicts the conditional probability of future events occurring, given the current musical context (Pearce & Wiggins, 2006).

Importantly, based, as it is, on the notion that melodic expectations arise solely from statistical learning, the Pearce and Wiggins model (2006) is arguably more parsimonious than previous approaches. Perhaps the most influential account of melodic expectations came from Narmour (1990) who suggested that listeners' expectations are influenced by two independent cognitive systems: *bottom up* influences which comprise innate and universal gestalt-like principles, and *style specific* influences, which develop through continued exposure to a given musical style. Narmour's Implication-Realisation model found support in a series of experimental studies which examined the bottom up principles he outlined (e.g. Cuddy and Lunny, 1995; Krumhansl, 1995), however after carrying out an independent analysis of the data, Schellenberg (1997) argued that bottom up models proposed by Narmour and Krumhansl are overspecified and may be expressed more parsimoniously.

Schellenberg's model, which suggested that two factors, namely '*principle of proximity*' (consecutive notes tend to be proximate in pitch) and '*pitch* reversal' (a tendency for registral direction change), are sufficient to explain listeners' expectation did indeed show greater simplicity along with comparable predictive power. However it was necessarily limited in making only local pitch predictions based on the preceding one or two notes. In contrast, the model of Pearce and Wiggins (2006) predicts which pitches will occur based on preceding melodic contexts of varying lengths. Perhaps as a direct result, it has been shown to outperform Schellenberg's two-factor model in predicting listeners' subjective expectations (Pearce & Wiggins, 2006; Pearce et al, 2010) with results from multiple regression analyses revealing that it accounted for more variance in the ratings and response times of a group of typical listeners than the two-factor model (78% of the variance in the ratings and 56% of the variance in the response times compared to approximately 56% and 33% respectively) (Pearce et al., 2010).

Another important property of model, which makes it more powerful than others is its use of a long-term and a short-term component to simulate how expectations are formed when a given piece of music is presented. The long term model component is trained on a corpus of western tonal melody, which represents schematic expectations learned over a lifetime of exposure while the short term model is trained incrementally for each melody that it is presented with, to simulate local influences on expectations that are formed dynamically as a given piece of music unfolds.

With this model, the expectedness of the individual notes in a melody are expressed in units of information content (IC), where IC (the negative logarithm, to the base 2, of the probability of an event occurring) is a lower bound on the number of bits required to encode an event in context (MacKay, 2003). According to the model, low IC events are expected while high IC ones are unexpected.

Results from a previous behavioural study in which participants judged the expectedness of individual notes in a melody showed a close relationship between the IC of target notes as predicted by the model and listeners' subjective expectedness ratings (Pearce et al., 2010). In the paradigm, participants were asked to listen carefully to melodies presented over headphones while remaining vigilant for the appearance of a visual response cue. The cue comprised an analogue clock, the hand of which counted down to the target, in time with the melody, pointing in turn to the 3, 6, 9 and finally 12 O' Clock positions on the clock. Participants were instructed to respond to the auditory event whose onset time coincided with the hand of the clock returning to 12, indicating on a scale of 1 to 7 how unexpected they found the probed note.

While the paradigm proved to be a good way of measuring dynamic melodic expectations, the associated task, which required participant to make explicit judgments, was necessarily limited in its ability to provide insights into listeners' *implicit* expectations. For many decades, so-called implicit priming paradigms have been widely used as a measure of implicit knowledge across perceptual and cognitive domains (e.g. Mimura, Goodglass & Milberg, 1996; Young, Hellawell & DeHaan, 1988). In a musical context, the implicit priming paradigm involves manipulating the relationship between a *prime context* and a *target* so that the two vary in their musical congruity. The ability to form musical expectations is then studied by observing whether performance on an irrelevant task is influenced by the degree to which the prime context and target are musically related. In the previous literature, this irrelevant task has included making intonation judgments (e.g. Bharucha & Stoeckig, 1987; Bigand, Poulin, Tillmann, Madurell, & D'Adamo, 2003; Marmel, Tillmann & Dowling, 2008), identifying phonemes in sung music (e.g. Bigand, Tillmann, Poulin, D'Adamo, & Madurell, 2001; Tillmann, Peretz, Bigand & Gosselin, 2007), and indicating the timbre in which a target note or chord has been played (e.g. Marmel & Tillmann, 2008; Tillmann et al., 2007;

Tillmann, Bigand, Escoffier & Lalitte, 2006).

A large body of studies has demonstrated that a reliable facilitation effect may be observed for more versus less expected targets (especially those targets rendered in the same timbre as the preceding context in a timbre discrimination task, or consonant target chords following an in-tune context in an intonation judgment task) (Bharucha & Stoeckig 1986, 1987; Bigand & Pineau, 1997; Marmel & Tillmann, 2008; Marmel, Tillmann & Delbe, 2010; Tillmann, Bigand & Pineau, 1998; Tillmann et al., 2006; Tillmann et al., 2007). This facilitation effect is typically measured using reaction times although it may also be observed in performance accuracy (e.g. Bharucha & Stoeckig, 1986).

Based on this robust phenomenon, the musical priming paradigm is commonly used to probe musical expectation formation and has convincingly demonstrated that listeners lacking in formal musical training nevertheless possess knowledge of musical structure (Bharucha & Stoeckig, 1986; Bigand & Pineau, 1997; Bigand et al., 2001; Margulis & Levine, 2006; Marmel & Tillmann, 2008; Marmel et al., 2008; Marmel et al., 2010; Tillmann et al., 2006). In addition, the priming paradigm has also been able to reveal spared musical knowledge in an acquired amusic individual, I.R. (Tillmann, et al., 2007). Tillmann and colleagues (2007) demonstrated that patient I.R. was unable to make subjective judgments regarding the extent to which target chords completed a chord progression, but nevertheless showed a processing advantage for targets that were more harmonically related.

Importantly, while the majority of musical priming paradigms have involved harmonic manipulations, where chord progressions can be manipulated to influence the degree to which a subsequent chord is expected (e.g. Bharucha & Stoeckig, 1986, 1997; Bigand & Pineau, 1997; Tillmann et al., 2006, Tillmann et al., 2007), other studies have shown that expectations about the likelihood of occurrence of a single note can be manipulated, in both non-musical and musical contexts (Greenberg & Larkin, 1968; Hafter, Schlauch, & Tang, 1993; Howard, O' toole, Parasuraman, & Bennet, 1984; Lynch & Eilers, 1992; Margulis & Levine, 2006; Marmel & Tillmann, 2008, Marmel et al., 2008, Marmel et al., 2010; Watson & Foyle, 1985). In a series of studies by Marmel and colleagues (2008a-b, 2010), evidence for the influence of musical expectations on the processing of a subsequent pitch has been compellingly demonstrated. Listeners were shown to be facilitated in their processing of more expected versus less expected pitches given a preceding melodic context using both an intonation task (Marmel & Tillmann, 2008; Marmel et al., 2008) and a timbre discrimination task (Marmel & Tillmann, 2008; Marmel et al., 2010).

With the aim of testing whether amusic individuals can form expectations as to how music will unfold, and more specifically investigating the extent to which failure to do so is as a result of the way in which knowledge is probed, two experiments were run in the current study. In Experiment 1, an implicit priming task, where listeners made speeded timbre discrimination judgments on target notes selected to be either high or low in IC, was run, while in Experiment 2, the original version of the priming paradigm soliciting subjective ratings regarding the expectedness of low and high IC target notes was run. Importantly, since previous studies (e.g. Marmel & Tillmann, 2008) reported that cued notes rendered in a deviant timbre failed to produce the predicted facilitation, owing to their timbral incongruence with the preceding melodic context, analysis of results in experiment 1 concentrated mainly on cued events that were rendered in the same timbre as the piano context (piano), Further, following previous research, and based on previous reports that amusic individuals have subtle difficulties in the discrimination of timbre compared to controls (Marin, Gringas & Stewart, 2012), facilitation in terms of reaction time was used as the primary measure of melodic priming. Reaction time analysis is usually limited to those trials on which a correct discrimination response has been made and for this reason a relatively easy timbre discrimination task was employed with the goal of obtaining high levels of accuracy across both groups.

With regard to the implicit task in experiment 1, it was hypothesized that amusic individuals, like controls, may show facilitation for low IC notes, a finding that would suggest that they have implicit musical expectations that do not always reach conscious awareness. On the other hand, for experiment 2, it was predicted that, compared with that of controls, amusic participants' ratings in the explicit task would be less discriminating between the two target categories given the difficulty these individuals face when required to detect melodic violations (Ayotte et al., 2002; Peretz et al., 2003).

3.2. EXPERIMENT 1: IMPLICIT MELODIC EXPECTATION TASK

3.2.1. *MATERIALS AND METHODS.*

3.2.1.1. Participants

A total of 24 participants (12 amusic, 12 control) recruited in the same manner as in the previous chapter, took part in the current study. Table 3-1 provides background information on the two groups in terms of age, gender, number of years of formal education and number of years of musical education. Table 3-2 provides scores on the MBEA subtests and psychophysically measured pitch change detection and pitch direction discrimination thresholds that were included as an additional background measure (see Liu et al., 2010 for procedural details).

Table 3-1: *Descriptive statistics and results of t-tests comparing amusic and control participant characteristics.*

		Age	Gender	Yrs. of musical training	Yrs. of education
Amusic	*M*	53.67	10F	1.17	15
	SD	9.27	2M	3.16	2.22
Control	*M*	49.42	10F	1.94	15.67
	SD	13.83	2M	4.41	1.72
t-tests	*t*	0.88		-0.49	-0.82
	p	0.39		0.63	0.42

M = mean, SD = standard deviation, t = test statistic of the independent samples t-test, p = probability value.

Table 3-2: *Descriptive statistics and results of t-tests comparing performance of amusic and control participants on subtests of the MBEA and psychophysically measured pitch thresholds. The maximum score possible on each subtest of the MBEA is 30 while the maximum possible pitch composite score (calculated by summing scores on the scale, contour and interval subtests) is 90.*

		MBEA scale	MBEA contour	MBEA interval	MBEA rhythm	Pitch composite	Detection* threshold	Direction* threshold
Amusic	*M*	18.67	20.58	18.58	24.5	58	0.19	1.23
	SD	2.53	3.03	2.27	4.36	5.83	0.09	1.38
Control	*M*	27.33	28.08	27.67	28.25	83.08	0.13	0.17
	SD	1.50	2.35	2.27	1.54	5.38	0.05	0.10
t-tests	*t*	-10.2	-6.77	-9.79	-2.81	-11.02	2.10	2.65
	p	<.001	<.001	<.001	.01	<.001	.05	.02

M = mean, SD = standard deviation, t = test statistic of the independent samples t-test, p = probability value. [*] *Detection and direction thresholds: Note data is missing from one amusic and control participant in these tasks. SD and t-tests computed using average threshold (of respective groups) to replace missing data points.*

3.2.1.2. Stimuli

The melodies of 58 hymns, randomly selected and transcribed from a Church of England hymnal (Nicholson, Knight, Dykes & Bower, 1950) were played in their original keys and rendered as MIDI files using the grand piano acoustic instrument of a Roland sound canvas (SC-88) MIDI synthesizer. In order to focus specifically on pitch expectations, the rhythmic structure of the melodies was removed in a musically sensitive manner by a skilled musicologist so that each note had the same duration and equivalent inter-onset interval of 700 ms. This note duration was chosen to give participants sufficient time to make their judgments and reorient to the ongoing melody. Although English hymnals do not usually contain tempo markings, the current IOI is within the normal range for this musical style. The melodies varied in length from 32 to 64 notes (47 melodies of 32 notes length, nine melodies of 48 notes length and two melodies of 64 notes length). The average pitch across all melodies was 68.60 in MIDI number (~ 440 Hz) and there was a mean range within melodies of 11.83 semitones.

The IC of individual notes occurring at a given point in a given melody was objectively defined using the computational model of melodic expectation referred to previously (Pearce & Wiggins, 2006). In this study, the model derived its pitch predictions from a representation of the given note's scale degree, relative to the tonic of the notated key of the melody, as well as the size and direction of the interval preceding it. In brief, each note in a melody is represented by this pair of values (pitch interval and scale degree), and the long term model (exposed to the entire training set -a large corpus of western tonal melody) and the short-term models (trained incrementally over each melody) each generate estimates for the likelihood of each note, represented as such a pair, given the preceding sequence of notes. The predictions of the long and short-term models are combined to produce a single probability distribution, predicting the pitch of the next note.

Figure 3-1 shows the musical notation of a sample melody used in the study along with a profile of the expectedness of all of the notes in the melody as defined by the model.

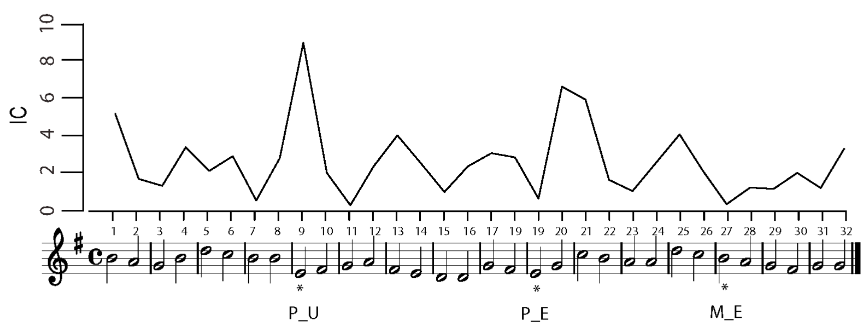

Figure 3-1: *The musical notation of a sample melody used in the study along with the information content profile of the melody as defined by the computational model of melodic expectation (Pearce, 2005). Asterisks mark the target notes, which were an 'unexpected' high IC note rendered in piano, an 'expected' low IC note rendered in piano and another 'expected' low IC note rendered in marimba.*

Target notes in the current study comprised those notes in each melody to which participants were required to make a response. Target notes were selected to be either in the low or high range of the IC profile for each melody with constraints that: *i)* selected notes were at least seven notes after the melody had begun and seven notes after the previously selected note, in order to allow a sufficiently clear context to be established before the participant had to make a response, and *ii)* an equal number of each target-type (low, high IC) occurred at the beginning, middle and end sections of each melody. The number of targets in each melody varied depending on the length of the melody from two to three probes in 32 note melodies, to as many as six probes in the 64 note melodies. The number and position of the target notes in each melody were chosen to be as unpredictable as possible. Figure 3-2 shows the distribution of information contents of all the notes in the 58 hymns that were used in the implicit task and the bimodal distribution of the 82 low IC (IC: M = 1.08, SD = 0.45, range = 0.22 - 1.97) and 82 high IC (IC: M = 4.66, SD = 1.59, range = 2.46 - 9.39) target notes which differed significantly in their IC values ($p < .001$). In the western tonal system the stability of a pitch within a key is related to its position in the tonal hierarchy, and higher ranking/more stable pitches appear more frequently than lower ranking ones (Krumhansl, 1990). In line with this, tonal stability values computed using the empirical key profiles derived from the judgment of expert musicians (Krumhansl & Kessler, 1982) were higher for low than high IC notes (High: M = 4.37, SD = 1.20, Range = 2.29 - 6.35; Low: M = 5.00, SD = 1.06, Range = 2.88 - 6.35, W=4396.5, $p < .01$). Furthermore, consistent with previous reports that large interval sizes are relatively rare in melodies (Huron, 2001), high IC notes tended to follow large interval jumps (High: M = 4.03, SD = 2.58, Range = 0-4) while this was less the case for low IC ones (Low: M = 1.44, SD = 0.8, Range = 0-12, W= 944, $p<.01$).

Once selected, half of the low IC and high IC target notes were altered to a deviant marimba timbre using Anvil studio (Freeware MIDI sequencer), to create the required second timbre category for the timbral discrimination task. Speeded judgments were therefore made on four types of targets: low IC and high IC notes rendered in piano (constituting the main targets of interest) and low IC and high IC notes rendered in marimba (constituting the task foils).

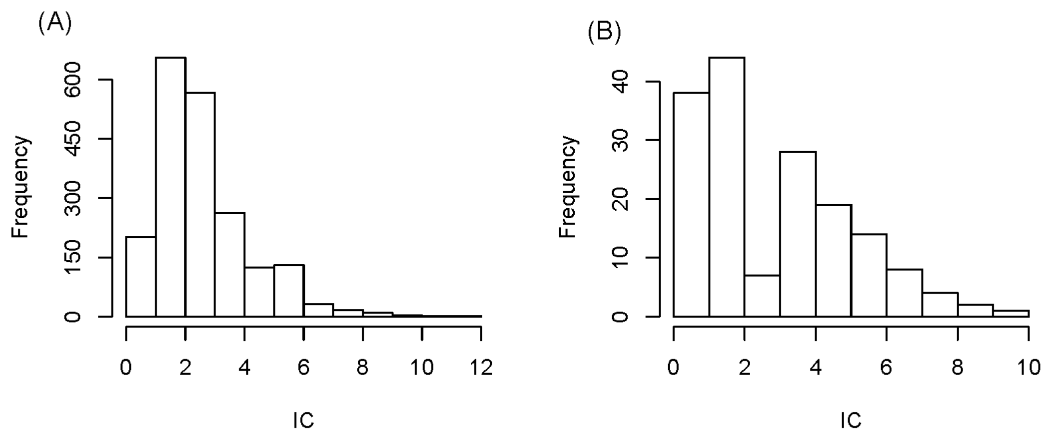

Figure 3-2: *The distribution of information contents (IC) for notes in the 56 hymns used in the implicit task (A) and the same for the 164 selected target notes alone (B). The bimodal distribution of the target notes reflects their selection from opposite ends of the IC distribution.*

3.2.1.3. Procedure

Participants gave written consent to participate and the study was approved by the Ethics Committee at Goldsmiths, University of London. All experiments were conducted in a sound-attenuated booth and controlled by a Java program running on a Dell laptop. Participants were asked to listen carefully to melodies presented over headphones (Sennheiser HD 202) while remaining vigilant for the appearance of a visual response cue. The cue comprised an analogue clock, the hand of which counted down to the target, in time with the melody, pointing in turn to the three, six, nine and finally 12 O' Clock positions on the clock. The participants were instructed to respond to the auditory event whose onset time coincided with the hand of the clock returning to 12. In particular, participants were required to indicate whether the note heard was played in the piano timbre (same as previous notes) or in the marimba timbre. These responses were made using the one and two number keys on a laptop keyboard.

Participants were instructed to respond as quickly and as accurately as possible. Two practice trials were provided to familiarize them with the experimental set-up. Once participants were confident that they understood the task requirements, the testing phase, which took approximately 45 minutes to complete, commenced. This was comprised of 56 melodies, the order of which was randomised across participants. Since veridical memory representations of familiar stimuli, as well as generic expectations (based on one's acquired knowledge of melodic structure) can contribute to the formation of expectations (Bharucha, 1994), participants were required to indicate at the end of each melody whether the melody that they had just heard was familiar to them using a drop-down menu at the bottom of the screen. This additional information could then be used as a covariate in the subsequent analysis to control for any differences that may arise between levels of familiarity reported by the two groups.

3.2.2. RESULTS

Based on previous melodic priming data (e.g. Marmel & Tillmann, 2008), facilitation in speed of response to those targets that were the same timbre as the prime context (the piano notes) was taken as evidence for the formation of pitch expectations. However for the sake of completeness, data from targets rendered with the marimba tone are also presented. Also, following previous research, (e.g. Bharucha & Stoeckig, 1986), additional analysis probing performance accuracy is reported.

Participants gave timbre discrimination responses for almost all trials (amusics: 99.5%, controls: 99.8%). Figure 3-3 shows the accuracy with which amusics and controls made all responses as well as the length of time it took them to make correct responses, presented as a function of target-type (low IC, high IC) and timbre (piano, marimba). Table 3-3 presents descriptive statistics for the same measures sorted by target-type, timbre and group. An independent samples *t*-test indicated that amusic participants reported familiarity with significantly fewer melodies than controls (amusics: 5.95%, controls: 19.05%, $t(1,22) = -3.12$, $p < .01$). For this reason, preliminary analyses were run to examine the influence of familiarity on accuracy and response times. Proportion of correct responses and response times for correct trials (logarithmically transformed) were submitted to separate repeated measures ANCOVA models with group (amusic, control) as between-subjects factor, timbre (piano, marimba) and target-type (low IC, high IC) as within-subject factors, and familiarity as covariate. This analysis revealed no influence of familiarity on either of these measures either when all notes were considered (accuracy: *p*

= .11, speed: p = .64) or when only piano notes were considered (both $p > .1$). Thus, in order to increase the power of statistical analyses addressing the study's main hypotheses, familiarity was not included as a covariate in subsequent analyses.

Figure 3-3. *Mean response times and accuracy in the implicit task presented as a function of target-type (low IC and high IC) and group (amusic and control) for piano and marimba target notes. The error bars represent the mean +/- standard error of the mean. C = Controls and A = Amusics. RT = response times*

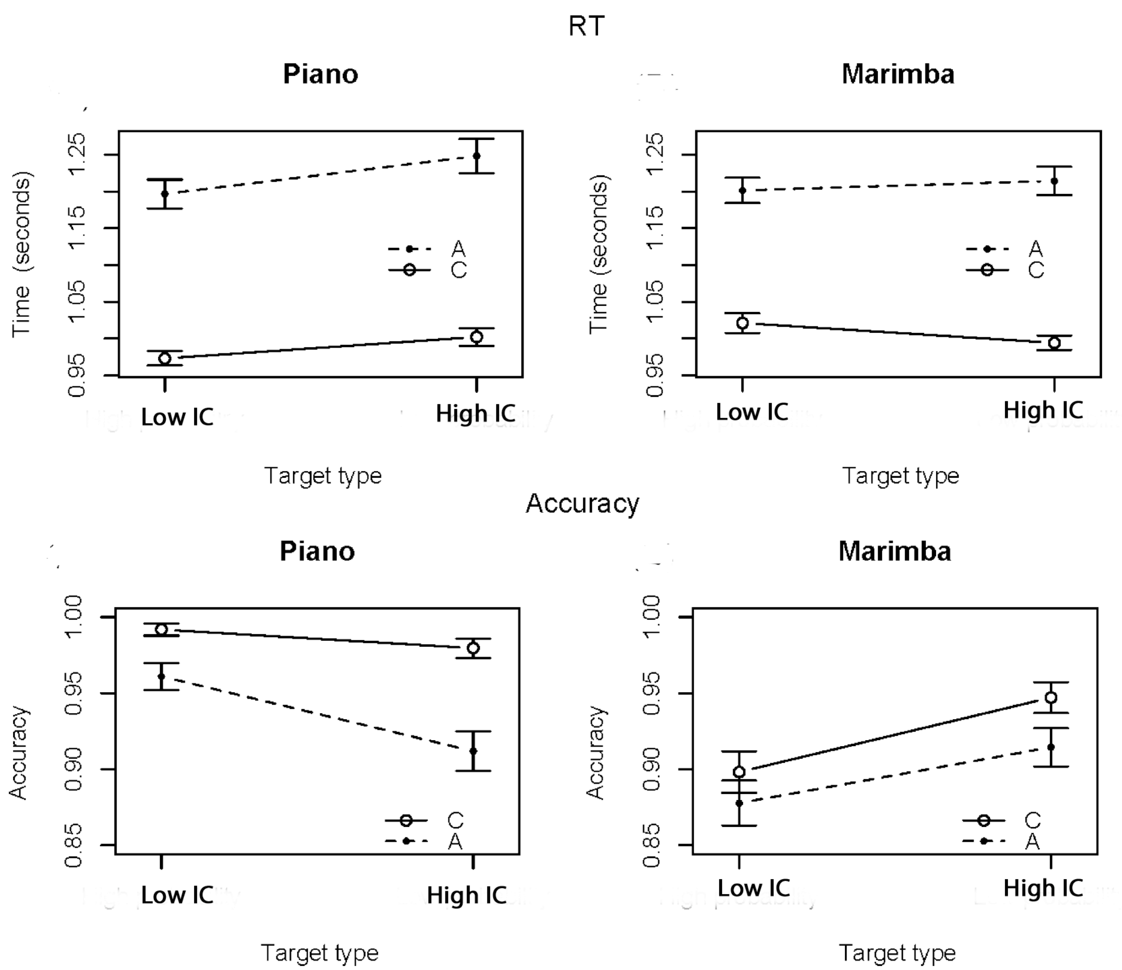

Table 3-3: *Descriptive statistics of accuracy and response times in the implicit task presented as a function of target-type, timbre and group.*

				Low IC	High IC
Accuracy	Amusic	Piano	*M*	.96	.91
			SD	.19	.28
		Marimba	*M*	.88	.91
			SD	.33	.28
	Control	Piano	*M*	.99	.98
			SD	.09	.14
		Marimba	*M*	.90	.95
			SD	.30	.22
RT (secs)	Amusic	Piano	*M*	1.20	1.25
			SD	0.42	0.49
		Marimba	*M*	1.20	1.21
			SD	0.36	0.41
	Control	Piano	*M*	0.97	1.00
			SD	0.21	0.27
		Marimba	*M*	1.02	0.99
			SD	0.28	0.21

M = mean, SD = standard deviation

3.2.2.1. Response time

Response times for accurate trials were logarithmically transformed and submitted to a 2 x 2 x 2 repeated measures ANOVA with group (amusic, control) as a between-subjects factor and timbre (piano, marimba) and target-type (low IC, high IC) as within-subject factors. The main effect of group was significant: $F(1,22) = 7.01$, $p < .05$, indicating that amusic participants were slower to respond than control participants. There was a tendency for participants to respond faster to low IC compared with high IC notes but the main effect of target-type failed to reach significance, $F(1,22) = 4.10$, $p = .06$. There were no other significant main effects or interactions (all $p > .05$) apart from a significant interaction between target-type and timbre: $F(1,22) = 5.6$, $p = .03$, which is investigated below.

Follow up 2 x 2 ANOVAs (group, target-type) were run separately for trials where piano notes were the target and trials where marimba notes were the target. Starting with the ANOVA for trials where piano notes were the target, a main effect of group was observed, indicating that amusic participants responded more slowly than controls, $F(1,22) = 6.97$, $p = .02$. A main effect of target-type was also observed, indicating that participants responded more quickly to low IC than to high IC notes: $F(1,22) = 6.13$, $p = .02$. The absence of a significant interaction of group and target-type showed that this tendency was similar for both groups: $F(1,22) = 0.74$, $p = .40$, and this was supported by follow up *t*-tests which showed comparable *t*-values in both groups (amusics: $t(11) = -1.84$, $p = .09$, controls: $t(11) = -1.94$, $p = .08$). The ANOVA pertaining to trials where marimba notes were the target revealed a main effect of group, reflecting the fact that amusics responded more slowly than controls: $F(1,22) = 5.99$, $p = .02$. There was no main effect of target-type but there was a significant interaction between target-type and group, $F(1,22) = 5.13$, $p = .03$. Paired *t*-tests revealed that while there was no difference in the speed with which amusic participants responded to low IC and high IC marimba notes, $t(11) = -1.10$, $p = .29$, controls responded faster to high IC than low IC marimba notes, $t(11) = 2.15$, $p = .05$.

3.2.2.2. Accuracy

The proportion of correct responses were submitted to a 2 x 2 x 2 repeated measures ANOVA with group (amusic, control) as a between-subjects factor and timbre (piano, marimba) and target-type (low IC, high IC) as within-subject factors. This resulted in a significant main effect of group, indicating that control participants were more accurate in their responses than amusics, $F(1,22) = 5.4$, $p = .03$. A significant main effect of timbre was also obtained, reflecting the fact that accuracy was higher for identification of notes rendered with piano rather than marimba tone, $F(1,22) = 48.76$, $p < .001$. Finally, there was a significant interaction between target-type and timbre, $F(1,22) = 27.86$, $p <. 0001$.

To investigate the significant interaction between target-type and timbre further, follow up 2 x 2 ANOVAs (group, target-type) were run separately for trials where piano notes were the target and trials where marimba notes were the target. Starting with the

ANOVA for trials where piano notes were the target, a main effect of group was found indicating that amusics were less accurate than controls, $F(1,22) = 9.4$, $p <. 01$, and a main effect of target-type showed that low IC notes were more accurately identified as piano notes compared with high IC ones, $F(1,22) = 5.37$, p = .03. The failure of the group x target type interaction to reach significance suggested that both groups showed the same pattern of performance in terms of responding more accurately to low IC notes, $F(1,22) = 1.93$, $p = .18$, although follow up paired *t*-tests revealed that the significant effect of target type in the main ANOVA was driven by the amusic group (amusics: $t(11) = 2.15$, $p = 0.05$, controls: $t(11) = 0.92$, $p = 0.38$).

The ANOVA pertaining to trials where marimba notes were the target revealed a significant effect of target-type, reflecting the fact that low IC notes were less accurately identified as marimba notes compared with high IC ones, $F(1,22) = 17.2$, $p < .001$). There was no significant effect of group (paired *t*-tests confirmed the effect of probe-type was largely present in both groups (amusic: $t(11) = -2.05$, $p = .06$, controls: $t(11) = -4.71$, $p < .05$) and there was no interaction between group and target-type.

3.2.3. DISCUSSION

The experiment here examined the extent to which the response made to a target note in an implicit melodic priming task was influenced by the probability of the target note occurring. Participants were required to make speeded timbral discriminations for notes that were high or low in terms of their IC, given the preceding melodic context. The precise points in the melody where a judgment was required were indicated to the participants using a visual cue as the melody unfolded. Faster processing time for low IC notes presented in the same timbre as the context was taken as evidence of a melodic priming effect. Results showed that amusics were generally slower and less accurate than controls in their timbre discrimination responses but like controls were facilitated in terms of response time for low IC relative to high IC piano notes. Additional analysis showed that amusic individuals were also, like controls, more accurate in identifying low IC notes.

With regard to the observed divergence in the patterns of responding to piano and marimba notes, the current findings are similar to the results of other musical priming experiments which demonstrate that when the target of the irrelevant task maintains the same parameters as the context (for example an in-tune chord following an in-tune context, or a piano note following a piano context) the effects of the musical manipulation are clear in showing a facilitation effect for more *expected* events. In contrast, when the target deviates in some way (e.g., in tuning or timbre), processing accuracy and speed may show no facilitation effects (e.g. Tillmann et al., 2006; Tillmann et al., 2007) or even a reverse facilitation effect whereby processing of the unexpected event is quicker than that of the expected (Bharucha & Stoeckig 1986; Bigand & Pineau, 1997; Marmel & Tillmann, 2008; Tillmann et al., 1998).

In the current study, both controls and amusics showed a reverse facilitation effect whereby they responded more accurately to high than low IC marimba notes. The reverse priming effect observed in intonation judgment tasks has been attributed to congruency effects similar to those found in linguistic priming tasks (Marmel & Tillmann 2008; Tillmann et al., 2006), while a reverse priming effect in the context of a timbral discrimination task has been attributed to a disruption of the acoustical surface and subsequently of the context effect that permits normal expectancy formation (Marmel & Tillmann, 2008; Tillmann et al., 2006). Observing similar results to those seen in the current control and amusic sample, Marmel and Tillmann (2008) proposed that strategic biases may result when a target is perceived as discontinuous with the context, such that a target which is mismatched both in the timbre and pitch domain may actually become easier to identity.

The controls also showed a negative priming effect in terms of reaction time, however, it is interesting to note this effect, believed to be due to the segregation of the deviant timbre from the auditory stream, (Bregman 1990), was not observed in the amusic sample in terms of RT even though it was observed in terms of accuracy judgments. While amusic individuals generally showed longer response times and poorer performance accuracy in their timbre discrimination responses, this does not explain the dissociation they show in terms of timing and accuracy here and thus further investigation may be needed to explain this pattern of results. Nevertheless, based on the facilitation effects shown in terms of accuracy and response time when considering the piano notes, the present results may be taken as indication that amusic individuals are able to form melodic pitch expectations, at least when probed at an implicit level, in turn suggesting that they have assimilated regularities concerning melodic structure over a lifetime of incidental listening

3.3 EXPERIMENT 2: EXPLICIT MELODIC EXPECTATION TASK

Experiment 1 showed an influence of melodic pitch expectations on both the accuracy and the speed with which amusic individuals made speeded timbral discrimination judgments. Experiment 2 investigated the extent to which this evidence of intact implicit processing of pitch probability was accompanied by explicit awareness of melodic pitch expectations. In this experiment, participants gave explicit ratings regarding the expectedness of cued notes in the context of the preceding melody.

3.3.1. MATERIAL AND METHODS

3.3.1.1. Participants

The same 12 amusic and 12 control participants as in experiment 1 took part in this experiment.

3.3.1.2. Stimuli

32 hymns (27 melodies of 32 notes length, four melodies of 48 notes length and one melody of 64 notes length) were selected from the same Church of England hymnal and treated in the same way as melodies in experiment 1. These melodies were distinct from those used in experiment 1 but were characterized by similar IC distributions. The

average pitch across all melodies was 68.28 in MIDI number (~ 415.3Hz) and there was a mean range within melodies of 11.98 semitones.

Target notes were selected to be as similar in IC range as those used in experiment 1, whilst following the same constraints regarding relative distance between target notes and the positioning of the two types of target notes at both the beginning and end of the melodic stimuli. Figure 3-4 shows the distribution of ICs for the 30 hymns used in the experimental phase and the bimodal distribution of the 43 low IC (IC: $M = 1.18$, $SD = 0.42$, range = 0.33-2.08) and 43 high IC (IC: $M = 4.88$, $SD = 1.50$, range = 2.40-9.76) notes selected to act as targets in the explicit task which differed significantly in their IC values ($p < .001$).

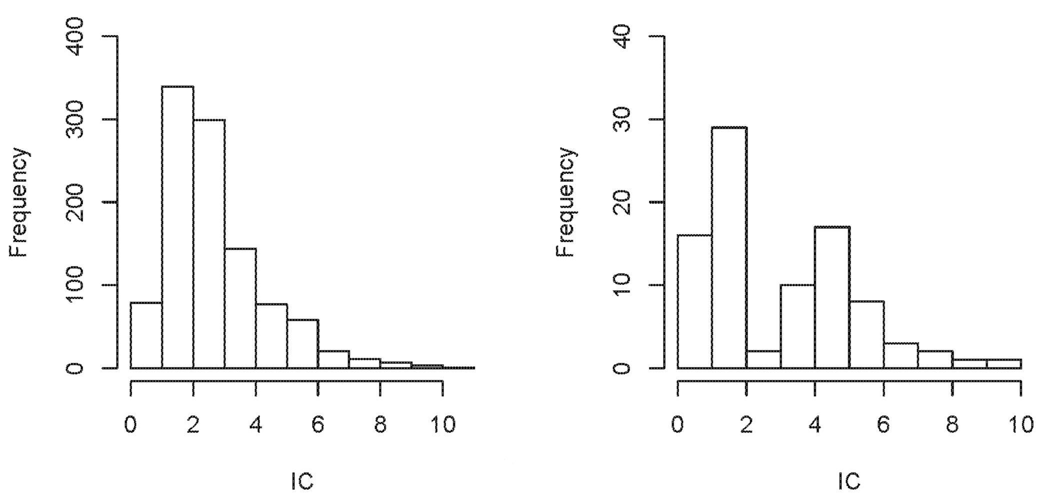

Figure 3-4. *The distribution of information contents for the notes in the 30 hymns used in the explicit task (A) and the same for the selected target notes alone (B). The bimodal*

distribution of the target notes reflects their selection from opposite ends of the distribution.

As with those in experiment 1, high and low IC notes in this experiment differed significantly in tonal stability (High: M = 4.12, SD = 1.33, Range = 2.33-6.35; Low: M = 4.96, SD = 1.09, Range = 2.88 - 6.35, t = 6.61, W = 1273.5, $p < .01$) and size of preceding intervals (High: M = 3.56, SD = 2.31, Range = 0 - 12, Low: M = 1.3, SD = 0.71, range = 0-2, W=407, $p < .01$). Importantly, however, they did not differ in these respects from the corresponding stimulus categories used in experiment 1 (all $p > .05$).

3.3.1.3. Procedure

As in experiment 1, participants were cued to make a response using a visual cue (analogue clock countdown). Participants made rating judgments, on a scale of 1 to 7, indicating how expected they found the cued notes to be, where 1 was *Very expected* and 7 was *Very unexpected*. Participants were encouraged to make their responses using the whole rating scale. At the end of each melody, participants indicated whether the melody that they had just heard was familiar or not. Two practice trials were given to familiarise them with the task before the 30 minute testing phase commenced.

3.3.2. RESULTS

Participants made judgments on almost all trials (amusics: 98.7%, controls: 99.8%). Table 3-4 shows the mean and standard deviations of ratings given by each group to low IC and high IC notes and Figure 3-5 presents mean ratings as a function of target-type.

Table 3-4: *Descriptive statistics of ratings given in the explicit task as a function of group.*

		Low IC	High IC
Amusic	*M*	2.04	2.53
	SD	1.70	1.87
Control	*M*	1.96	3.22
	SD	1.16	1.77

M = mean, SD = standard deviation.

An independent samples *t*-test showed that there was no difference in the levels of familiarity reported by the two groups (amusics: 8%, controls: 14%, $t(1,22) = -1.03$, $p = .31$) and a repeated measures ANCOVA with group (amusic, controls) as a between-subjects factor, target-type (low IC, high IC) as within-subject factors and familiarity as covariate revealed that any within-group influence of familiarity on ratings was not significant ($p > .05$). Familiarity was therefore not included as a covariate in subsequent analyses. Ratings were submitted to a 2 x 2 ANOVA with group as a between-subjects factor and target-type as a within-subjects factor. There was no effect of group: $F(1,22) = .48$, $p = .49$, indicating that there was no difference in the way the two groups used the scale, however a significant main effect of target-type was observed indicating that participants rated low IC notes as more expected than high IC ones, $F(1,22) = 61.72$, $p < .001$. There was also a significant interaction between group and target-type, $F(1,22) =$

11.82, $p < .01$. Further analysis was carried out to investigate the effect of target-type in each group separately. Paired t-tests revealed that although both groups rated low IC notes as more expected compared with high IC notes (amusics: $t(11) = -3.17$, $p < .01$; controls $t(11)= -7.86$, $p < .001$), this effect was stronger in controls than in amusics (effect sizes: controls: $r = .92$, amusics: $r = .69$).

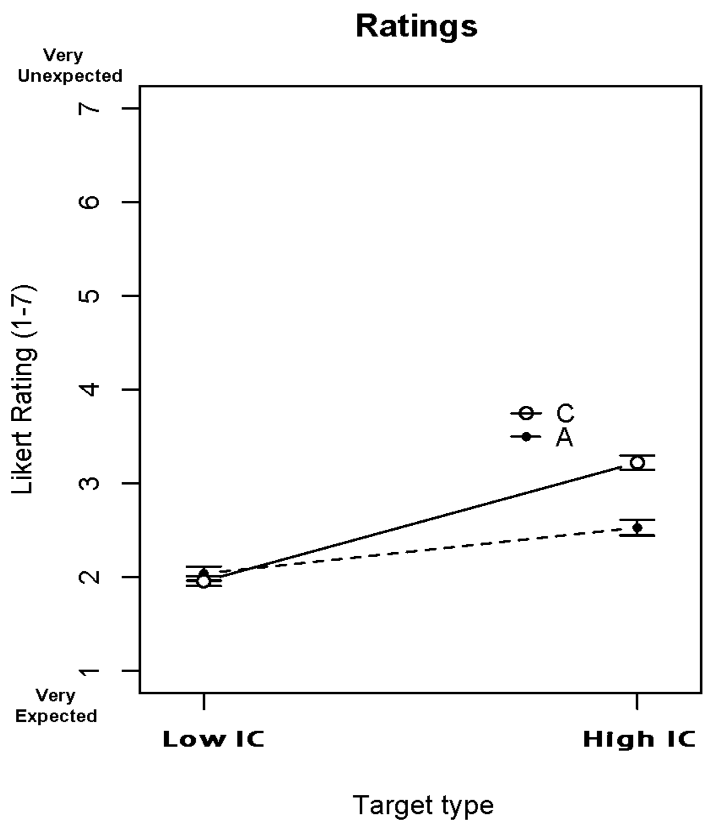

Figure 3-5 *Mean ratings presented as a function of target type for control and amusic groups. The error bars represent the mean +/- standard error of the mean. C = Controls and A = Amusics.*

A further question of interest was whether performance on the implicit and explicit tasks could be predicted by performance on the MBEA scale subtest, or psychophysically measured pitch thresholds. The former constitutes a measure of sensitivity to musical violations and may thus be predicted to correlate with the ability to form expectations, while the latter have been implicated as underlying the disordered musical perception that is seen in individuals with amusia. The difference in accuracy between low and high IC piano notes, as well as the difference in response times between low and high IC piano notes, served as measures of the strength of implicit expectations. Similarly, the difference in ratings between low and high IC notes served as a measure of the ability to make explicit responses regarding melodic structure. As individuals showed differences in average response time, timbre discrimination ability and also in the way the rating scale was used, values on each trial were individually normalized to z scores to focus on the individual difference in response across the two categories.

The only significant correlation found was between the pitch detection thresholds of the amusic sample and their accuracy on the explicit rating task ($r = -.67$, $p = .02$). However further analysis revealed that this relationship was driven by a single amusic participant who gave higher unexpectedness ratings to low IC notes than to high IC notes and the effect did not hold when this individual was removed from the analysis ($p = .34$).

3.3.4. DISCUSSION

Experiment 2 investigated the extent to which the explicit expectedness ratings of amusics and matched controls reflect the varying IC of pitches in the context of the preceding melody. As in the previous implicit task, the precise points in each melody where a judgment was required were indicated using a visual cue, and were selected to be high or low in IC in the context of what had gone before. However, in contrast to the implicit task of experiment 1 where only automatic processing was investigated, the current task assessed the ability of participants to consciously reflect on the perceived expectedness of target pitches given the melodic context.

Analysis revealed that amusic participants were significantly worse than controls at this task. This is in contrast to the implicit task of experiment 1 where, even though amusics were slower and less accurate in discriminating target timbres, they showed equivalent facilitation compared with controls in terms of the speed which with which they responded to low versus high IC targets rendered in the piano timbre (as well as an effect of target type on performance accuracy).

The current findings demonstrate that a different pattern of performance may be seen, depending on whether melodic expectations are probed at an implicit or explicit level. Such a finding parallels the work of Tillmann and colleagues (2007) who showed a similar pattern of results in a single acquired amusic individual. Patient I.R. showed a harmonic priming effect equivalent to matched controls in both a phoneme identification and timbre discrimination task but was deficient relative to controls when required to explicitly judge how well a final chord completed a sequence of chords. Tillmann and colleagues suggested that this demonstrates preserved musical knowledge in I.R. despite her inability to report it.

However it is important to note that despite the impairment amusic individuals showed relative to controls in the explicit task, they were nevertheless able to distinguish between low and high IC notes using their ratings. In this regard they differ from patient I.R., for whom completion judgments for related sequences did not significantly differ from completion judgments for less related sequences. The conscious processing of subtle variations in musical structure shown here by amusic individuals lies in stark contrast to their performance on the scale subtest of the MBEA where they fail to observe gross musical deviants in the form of out of key notes.

3. 4. GENERAL DISCUSSION

An extensive experimental literature has shown that expectations influence the way we perceive events in our environment (Bubic, von Cramon & Schubotz, 2010). The present study investigated whether or not individuals with amusia generate normal schematic pitch expectations implicitly, even if they are impaired in consciously reporting them. In doing so, it provided a test of the extent to which amusic individual possess an important mechanism that is critical for competence in a range of musical tasks. More specifically, it proved a direct test of the emerging notion that amusia may be more accurately considered a disorder of awareness rather than perception.

Implicit expectations have been shown to influence the speed and accuracy with which typical listeners process the acoustic properties of an incoming pitch (Lynch & Eilers, 1992; Margulis & Levine 2006; Marmel & Tillmann, 2008; Marmel et al., 2008; Marmel et al., 2010). While the prediction was that the amusic cohort would be impaired in their ability to explicitly report musical expectations given previously reported deficits; it was hypothesized that their performance on an implicit task may nevertheless reveal the possession of intact expectations outside of conscious awareness (Tillmann et al., 2007). This original hypothesis was confirmed: analysis revealed equivalent levels of facilitation between groups in terms of response time in the implicit task for low IC relative to high IC piano notes while performance in the explicit task revealed a significant difference between the two groups in terms of their ability to use subjective ratings to discriminate between low and high IC notes.

A surprising finding, however, was that amusic individuals, while impaired relative to controls, nevertheless showed a relatively high level of competence in explicitly distinguishing between low and high IC notes. This is particularly striking given the subtle differences that exist between such notes in the natural melodies used in the current experiment. Considering that a previous study showed a complete lack of explicit musical knowledge in an acquired amusic individual (Tillmann et al., 2007), this suggests that those with the congenital form of the disorder are either less severely impaired than acquired patient I.R. and/or the phenomenology of the congenital versus the acquired forms of amusia differ. While it is worth noting that the experimental paradigms differed in terms of both positioning of the targets (interspersed in the current experiment versus final in Tillmann et al, 2007) and the nature of the events (notes in the current versus chords in Tillmann et al, 2007) it is not clear why either or these would result in the differences in performance seen here. Specifically, it does not follow either that expectations would be easier to explicitly report when the target events are within rather than at the end of the melody, nor is there any indication in the literature that melodic deviants should be easier to report than harmonic ones even though these have slightly different neural correlates whereby in addition to an early negativity at the latency of the N1, responses to deviant chords also elicit an additional negativity at a latency of 180ms (Koelsch & Jentsche, 2010).

What the study seems to suggest is that the difference between congenitally amusic and typical individuals, in terms of conscious access to musical knowledge, is not a purely categorical one and that rather than being an “all or none” phenomenon, awareness may be graded. This is in line with theories that suggest that implicit and explicit knowledge are not separate phenomena but rather that implicit knowledge indicates the presence of some, if not complete, levels of knowledge (Cleeremans, 2003). Following in this vein, the current data may be interpreted as suggesting that amusic individuals are not categorically different from controls in terms of their levels of awareness, but lie lower in the spectrum of possible degrees of awareness. Here, it is also worth considering the hypothesis that auditory information is analysed in two main processing streams: a ventral stream, which is concerned with perception, and a dorsal stream, which is concerned with motor functions. On revealing that amusic individuals are able to produce changes in vocal output in relation to pitch changes that they cannot perceive, Loui, Guenther, Mathys, & Schlaug (2008) suggested that the action auditory stream in amusia may be preserved relative to the perception (ventral) stream. One may speculate that the mechanisms employed during vocal production may drive the implicit ability seen in amusic participants in the current study.

Notwithstanding the evidence of present, if diminished, conscious processing of musical structure in amusic individuals, the findings from the current study extend previous work showing that congenital amusia may be better characterised as a disorder of awareness rather than perception (Peretz et al., 2009). A previous study by Peretz and colleagues (2009) used electrophysiological methods to examine the sensitivity of the amusic brain to out of tune and out of key notes in the context of a melody. These authors found an increased early negativity (termed the N200) for out of tune notes that the amusic sample had failed to report, leading the authors to suggest that amusic individuals may be able to process fine-grained pitch differences outside of conscious awareness (although this same dissociation was not seen in response to out of key notes, leading the authors to suggest that amusic individuals lack knowledge of the tonal hierarchy).

In contrast to the afore-mentioned study, which sought to determine whether those with amusia could detect out of tune or out of key deviants, the current study asked whether those with amusia could make a more subtle distinction, distinguishing between notes that were relatively likely versus unlikely to occur, given the preceding melodic context. Critically, the high IC notes were not inserted deviants, rather they were points within an existing melody which were identified by a computational model as relatively unexpected, given the preceding melodic context. Thus, the findings from this study could be said to be more generalisable to everyday music than those of Peretz and colleagues. However, it is worth noting that the current studies used real melodies, which were sometimes familiar to the listener. While analyses were carried out to avoid any potenital confounds, an alternative more parsimonious approach may have been to use novel melodies composed in the relevant musical style (western tonal music).

The conception of amusia as a disorder of awareness rather than perception has also found support in previous observations of individuals with a developmental disorder known as *Tune Deafness*. This disorder, whilst diagnosed using a different diagnostic test to the MBEA, may be related to congenital amusia (Braun, McArdle, Jones, Nechaev, Zalewski, Brewer & Drayna, 2008). Braun and colleagues (2008) investigated the sensitivity of a cohort of tune deaf individuals to deviants in melodic sequences using electrophysiological methods. Like Peretz and colleagues did for out of tune notes in the context of a melody, they observed evidence of one intact electrophysiological index of deviance detection (the P300) in the absence of another (the MMN). The authors proposed a patho-physiological account of the disorder whereby the former electrophysiological marker was taken as evidence of preserved implicit processing, while the absence of the latter was proposed to reflect the absence of conscious awareness of deviations in melodic structure.

Importantly, while exact mechanisms remain to be established, the current findings suggest that amusia may be likened to other conditions such as aphasia, alexia and prosopagnosia, in which reports of a discrepancy between implicit and explicit processing have also been made (Avidan & Behrmann, 2008; McKeeff & Behrmann, 2004; Mimura et al., 1996; Young et al., 1988). Also it is interesting to note that in the visual and auditory agnosia literature, it is common to discriminate between two subtypes namely apperceptive agnosias, and associative agnosias (e.g. Kertesz, 1979, Buchtel & Stewart, 1989). In the former, an individual shows little evidence of appreciating the auditory or visual object's form while in contrast, the latter subtype manifests as an ability to associate an intact auditory or visual percept with the relevant semantic information. The present results tie in with an interpretation of congenital amusia as an associative agnosia, where deficits are seen in labelling or reporting on the properties of an auditory object rather than in perception of the object per se.

In demonstrating that amusic individuals are capable of forming both implicit and explicit pitch expectations, the current findings speak against the characterisation of amusia as a disorder of fine-grained pitch perception (see also Hyde et al., 2010; Moreau et al., 2009; Peretz et al., 2009), since, in order to perform as well as controls in the implicit task and to the extent they did in the explicit one, amusics would need to be sensitive to pitch excursions of differing size. The findings reinforce the suggestion that the performance of amusic individuals on pitch-based tasks may be critically dependent on the way in which knowledge is probed (Liu et al., 2010). Here it is interesting to consider another situation in which pitch discrimination thresholds have been shown to exceed the perceptual abilities required for an alternative task. Hutchins and Peretz (2011) showed that pitch matching abilities in poor singers may sometimes arise from a timbral translation problem. When required to match the pitch of a target note rendered either in their voice or in a voice like timbre, participant were shown to perform much more accurately in the self matching condition.

In sum, the current study provides evidence that while individuals with amusia differ from controls in their ability to explicitly report musical expectations, they do nevertheless form normal musical expectations at an implicit level. This complements results from the previous chapter, which demonstrates that amusic individuals are also able to learn about regularities in novel tonal materials in the context of a short-term incidental learning task. The next chapter describes an experiment that sought to provide a functional account of the disorder by investigating the neurophysiological correlates of the impaired explicit processing of musical structure in amusia.

CHAPTER 4

IMPAIRED PROCESSING OF MELODIC VIOLATIONS IN AMUSIA

To investigate potential differences in the electrophysiological correlates of melodic processing between amusics and controls, electrophysiological recordings were taken from a sample of amusic and control participants as they monitored melodies for a deviant timbre. As in the previous chapter, points of high and low IC in these melodies were identified using a computational model of melodic expectation and ERP analysis investigated how the amusic brain differs from that of controls when processing ecologically valid musical violations. The data revealed an effect of note IC that was highly comparable in both groups: high IC notes reliably elicited a delayed P2 component relative to notes with lower IC, suggesting that amusic individuals, like controls, found these notes more difficult to evaluate. However, high IC notes were also characterized by an early frontal negativity in controls that was attenuated in amusic individuals in line with evidence of a close relationship between the amplitude of such a response and explicit knowledge of musical deviance. The current findings thus suggest that the neural basis underlying amusia may be related to abnormal early mechanisms necessary for the processing of musical pitch deviations. This finding is shown to be reconcilable with previous studies in which later rather than earlier components of the auditory evoked potential have been taken as markers of intact conscious processing.

4.1 INTRODUCTION.

The experiments described in the previous chapter examined how amusic listeners respond to notes of low and high IC based on the predictions of a computational model of melodic expectation. These experiments showed that while amusic and controls were no different in the extent to which they showed evidence of implicit musical expectations, amusics were significantly worse than controls at using explicit ratings to differentiate between low and high IC events in a melodic context.

More recently, also by means of an implicit priming paradigm, but this time, to investigate processing of harmonic structure, amusic participants were shown to be facilitated in their processing of functionally important as opposed to less important chords in the context of chord sequences, providing further evidence that amusic participants can develop expectancies for musical events at an implicit level (Tillmann, Gosselin, Bigand & Peretz, 2012). The current study sought to further investigate this discrepancy between the implicit and explicit music anticipatory capacities of those with amusia by collecting electrophysiological recordings from a sample of such individuals and control participants as they listened to real melodies. To ensure participants maintained attention, they were asked to detect occasional notes played in a different timbre.

Several previous studies have used the ERP approach to investigate how the amusic brain processes musical or pitch-related information (Moreau et al., 2009; Peretz et al., 2005; Peretz et al., 2009). The results of some of these studies have raised the interesting possibility that the brains of individuals with amusia process aspects of pitch that they are unable to report (Moreau et al., 2009; Peretz, et al., 2009) although the use of simple oddball stimuli and manipulated melodies limited the extent to which these studies' findings can be generalized to the processes involved in everyday music listening. To address this, the current study aimed at investigating the neurophysiological correlates of disordered melodic pitch processing in amusia, in the context of ecologically valid stimuli.

In typical listeners, violations of musical expectations have been associated with a number of ERP effects but one in particular has received a great deal of attention due to its presence even when no task is required of the listener. This early negative response occurring at around 150 ms post onset of the deviant musical event has been termed the *Early right anterior negativity* or ERAN (Koelsch, Gunter, Friederici & Schröger, 2000; Koelsch, Schroger & Gunter, 2002; Leino, Brattico, Tervaniemi, & Vuust, 2007) although it is sometimes also referred to as the *Early anterior negativity* when no lateralization is observed (Koelsch, Schröger & Tervaniemi, 1999; Loui, Grent-'t-Jong, Torpey & Woldorff, 2005). The ERAN may be considered as the musical syntactic version of the MMN, which has a similar latency and topography (Näätänen, Paavilainen, Rinne & Alho, 2007).

The ERAN and MMN are often distinguished based on the fact that the MMN is elicited in response to regularities internalised online, during the listening session, while the ERAN is elicited in response to violations of rules present in long term musical knowledge. However they are both similar in being elicited by deviant events that have a high probability of occurring in an auditory stream. In the case of the MMN, this is in relation to an ongoing stream of standard events while in the case of the ERAN, this is in relation to the local context as opposed to the overall probability of the event occurring. Nevertheless, it has been suggested that the two kinds of neural signature may be based on the same mechanism of probabilistic learning. Loui, Wu, Wessel, & Knight (2009) showed that the time course and scalp topographies of the ERP response to violations within an artificially constructed music system are identical to those observed when violations are encountered while listening to stylistically familiar music, while Kim, Kim & Chung (2011) showed that neuro-magnetic responses to musical chords correlate with the probability of that chord occurring in a representative sample of Western tonal music. Importantly, while the ERAN is typically associated with harmonic violations, several recent studies have also reported a similar early negative response, at the latency of the N1, to violations in the context of monophonic melodies (Koelsch & Jentschke, 2010; Loui et al., 2009; Miranda & Ullman, 2007).

Based on the evidence that melodic violations result in a negative deflection at the latency of the N1 (Koelsch & Jentschke, 2010), the amplitude and latency of this component was examined in the current study. As the size of the early negative response elicited in a musical context (the ERAN) has been shown to be related to the probability of an event occurring (Kim et al., 2011; Loui et al., 2009) it was predicted that the size of the observed early negative response in controls would correlate with the degree of note expectedness as predicted by the model. However, as the early negative response has also been shown to correlate with conscious awareness of a musical event as a deviant (Koelsch, Jentschke, Sammler & Mietchen, 2007; Koelsch, Schmidt & Kansok, 2002; Koelsch, Schroeger, & Tervaniemi, 1999; Miranda & Ullman, 2007) it was predicted that individuals with amusia – who lack sensitivity to musical violations at a behavioural level - might show an attenuated early negative response. In addition, as the influence of tonal expectations has been shown on a number of other ERP components, even as early as within the first 100 ms after tone onset (e.g. Marmel, Perrin & Tillmann, 2011), the other obligatory components of the auditory evoked potential, the P1 and P2, were systematically examined to investigate whether there is any effect of note probability on the amplitude and latency of these responses (Naatanen, 1992).

Two sets of analysis were carried out to examine the effect of note probability on components of the auditory evoked potential: In the primary analyses, designed to identify robust neural correlates of musical expectation, notes of low, medium and high IC in each melody were selected using the computational model, and the mean amplitude and latency of the obligatory ERP responses to these types of events were compared. In the secondary analysis, the notes of each melody were sorted by their IC and assigned to ten categories of increasing IC so that the parametric relationship between note probability and the observed ERP effects could be further examined using correlation analyses.

4.2. MATERIALS AND METHODS

4.2.1 Participants

A total of 30 participants (15 amusics, 15 controls), recruited in the same manner as in the previous two chapters took part in the study. Table 4-1 provides background information on the two groups in terms of age, gender, number of years of formal education and number of years of musical education**.** Table 4-2 provides scores on the MBEA subtests and pitch change detection and pitch direction discrimination thresholds that were included as an additional background measure (see Liu et al., 2010).

Table 4-1: *Descriptive statistics and results of t-tests comparing amusic and control participant characteristics.*

		Age	Gender	Yrs. of musical training	Yrs. of education*
Amusic	*M*	56.27	10F	0.27	16.15
	SD	8.51	5M	1.03	1.81
Control	*M*	50.53	10F	0.75	16.4
	SD	10.74	5M	1.62	2.29
t-tests	*t*	1.62		1.00	0.23
	p	.12		.34	.81

*M = mean, SD = standard deviation, t = test statistic of the independent samples t-test, p = probability value. *Yrs of education: Two amusics missing data. SD and t-tests computed using average score (of amusics) to replace missing data point.*

Table 4-2: *Descriptive statistics and results of t-tests comparing performance of amusic and control participants on subtests of the MBEA and psychophysically measured pitch thresholds*

		MBEA scale	MBEA contour	MBEA interval	MBEA rhythm	Pitch composite	Detection* threshold	Direction* threshold
Amusic	*M*	19.4	19.73	18.27	23.67	56.67	0.25	1.40
	SD	2.22	2.55	1.62	3.5	5.19	0.3	1.3
Control	*M*	27.67	27.93	28.00	28.27	83.6	0.14	0.18
	SD	1.63	2.15	2.20	1.39	5.14	0.05	0.09
t-tests	*t*	11.58	9.51	13.77	5.47	14.0	3.29	3.64
	p	<.001	<.001	<.001	<.001	<.001	.005	.002

*M = mean, SD = standard deviation, t = test statistic of the independent samples t-test, p = probability value. * Detection and direction thresholds: Missing data from one amusic and 4 control participants in the pitch thresholds. SD and t -tests computed using average threshold (of respective groups) to replace missing data points.*

4.2.2. Stimuli

4.2.2.1. Musical material

The stimuli consisted of the 58 hymns (including two practice trials), selected and transcribed from a Church of England hymnal (Nicholson et al., 1950) that were used in Experiment 1 (the implicit task) of the previous chapter. However, here, individual notes were created using the electronic piano 1 instrument of a Roland sound canvas (SC-88) MIDI synthesizer and then converted to individual wav files. As before, the melodies were either 32 or 64 notes long and each note had the same duration of 600 ms and an equivalent inter-onset interval of 700 ms. Individual sound files for each note were presented using an E-Prime program, which played each melody in turn. In six out of the 56 melodies presented in the experiment, a single note was modified to play in a different timbre (the electric grand piano instrument of the Roland sound canvas (SC-88) MIDI synthesizer).

4.2.2.2. Selecting the probe notes

Points of varying IC in each melody were objectively defined using the computational model of melodic expectation (Pearce & Wiggins, 2006) used in the previous chapter. Probe notes were selected in different ways for the two types of analysis that were carried out. In the primary analysis, designed to observe which ERP components showed sensitivity to the note expectedness, two notes were selected from the low, medium and high range of the IC profile of each melody. In a secondary analysis, carried out to further explore the relationship between the observed ERP effects and IC, all but the first few notes in each melody (two notes in 32 note melodies, and four in 64 note melodies) were sorted according to IC values and assigned to ten bins of increasing IC. The binning was done on a per-melody basis: three notes of each 32 note melody and six notes of each 64 note melody were assigned to one of 10 linearly spaced IC bins. Figure 4-1A shows the IC profile of a sample melody used in the experiment and Figure 4-1B shows the distribution of ICs of all the notes in the 58 hymns, along with a histogram of the notes selected to act as probe notes in the initial analysis. Figure 4-1C shows the mean IC of the notes allocated to the ten bins that were used in the secondary analyses.

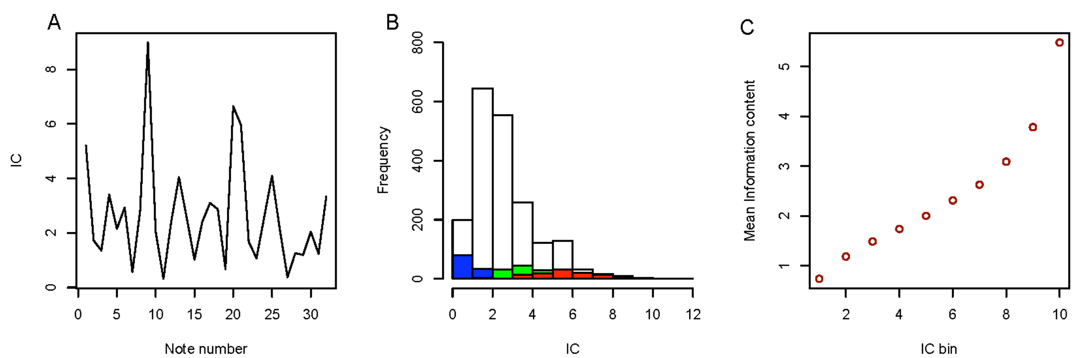

Figure 4-1 *Sample melody IC profile and note categorisation. A) IC profile of an example melody used in the experiment. B) The distribution of ICs for all notes in the 56 hymns (clear bars) and selected target notes alone (low, mid and high rendered in blue, green and red respectively) for the initial analysis. The distribution of the target notes reflects their selection from specific regions of the distribution of the full set of notes. C) The mean IC of notes allocated to ten bins for the correlation analysis.*

Table 4-3 shows properties of the probe notes including mean IC, the mean size of the preceding intervals, the mean tonal stability values computed using the empirical key profiles derived from the judgment of expert musicians (Krumhansl & Kessler, 1982), the mean pitch height (in MIDI numbers) and the mean position of the target note in the melody for the three types of probe notes. Table 4-4 shows the same information for the categories used in the secondary analysis.

Table 4-3: *Descriptive statistics and structural features of low, mid and high IC probe notes*

		IC	Size of preceding interval	Tonal stability	Pitch height	Note position
Low IC	*M*	.83	1.51	4.97	68.9	17.5
	SD	.35	0.71	0.98	3.47	8.41
Mid IC	*M*	3.40	3.29	4.53	69.35	17.86
	SD	0.87	2.04	1.29	3.41	7.89
High IC	*M*	5.92	5.44	4.06	68.79	17.89
	SD	1.7	2.78	1.37	3.97	10.02

M = mean, SD = standard deviation, Pitch height = Mean Midi number, Note position = Mean note number

Table 4-4: *Descriptive statistics of structural features of notes in the 10 IC bins*

		IC	IC Range	Size of preceding interval	Tonal stability	Pitch height	Note position
1	*M*	0.74	0.12-1.42	1.49	4.97	68.82	21.96
	SD	0.30		0.72	0.99	3.25	11.58
2	*M*	1.19	0.46-1.96	1.55	4.77	68.17	19.96
	SD	0.28		0.78	1.11	3.27	11.06
3	*M*	1.49	0.64-2.24	1.35	5.01	67.95	22.08
	SD	0.30		1.04	1.14	3.57	11.53
4	*M*	1.74	0.79-2.59	1.27	4.63	68.30	20.17
	SD	0.33		1.11	1.15	3.48	12.41
5	*M*	2.00	1.15-2.76	1.29	4.62	68.57	21.44
	SD	0.33		1.44	1.11	3.40	11.29
6	*M*	2.31	1.48-3.42	1.42	4.47	68.57	19.82
	SD	0.40		1.53	1.14	3.23	11.42
7	*M*	2.63	1.69-3.69	1.67	4.19	69.42	20.66
	SD	0.45		1.64	1.05	3.32	10.92
8	*M*	3.09	2-5	2.41	4.15	68.94	18.99
	SD	0.62		1.80	1.08	3.38	11.82
9	*M*	3.78	2.11-6.73	3.17	4.20	69.18	20.00

	SD	0.85		2.10	1.17	3.42	10.42
10	*M*	5.48	2.68-10.01	5.1	4.05	68.82	19.01
	SD	1.53		2.65	1.31	3.96	10.61

M = mean, SD = standard deviation, Pitch height = Mean Midi number, Note position = Mean note number

4.2.3. Procedure

Participants were seated in front of a computer monitor in a dark, quiet testing room. Stimuli were presented at a comfortable listening volume through speakers placed behind the participant. The stimuli were presented using the software E-prime in three blocks lasting approximately 12 minutes each. The melodies in each block were presented in randomised order. Participants were instructed to listen to each melody with their eyes closed and detect whether any note in the melody had been played in a different timbre. They were asked to indicate, using a response box, whether or not they had heard a change in timbre. Responses were given after a melody was heard. The purpose of this task was to ensure that participants attended to the stimuli during the EEG recording session. Two practice trials, both of which contained the target timbre, were presented to familiarise the participants with the procedure.

4.2.4 EEG recording

Participants' EEG was measured using the Neuroscan measuring system

(Neuroscan SynAmps2; Compumedics, El Paso, TX). Scalp EEG was recorded at a sampling rate of 500 Hz, using 64 electrodes mounted into an elastic cap. Bipolar vertical and horizontal electro-oculograms (EOG) were recorded from four additional channels to monitor eye movements and blinks. Electrode impedances were kept below 5 kΩ. The average of two ear electrodes (one from each earlobe) was used as a reference. Preprocessing of the raw data was carried out using batch scripts created with the EEGLAB toolbox (Delorme & Makeig, 2004) for MATLAB (The Mathworks Inc, Natick).

Raw EEG data was subjected to a low pass filter of 70 Hz and a notch filter (45-55 Hz) was applied to remove power line noise. Data epochs representing single trials time-locked to the onset of the target notes were extracted from 100 ms pre-onset to 1000 ms post-onset of the target note. Notes from melodies containing the targets (notes played in the different timbre) were not included in the analysis. All epochs were base-lined to the 100 ms pre-stimulus onset period.

The data was cleaned of artefacts by running wavelet enhanced independent component analysis (ICA) on all of the trials from each participant separately (Castellanos & Makarov, 2006). Those components that were clearly artefacts of vertical and horizontal eye movements as well as subjects' heartbeats were identified and manually removed. Epochs were then sorted by probe note and averaged to obtain mean evoked responses for each type of probe note (low, medium and high IC probe notes for the primary analysis and probe notes in IC bins 1-10 for the secondary analysis).

4.2.5. ***.*** *Data analysis*

The primary analysis examined which components showed significant differences according to probe category. ERPs time-locked to the onset of the target note from the individual waveforms were analysed at 16 electrodes over four regions of interest: Left anterior (F1, F3, FC1, FC3), Right anterior (F2, F4, FC2, FC4), Left posterior (P1, P3, PO5, PO3) and Right posterior (P2, P4, PO6, PO4) sites. Peak latencies for the P1, N1 and P2 components were computed, for each participant separately, as the time point of the maximum amplitude in the 0 to 100 ms time window, the time point of the minimum amplitude in the 50 ms to 150 ms time window and the time point of the maximum amplitude in the 100 to 300ms time window, respectively, relative to the 100 ms baseline activity before the note onset, so that subsequent ANOVAs could be used to examine whether individuals from the two groups showed systematic differences in these latencies.

Peak amplitudes for the P1, N1 and P2 components were computed as the mean amplitude of a time window running from 20 ms before to 20 ms after the mean peak latency. Latencies and peak amplitudes were submitted to individual four way mixed ANOVAs with group (amusic, controls) as a between subject factor and probe-type (high, medium and low IC), frontality (frontal, posterior), and laterality (left, right) as repeated measures for each component separately. In the secondary analysis, the electrophysiological components identified in this first analysis, which maximally differentiated low versus high IC events, were correlated with mean IC to further examine the nature and strength of the observed relationships.

4.3. RESULTS

4.3.1. Primary analysis: Identifying correlates of musical expectation

Figure 4-2 and 4-3 show the grand average waveforms for the ERP responses of amusics and controls respectively to low (blue), medium (green) and high (red) IC notes, for all 16 electrodes used in the statistical analyses. Six initial four way ANOVAs (group x probe-type x frontality x laterality) were run**:** three examining the latency of the P1, N1 and P2 and three examining the amplitude of the same components. Follow up ANOVAs were run, where necessary, to examine any observed interactions.

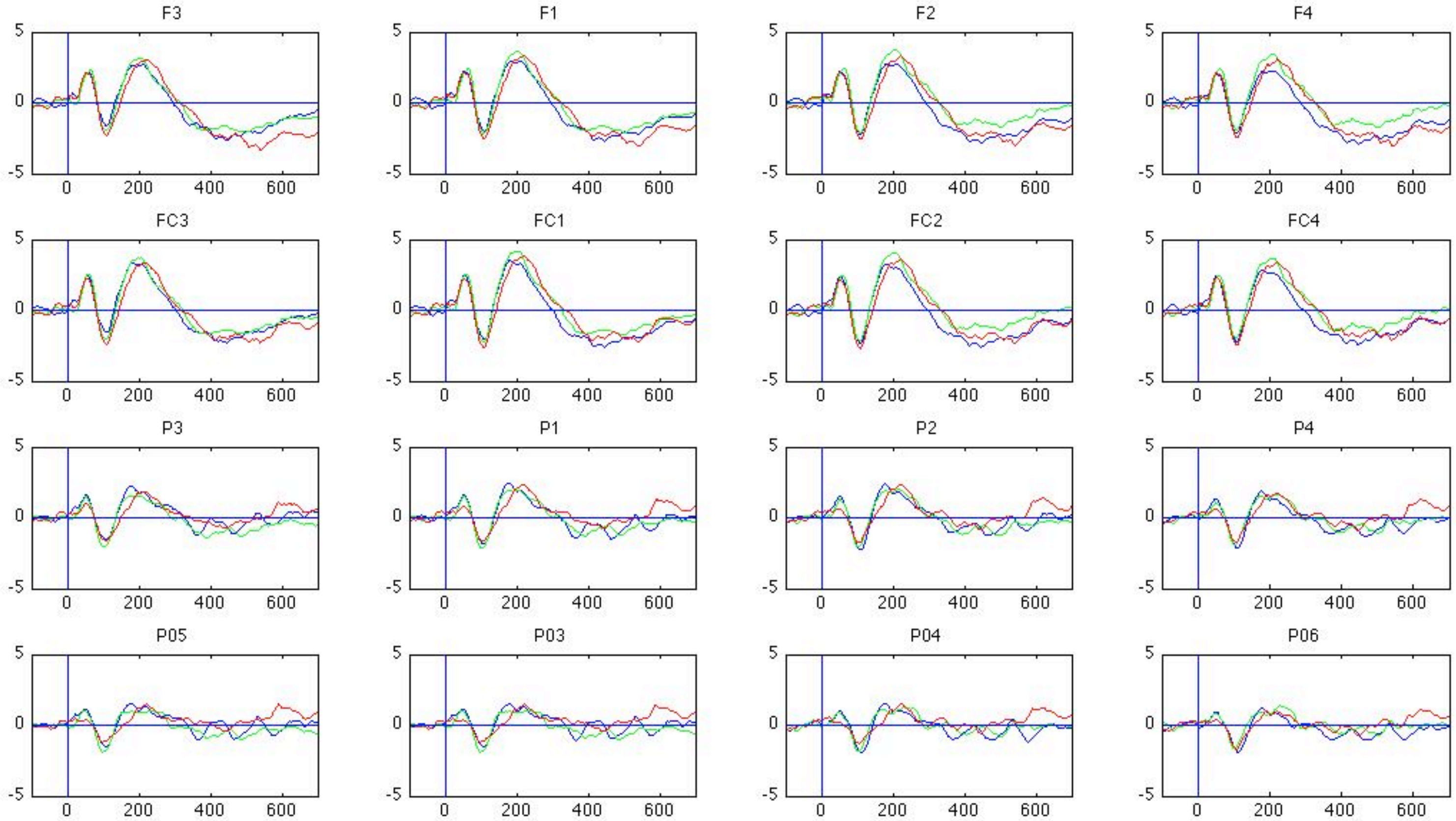

Figure 4-2: *Grand average waveforms for amusics for low (blue), medium (green) and high (red) IC notes, for the 16 electrodes used in the statistical analysis.*

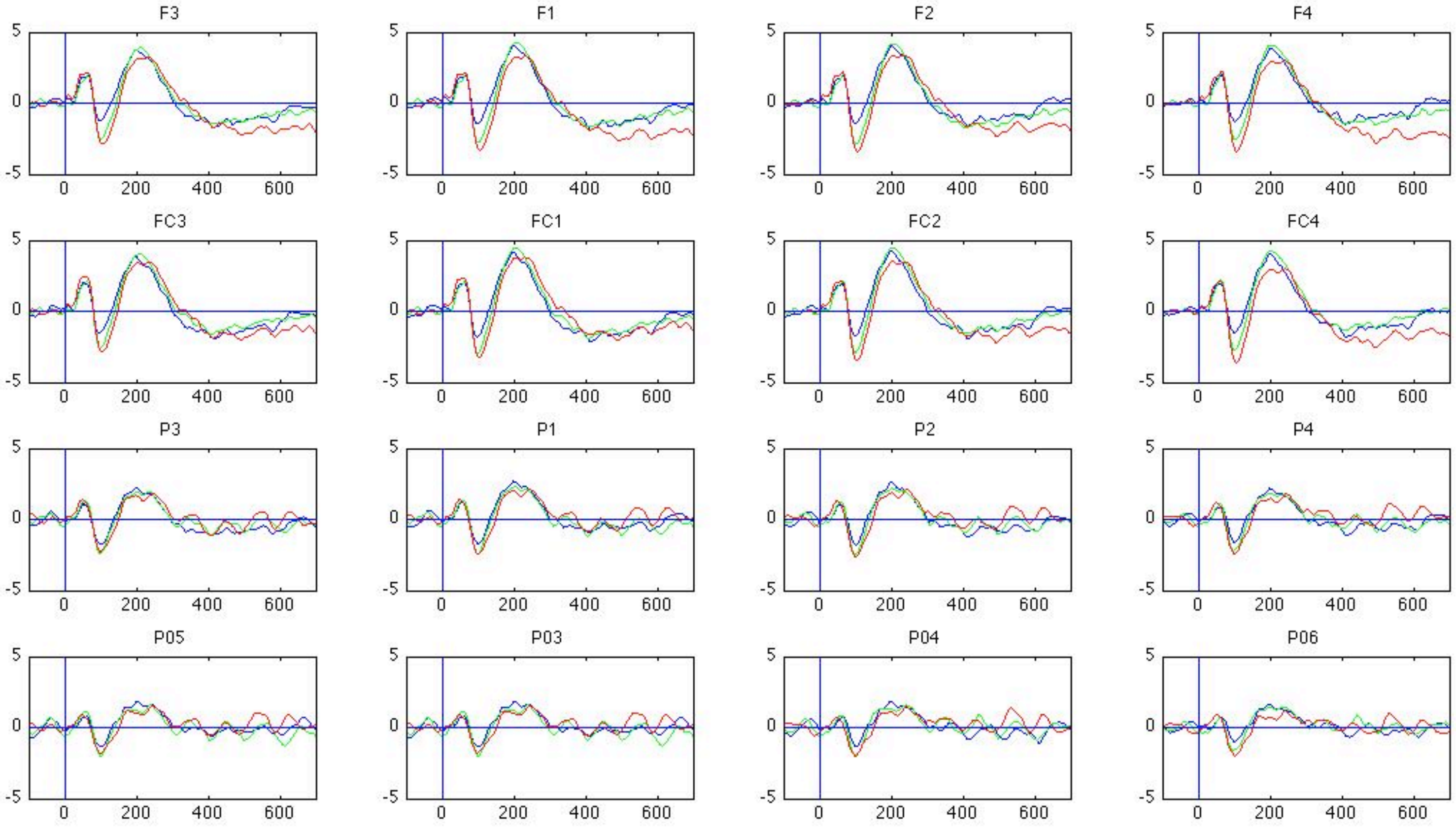

Figure 4-3: *Grand average waveforms for controls for low (blue), medium (green) and high (red) IC notes, for the 16 electrodes used in the statistical analysis.*

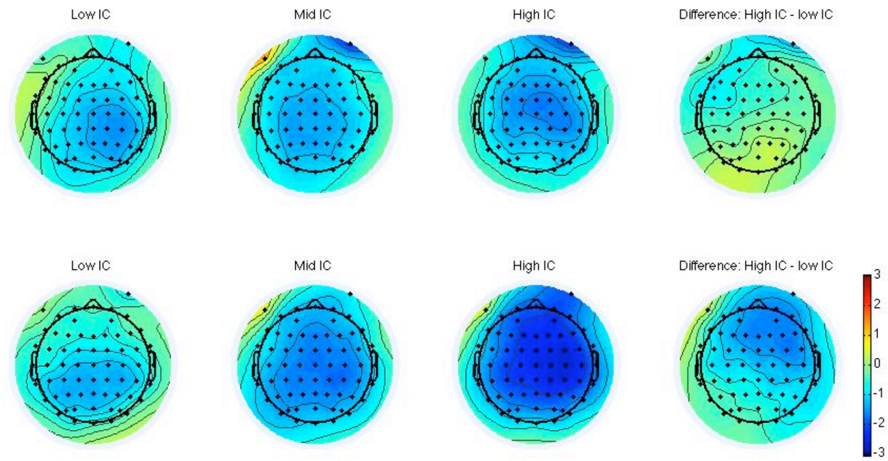

Figure 4-4 *Scalp maps for amusics (top row) and controls (bottom row) showing voltage and illustrating the negativity in the N1 time window for low, medium and high IC notes, and the difference in voltage between the low and high IC conditions.*

4.3.1.1. Latency

No significant effects were found in the four way ANOVA (group x probe-type x frontality x laterality) analyses examining latency of the P1 and N1 components. For the P2 component, a significant effect of probe type, $F(2,56) = 5.52$, $p = .007$, a significant effect of frontality, $F(1,28) = 4.4$, $p = .05$, and a marginally significant interaction between the two, $F(2,196) = 2.81$, $p = .06$, was observed. The significant main effects reflected the finding that high IC events were delayed relative to low IC ones (low IC = 205.86 ms, mid IC = 214.16 ms, high IC = 221.4 ms) and that the P2 latency was shorter in the frontal than the posterior electrodes (anterior = 210.47 ms, posterior = 217.97 ms). Follow up three way ANOVAs (group x probe-type x laterality), exploring the marginally significant interaction between probe type and frontality by examining anterior and posterior electrodes separately, revealed a significant effect of probe type in anterior, $F(2,56) = 10.65$, $p < .001$, but not posterior electrodes, $F(2,56) = 1.10$, $p = .34$. No other effects reached significance (all $p > .1$).

4.3.1.2. Amplitude

Analysis of amplitudes for the P1 and P2 components did not indicate any main effects of group or probe type or any interactions between these factors. However, for the N1 component, there were significant main effects of probe type, $F(2,56) = 3.28$, $p = .045$), and frontality, $F(1,28) = 4.03$, $p = .05$, and significant interactions between group and probe type, $F(2,56) = 4.32$, $p = .018$, and between frontality and probe type, $F(2,196) = 15.8$, $p < .001$. The significant main effects of probe-type and frontality reflected larger N1 amplitudes for high relative to low IC notes (low IC = -1.38 mV, mid IC = -1.73 mV, high IC = -1.94 mV) and larger N1 amplitudes in anterior than posterior electrodes (frontal = -1.91 mV, posterior = -1.46 mV) respectively, in line with the scalp map distribution seen in Figure 4-4.

Follow up three way ANOVAs (probe-type x frontality x laterality) exploring the significant interaction between the group and probe-type interaction by examining amusic and control groups separately, revealed a significant effect of probe type in controls, $F(2,28) = 9$, $p < .001$, but not amusics, $F(2,28) = .06$, $p = .9$. Further follow up three way ANOVAs (probe-type x group x laterality) exploring the significant interaction between frontality and probe-type examined anterior and posterior electrodes separately and revealed a significant effect of probe-type in anterior, $F(2,56) = 7.34$, $p = .001$, but not posterior electrodes, $F(2,56) = 0.32$, $p = .72$. The three way ANOVA (group x probe-type x laterality) examining anterior electrodes alone also revealed a significant interaction between group and probe type, $F(2,56) = 4.25$, $p = .019$, and follow up two way ANOVAs (probe-type x laterality) examining amusic and control groups separately confirmed the significant effect of probe-type in control, $F(2,28) = 10.83$, $p < .001$, but not amusic participants, $F(2,28) = .06$, $p = .54$.

To summarise, two main effects were seen in response to unexpected notes in controls, namely a longer latency P2 and a larger N1 for high IC versus low IC notes at frontal scalp locations. Amusic participants showed the former but not the latter effect.

4.3.2. Secondary analyses: Examining the relationship between observed effects and IC

Analysis was carried out to further investigate the strength and nature of the frontally maximal early negative response (increase in N1 amplitude with increasing IC) and the P2 latency effect (increase in P2 latency with increasing IC) observed in the primary analyses. The mean amplitude of the N1 component and the mean latency of the P2 component across frontal electrodes for each of the ten IC bins shown in Table 4-4 were correlated with the mean IC of the notes in respective bins.

Figure 4-5 illustrates how the N1 amplitude and P2 latency varied as a function of IC bin, and therefore increasing IC level, in control and amusic participants. In controls, significant correlations were found for N1 amplitude (r = -.82, p = .004) and for P2 latency (r = .69, p = .02) providing further support for the earlier observed relationships. In amusics, a marginally significant correlation was observed between P2 latency and IC (r = .58, p = .07) also in line with the primary analyses. However, despite the lack of a significant effect of probe type in the primary ANOVA analyses, a significant relationship between N1 amplitude and IC was also observed in amusic individuals (r = -.72, p = .02) suggesting that they were processing these structural features, although to a reduced extent relative to controls.

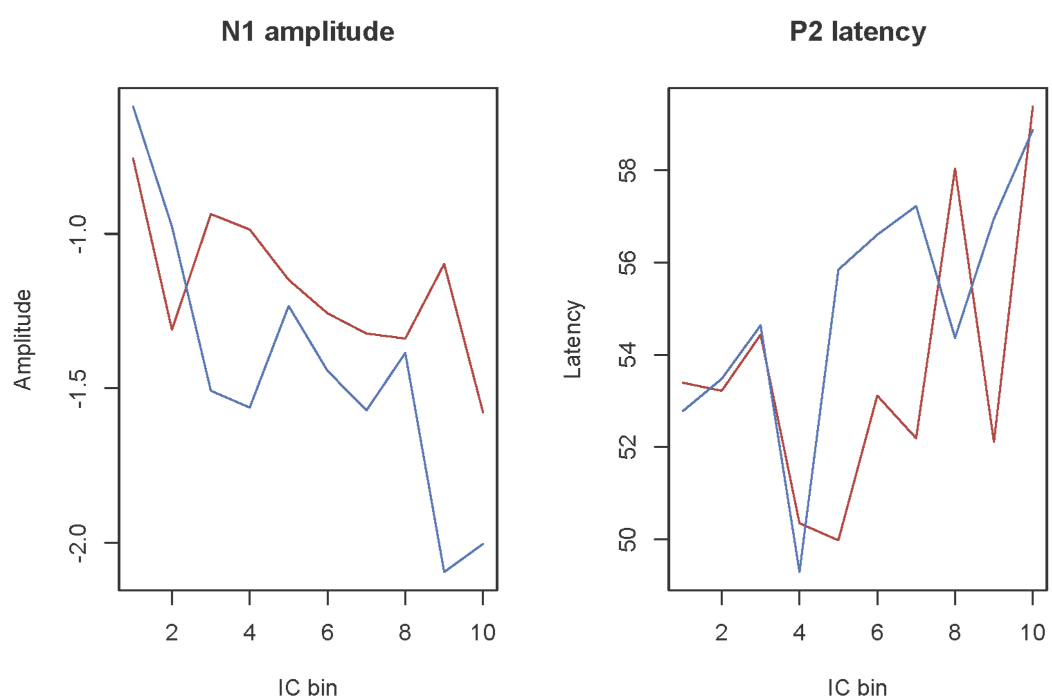

Figure 4-5: *Plot showing* mean *N1 amplitude and P2 latency across frontal ROIs as a function of IC bin in control (blue) and amusic participants (red)*

4.4 DISCUSSION

A defining characteristic of individuals with congenital amusia is difficulty in the detection of gross musical violations. In the previous chapter, two versions of a melodic priming paradigm and the predictions of the current computational model of melodic expectation were used to examine how amusic listeners responded to notes of low or high IC in the context of ecologically valid melodies. It was observed that amusic and controls were similar in the extent to which they showed evidence of implicit musical expectations but critically, that amusics were significantly worse than controls at using explicit ratings to differentiate between low and high IC events in a melodic context.

The current study used electrophysiological recordings, a sensitive measure of pre-attentive and attentive processing of melodic events, to further investigate the observed discrepancies between the implicit and explicit music anticipatory capacities in those with amusia. An effect of note IC that was highly comparable in both groups was found: high IC notes reliably elicited a delayed P2 component, suggesting that amusic individuals, like controls, found these notes more difficult to evaluate. As predicted, high IC notes were also characterized by an early frontal negativity in controls that was diminished in amusic individuals.

The predicted finding of a diminished early frontal negativity in amusic individuals is in line with a previous study investigating melodic processing in amusia, which showed the absence of an N200 in response to out of key notes (Peretz et al., 2009). To account for the lack of an early negative response to deviant events, the authors suggested that amusic individuals may have failed to internalize the regularities present in music. While conceivable, results from the correlation analysis in the current study suggest that any such failure can only be partial. Despite being attenuated relative to controls, a significant correlation between the size of the early negative response and IC was observed in the amusic group. One possibility is that amusic individuals have internalized the regularities in music but have a less robust representation of this information. This interpretation is supported by results from chapter 2 showing that individuals with amusia are just as capable as controls of internalising transition probabilities in novel tonal materials even though they show much less confidence in their decisions as well as inferior explicit knowledge of how they perform.

One important implication of the diminished early frontal negativity observed in the brains of amusic individuals is its support for the notion that early pre-attentive mechanisms predict the degree of musical expertise a listener has. Indeed, a number of studies have provided support for this notion. In one study (Koelsch et al., 1999), expert violinists and musical novices were presented with an oddball sequence in which perfect major chords (standard stimuli) were interspersed with the same chords with a slightly mistuned centre tone (the deviant stimulus). Koelsch and colleagues showed that superior ability of expert violinists to consciously detect the slightly impure chords was reflected in a much larger MMN than for novices who were less able to detect these deviants. In another study, Koelsch and colleagues showed that musical experts possessed a larger ERAN than novices, to harmonically inappropriate chords in the context of a chord progression (Koelsch et al., 2002). They speculated that this might be because musicians have more specific expectations of how music should unfold due to greater explicit knowledge of the theory of musical harmony (Bharucha, 1984). In a follow up study, support for the relationship between explicit knowledge and the ERAN amplitude was provided by the findings that, in addition to producing a larger ERAN, musicians were indeed more accurate than non-musicians at identifying irregular endings to a chord progression (Koelsch et al., 2007).

It is likely that the attenuated early negative response seen in amusic individuals is related to the reduced ability they show in detecting melodic deviants. A similar conclusion was drawn in a recent paper, which showed that the brains of individuals with Tune deafness do not generate an early negativity to altered notes in familiar melodies (Braun et al., 2008). Results from the current study show that this finding generalizes to amusia, a more thoroughly investigated and well understood condition. Further, results from this study show that an attenuated early negativity may occur not just in response to veridical melodic deviants (Braun et al., 2008) or artificial inserted schematic violations (Peretz et al., 2009) but also to subtle violations in the context of natural melodies without alteration.

Importantly, studies relating the amplitude of early negative responses to discrimination performance are in line with the theory that early pre-attentive mechanisms increase the probability that a stimulus change in the environment will be consciously perceived (Rinne, Särkkä, Degerman, Schröger & Alho, 2006). It has been suggested that early pre-attentive mechanisms play an important role in the emergence of conscious perception of less probable events in the auditory environment (Naatanen, 1990) with the theory holding that these pre-attentive mechanisms possess attention-triggering properties (Naatanen, 1990; Winkler, 2007). The current data from amusic individuals provide support for the notion that robust sensitivity of early pre-attentive mechanisms is critical for normal conscious perception of auditory deviance.

An important question is how the N1 amplitude enhancement effect observed in the current study compares to the commonly reported signature of musical expectation violation, the ERAN. Source reconstruction of the ERAN elicited in the context of chord sequences has suggested that it originates in the bilateral inferior frontal lobes and superior temporal cortices (e.g. Maess et al, 2001). Previous studies investigating the ERAN in a melodic context have however shown slight differences in the neural responses to deviant notes and chords (Koelsch & Jentsche, 2010). Specifically while melodic deviants elicit a negative defection at the latency of the N1 (Koelsch & Jentsche, 2010), deviants in the context of a chord sequence tend to elicit two negative deflections one of which occurs later than at the latency of the N1 (Koelsch & Jentsche, 2010). That the negative deflection observed here occurs at latency of the N1 may be taken to implicate potential generators in the Planum Temporale as opposed to having frontal origins. However one may also speculate that the negative deflection observed here reflects communication between temporal and frontal regions as has been suggested is the case with harmonic violations. A recent intracranial EEG study examining the neural substrate of syntactic violations in music and speech emphasised the role of the bilateral temporo–fronto-parietal neural networks, with the authors suggesting that the putative role of the temporal lobe is be to identify the syntactic status of the incoming item and to "match it with local syntactic expectancies in cooperation with the inferior frontal lobe". (Sammler et al, 2012). According to this account, a deflection seeming to originate from sources in the region of the temporal lobe may still reflect the downstream effect of higher order predictions from frontal areas.

An interesting additional finding was that of a significant influence of note probability on the latency of the P2 in both amusic and control participants. While numerous studies have examined the neural correlates of musical expectation (Besson & Faïta, 1995; Besson & Macar, 1987; Paller, McCarthy, & Wood, 1992; Verleger, 1990), to our knowledge, the current study is the first report of a P2 latency effect. It has been suggested that the latency of certain ERP components is an indication of the speed with which stimuli are evaluated (Polich, Ellerson & Cohen, 1996) and indeed, the latency of several ERP components has been shown to co-vary with task difficulty, whereby more complex tasks result in longer latencies of the P1, N1, P2 and P3 (Goodin, Squires & Starr, 1983).

Another possibility is that the delayed P2 is a result of slower recovery from a deeper N1, however the fact that only the N1 component showed a group effect speaks against this interpretation. In the current study, participants were required to evaluate each note for a change in timbre and the P2 latency effect observed here is interpreted to reflect the greater difficulty participants had in processing unexpected notes relative to expected ones. Indeed, in the behavioural study in the previous chapter, both amusic and control participants showed longer response times when determining the surface feature (timbre) of high IC notes, relative to low IC ones, perhaps as a result of the increased processing time required for processing the unexpected pitch.

Finally, it is interesting to consider how the effects seen in the N1 and P2 tie in with the anomalies that have been shown in amusic individuals. Repeated MEG recordings in a single subject (Lutkenhoner & Steinstrater, 1998) also corroborated by findings from other studies (e.g. Ross & Tremblay, 2009) have suggested that N1 sources lie in the Planum Temporale, an auditory association area in the temporal lobe, while P2 sources lie in lateral Heschl's gyrus, the secondary auditory cortex, also in the temporal lobe. The fact that amusic individuals showed equivalent P2 responses with controls is in line with functional imaging data suggesting that amusia is not simply due to a dysfunction of the auditory cortex (Hyde et al, 2011). The authors showed that brain activity increased as a function of increasing pitch distance, even for fine pitch changes, in both the left and right auditory cortices but that there was an anomalous deactivation of the frontotemporal auditory pathway in the same context. Given the involvement of the planum temporale in the fronto-temporal network, the current data, showing insensitivity of the N1 to IC in amusia, seem to support the conceptualization of amusia as a deficit of impoverished communication between frontal and temporal regions of the brain.

In sum, the current electrophysiological study provides an interesting extension to the findings from the previous chapter, which demonstrated diminished explicit awareness of musical deviance alongside seemingly intact implicit knowledge in amusia. Firstly, although further work is clearly needed to examine the nature of this novel effect, the finding - across both groups - of a delayed P2 component in response to high IC notes suggests a potential neural correlate for the intact knowledge of musical structure amusics show at an implicit level (Chapter 3). Secondly, given the established link between the amplitude of early negative deflections and explicit knowledge of musical deviance (e.g. Koelsch et al., 2007, Miranda & Ullman, 2007), the finding of an attenuated early negative response in amusic individuals suggests a potential biological correlate of the reduced explicit knowledge shown by these individuals.

The next and final chapter asks whether previously reported impairments, along with the abnormal levels of awareness of musical structure shown in the studies in this thesis, influence the extent to which amusics show normal engagement and appreciation of music. The answer to this question is of relevance not just for a better understanding of the disorder but also for a better understanding of the relationship between music perception and appreciation

CHAPTER 5

THE EXPERIENCE OF MUSIC IN EVERYDAY LIFE: AN EXPERIENCE SAMPLING STUDY

Much research has focused on trying to identify the deficits underlying congenital amusia, however the extent to which these have an impact on the ability to engage with and appreciate music remains mostly unexplored. The final study in this thesis sought to address this issue by using experience sampling methodology to examine patterns of music-related behavior in individuals with amusia and matched controls. A multivariate analysis technique, cluster analysis, was used to group individuals according to the similarity of their behavior, regardless of their status as amusic or control. This yielded a two-cluster solution: one cluster comprising 59% of the amusic sample and 6% of controls and the other comprising 41% of the amusic sample and 94% of controls. Comparisons of the two clusters in terms of specific aspects of music listening behavior revealed differences in levels of music engagement and appreciation. Further comparisons provided support for the existence of amusic subgroups showing distinct attitudes toward music.

5.1 INTRODUCTION

Behavioral testing has typically been concerned with characterizing the deficits underlying amusia, but little attention has been paid to the impact these have on everyday uses and appreciation of music. At least two alternative scenarios may be anticipated regarding the extent to which amusia impacts on engagement with music. In one scenario, if engagement and appreciation of music are dependent upon the listener having an intact and conscious representation of its intrinsic features, then one would expect that individuals with amusia would be unable to fully engage with and appreciate music. Cochlear implant users constitute one group of individuals for whom an impoverished perception of music's intrinsic features negatively impacts on levels of music appreciation (e.g., Gfeller, Christ, Knutson, Witt, & Mehr, 2003; Leal et al., 2003). Due to limitations in the current state of technology, the cochlear implant device is constrained in its ability to code the spectrum of sound needed to perceive pitch and timbre (Galvin, Fu, & Nogaki, 2007; Sucher & McDermott, 2007). Not surprisingly, some cochlear implant users describe music as "*hard to follow*" and rate the sound of musical instruments as "*emptier*" than they would have expected a normal hearing listener to have perceived it (Gfeller, Witt, Woodworth, Mehr, & Knutson, 2002; Gfeller et al., 2003). In line with the suggestion that impaired perception may be a limiting factor in the appreciation of musical sound, several amusic individuals report difficulty in making sense of their perceptual experience. One individual says:

> *I know that [music] is respected and loved by many but I just cannot get the point. I do not see what enthuses people or why it is so pleasurable. Growing up in the 60's, I did learn lyrics and tunes but could never hold the tunes… I can remember lyrics as poems, and whilst I can appreciate the words, the tunes leave me thinking 'what is that all about…?' (J.S., personal communication, 9/1/2007).*

On the other hand, it may be that engagement and appreciation of music can emerge from factors that are extrinsic to the music itself. Sociological, psychological, and ethnographic research emphasizes music's many different affordances in aspects of our personal lives, our social lives, and at different stages of our maturity. Young listeners may exploit specific types of music to construct a sense of self, communicating their values and beliefs through their musical preferences while older listeners may use the music of their youth to evoke memories and maintain a sense of identity even as the need for impression management wanes (MacDonald, Hargreaves, & Miell, 2002; North & Hargreaves, 1999; Zillmann & Gan, 1997). DeNora (2000) describes the widespread use of music as a way of "*organizing one's internal and social world, helping to continually reconstruct the aims of various activities*" and provides multiple real-life examples of music's various roles, from creating a personal sound environment to managing social situations while Small (1998) coins the term "*musickin*g" to describe music as something that is done and taken part in, rather than an abstract art to be contemplated.

According to this view, imprecise encoding of music's intrinsic features, as occurs in amusia, would not necessarily prevent engagement and appreciation of music. Small (1998) further describes the widespread phenomenon of audience members "*sharing with strangers*" at musical performances and the "*underlying kinship*" that exists between them even though they do not speak. Furthermore, a plethora of literature from different disciplines emphasizes music's power to create feelings of belonging in its listeners (Hays & Minchiello, 2005; Russell, 1997). Thus, it is presently unclear whether music processing deficits, as seen in amusia, can be expected to impact upon the engagement with and appreciation of music and addressing this question empirically was the focus of the present study.

A previous study provided information on this question. In order to investigate the uses and importance of music in the everyday lives of a group of individuals with amusia, McDonald and Stewart (2008) used a questionnaire study to probe the situations in which amusics individuals used music, the psychological functions they attributed to music, and their feelings about music in public places. The results showed that, in general, amusic individuals did not incorporate music into their lives to the same extent as matched controls. Moreover, music did not seem to fulfill psychological functions (such as matching or changing mood; evoking memories of past people and places) to the same degree. Nevertheless, the authors found a wide range of profiles within the sample of amusic individuals they evaluated, with a subgroup proving indistinguishable from the controls in these respects.

While informative, the authors' questionnaire study was limited in the level of detail it provided. The study neither afforded the opportunity to probe individual instances of musical listening, nor captured the possible mediating effects of situation and company, both of which may be important factors in the use and experience of music (North, Hargreaves, & Hargreaves, 2004). Experience Sampling Methodology (ESM; Larson & Csikszentmihalyi, 1983) allows collection of data on the uses, functions, and effects of music, as well as detailed information on the different contextual factors that may influence listeners' reactions and behavior. ESM data can be summarized quantitatively and so lends itself to statistical analysis. The technique, which involves contacting participants in the "*stream of everyday life*" (Konecni, 1982) and prompting them to complete pre-prepared diary forms relating to their experience of music at that point in time, offers a degree of ecological validity that is lacking from retrospective reports while maintaining a systematic framework that allows experiences and listening behaviors to be evaluated and compared.

Sloboda, O'Neill, and Ivaldi, (2001) demonstrated the value of the ESM approach for probing the uses and importance of music in every day life in a seminal study focusing on a small sample of individuals. Subsequently, North and colleagues (2004) used the same methodology on a much larger sample of individuals and in doing so were able to demonstrate the ubiquity of music listening in the general population. Typical listeners in the study reported a high incidence of exposure to music - often, though not always, as a result of consciously incorporating it into a range of everyday activities (from driving to bathing) and with the aim of achieving various psychological states. Results further demonstrated that effects of music on a listener and the levels of engagement and appreciation they exhibited depended on a range of factors including the degree of control the listener had over the music being heard, the situation in which the music was heard, and whether or not the listening episode occurred in the presence or absence of others.

The present study used an ESM approach with a group of amusic individuals and a group of controls matched on age, gender and years of music training to address the question of whether individuals with amusia engage with music differently in everyday life compared to typical listeners and the extent to which this is mediated by contextual factors such as situation and company. A questionnaire based on that used by North and colleagues (2004) probed details concerning the frequency of exposure to music, the frequency of choosing to listen to music, and the subjective levels of liking and attention reported by amusic and control individuals. These profiles also included information on the frequency of reporting different reasons for listening (if chosen) and effects of listening (if not chosen) as well as what the participant was doing and who they were with during ESM episodes in which music was heard.

In order to make full use of the rich dataset afforded by the ESM approach, data incorporating information relating to all variables were obtained and summarized into profiles for each individual. Cluster analysis allowed grouping of individuals, regardless of their status as amusic or control, according to the similarity of their profiles. Once a grouping solution was found, the composition of groups in terms of individuals (amusic versus controls) could then be established, followed by post-hoc testing to probe which facets of musical behavior differed between the groups that were identified as dissimilar. In this way, the method initially determined whether individuals with amusia are similar or different compared with non-amusics while subsequent tests described the precise ways in which they differed.

5.2 MATERIALS AND METHODS

5.2.1 Participants

Seventeen individuals with amusia and 17 controls recruited in the same manner as in the previous chapters and matched for age, gender, and musical training, participated in the study. During the study, a comparable proportion of participants were involved in full time employment in the two groups (70%). Table 5-1 provides background information on the amusic and control groups, while Table 5-2 provides demographic and individual scores on the MBEA subtests.

TABLE 5-1: *Descriptive statistics and results of Mann Whitney U tests comparing amusic and control participant characteristics*

		Age	Gender	Years of Musical Training
Amusic	*M*	45.65	5M,12F	0.97
	SD	12.08		1.94
Control	*M*	45.06	5M,12F	1.88
	SD	12.24		3.08
	U	152.5		128
	p	.796		.528

M = mean, SD = standard deviation, U = test statistic of Mann Whitney U test, p = probability value

TABLE 5-2: *Demographic details and individual MBEA subtest scores for amusic participants and performance of controls on scale subtests. The maximum score possible on each subtest is 30 while the maximum possible pitch composite score (calculated by summing scores on the scale, contour and interval subtests) is 90. A cut off score of 22/30 was applied for each of the subtests. Individuals were classified as amusic if their pitch composite score fell below a cut off score of 65.*

AMUSICS	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17
Demographics																	
Gender	F	M	M	F	M	M	F	F	M	F	F	F	F	F	F	F	F
Age	28	32	35	38	38	48	48	54	56	56	56	57	57	62	39	21	51
Education	18	16	13	16	20	11	13	14	16	16	16	20	17	17	11	13	20
Music training	0.5	0	0	0	0	0	0	1	0	0	0	3	0	0	1	7	4
MBEA																	
Scale	17	20	14	20	18	21	17	23	18	23	16	19	19	23	17	23	20
Contour	15	22	15	22	20	18	24	16	21	20	14	23	19	23	25	23	20
Interval	17	19	14	22	18	18	24	17	16	19	16	18	16	18	20	17	21
Composite	49	61	43	64	56	57	65	56	55	62	46	60	54	64	62	63	61
Rhythm	19	25	18	23	14	24	29	23	20	29	24	27	21	28	27	24	22
CONTROLS	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
Gender	F	M	M	F	M	M	F	F	M	F	F	F	F	F	F	F	F
Age	28	28	37	34	38	47	52	50	57	53	54	63	54	60	39	22	50
Music training	8	0	0	0	0	0	0	1	0	2	0	0	0	3	3	10	5
Scale test 1	27	26	29	28	26	28	26	27	25	26	27	27	27	26	26	30	27
Scale test 2	28	27	30	29	30	29	26	28	26	28	-	-	28	27	28	30	29
Average	27.5	26.7	29.5	28.5	29	28.5	26	27.5	25.5	27	27	27	27.5	26.5	27	30	28

5.2.2 The Experience Sampling Diary

Each participant was provided with a compact and portable diary, allowing them to detail information about their experience of any music in the environment when contacted. Participants were required to fill in one sheet every time they received a text message on their mobile phone. Each sheet, shown by pilot testing to take less than a minute to complete, contained roughly ten items. The initial section on each diary sheet asked for information about the date and time that the text message was received, the time when the sheet was completed and whether or not music could be heard. The subsequent items were only relevant if music could be heard. Following North and colleagues (2004), participants were probed on the following aspects of their music listening behavior: whether the participant was alone or with company (yes/no) and whether or not they had chosen to hear the music (yes/no). Episodes where music was heard were probed concerning reasons for listening (if self-chosen), effects of the music (if not self-chosen), degree of liking and attention, and ongoing activities (respondents were required to circle from a list of items including housework, getting dressed, and bathing). Details about the genre of music were also requested (see Appendix 1 for a sample sheet of the diary).

5.2.3 Procedure

All participants completed and returned written consent forms to participate in the research, which was reviewed and approved by the Goldsmiths, University of London Ethics Committee. Diaries were sent out to all participants along with a detailed instruction sheet explaining what was required of them. Participants were requested to keep the diaries with them at all times for the duration of the study and to fill in one sheet of the diary as soon as possible after receiving a text message, noting the time at which the entry was made.

Over the duration of the week-long study, participants were contacted by text message using an online messaging service (http://www.fastsms.co.uk/). They were sent six text messages a day for seven days between the hours of 8:00 a.m. and 11:00 p.m. The six text messages sent to each participant were spread out across the time window to sample twice, on average, from different parts of the day (morning, afternoon, evening) while varying the exact times from day-to-day to avoid predictability. Exact times differed across participants but were balanced between groups. At the end of the study, participants returned the diaries using pre-stamped/addressed envelopes.

5.2.4 Analysis

5.2.4.1 Data Pre-processing

All items in the paper ESM diaries were coded and entered into an electronic spreadsheet. Participants showed a high compliance rate with 98.80% (1,411 out of 1,428) of all forms completed in total. Of these 73.14% (1,032) were completed within ten minutes of receiving the text message. No difference was found between controls (M = 17:39) and amusic (M = 16:99) participants regarding the delay between receiving the text message and responding to it, $t(32) = 0.07$, $p = .94$. For the purposes of reliability, a limit of three hours was chosen as the longest acceptable delay. This qualified for further analysis a total of 705 (amusics) and 670 (controls) episodes. Of these, 166 (23.50%) and

294 (43.90%) were listening episodes (diary entries where music was reported to be present) for each respective group. Details for each listening episode were coded into two formats: Yes/ No responses representing binary judgments (e.g., music chosen or not, listening alone or not, listening to pass the time or not, etc.) and numeric scores on a Likert rating scale (1 to 10) representing listeners' reported psychological state (e.g., liking and attention).

5.2.4.2 Hierarchical Cluster Analysis

To make full use of the rich dataset, a multivariate technique was employed to allow simultaneous consideration of multiple variables. A cluster analysis groups objects into subsets such that objects in subsets are similar to each other but dissimilar to members of the other subsets (Everitt, 1974). Agglomerative hierarchical clustering (the specific type of clustering employed) starts with every single object forming a single cluster and, over each successive iteration, merges the most similar pairs until all of the data is in one cluster (Everitt, 1974). In the current study, individuals were the objects merged over successive iterations, according to their similarity. One advantage of the technique is that it allowed individuals to be categorized into groups based on the multiple variables needed to satisfactorily summarize listening behaviour. Another advantage of the technique is that it provided an unbiased method of identifying potential heterogeneity within the amusic and control samples.

To make the data suitable for cluster analysis, it was necessary to transform them into a format that defined a listening profile for each of the 34 participants. Proportion variables were created from single episodes by expressing the incidence of a given observation as a proportion of the number of times the observation could possibly have been made. Thus, for each individual, the number of episodes where music was heard (listening episodes) was expressed as a proportion of the total number of times the individual made a response in the diary. Similarly, the number of listening episodes experienced with company, the number of chosen music episodes, and the number of episodes with which individuals reported different company types, were expressed as a proportion of the total number of listening episodes. The frequency of each possible reason for listening to music was expressed as a proportion of the number of times they actually chose to listen to music, while the frequency of each of the effects of listening was expressed as a proportion of the number of times they heard music without having chosen it. The degree of liking and attention was expressed as the mean rating across all music episodes experienced. In order to convert these condensed responses into a series of dimensionless quantities, each individual's value for each variable was expressed as a *z*-score with respect to the means and SDs of both groups combined. A log transform was first applied to all proportion variables in order to make the distribution of the proportion variables comparable to those variables that were derived by averaging Likert scores. The result of these steps was a data frame consisting of 44 standardized variables for all 34 participants (see Table 5-3 for a list of variables included in the analysis).

TABLE 5-3: *List of variables included in the cluster analysis*

Listening & appreciation	Music heard Choice Liking Attention
Reasons for listening	To pass the time Habit To help me concentrate To match my mood To change my mood To create a certain atmosphere Relaxation I knew those I was with would like it To increase my energy Catharsis To remind me of past people and places
Effects of listening	It matched my mood It positively changed my mood It negatively changed my mood It increased my energy Relaxation It reminded me of past places

	Catharsis It helped me concentrate It hindered my concentration It helped create the right atmosphere It created the wrong atmosphere
Activities	Housework Getting dressed Having a bath Travelling Working Studying Reading a book Shopping Exercising Socialising
Company & Company type	Alone Friends Spouse/Partner Work colleagues Family members Stranger Boyfriend/Girlfriend

The cluster analysis was conducted in the R environment (R Development Core Team, 2009) using the *stats* package. A distance matrix was computed from the 34 by 44 data frame using the *dist* function, and specifying the *euclidean* distance measure.[1] A hierarchical cluster analysis[2] was then run on the resulting distance matrix using the *hclust* function, specifying the *ward*[3] method, which uses an analysis of variance approach to evaluate the distance between clusters during the agglomeration process. Other agglomeration techniques were also explored but they often resulted in several non-compact clusters, which made subsequent post hoc analysis of the variables differentiating the clusters impossible. The set of distance measures showed more reasonable solutions but as they tended to produce a similar pattern of responses to that obtained with the euclidean distance measure and as this (the euclidean distance measure) is the most commonly used, this solution is reported.

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[1] The euclidean distance is the most widely used distance metric for continuous variables. In this particular implementation, variables were excluded from the pair-wise distance computations if they had a missing value for at least one of the two participants. Thus, the handling of many missing values was dealt with at the level of the distance computation.

[2] While there are many different clustering techniques in the literature, hierarchical clustering was deemed most suitable for this dataset because of the large number of variables, the many skewed variable distributions, the zero inflated variables and the many missing values (the majority of these were due to idiosyncracies of participants' listening profiles. Some variables were irrelevant (110 values)). Furthermore, lack of prediction as to how many tangible clusters could be formed with a sample of this size made *kmeans* clustering and similar methods that require the number of cluster to be derived as input unsuitable.

[3] The *ward* clustering method, which clusters observations according to the minimum variance within groups and the maximum variance between groups, provided compact spherical clusters that could be compared and contrasted.

5.2.4.1 Post-hoc Comparisons

Due to the unequal sample sizes and deviations from a normal distribution (Shapiro-Wilk normality tests), non-parametric tests were performed on all data. Mann, Whitney *U*-, and Kruskal-Wallis tests were used for between-group comparisons and Wilcoxon signed rank tests were used for within-group comparisons. Exact significance values (as opposed to asymptotic values) were reported in all cases as recommended for smaller sample sizes (Field, 2005). Bonferroni corrections were applied for multiple comparisons. All tests were two-tailed.

5.3. RESULTS

5.3.1 The Cluster Solution; Distributions of Control and Amusic Participants

Figure 5-1 shows the stages of cluster agglomeration via a dendrogram: a 2D representation of the hierarchical classification process that illustrates the fusions made at each stage of the analysis.

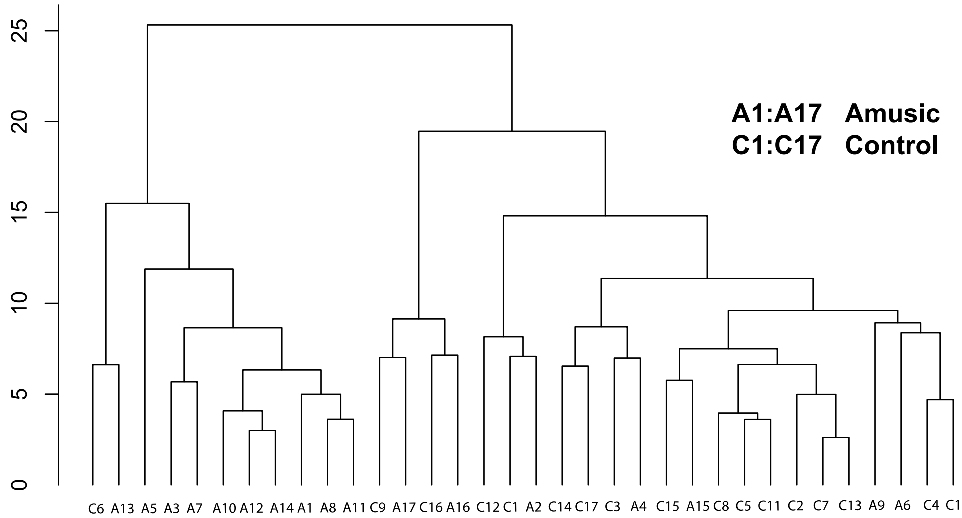

FIGURE 5-1: *Dendrogram showing the order in which the clusters were merged. All participants are shown starting in a cluster of their own and then progressively merging to form larger clusters until all the participants are finally merged into a single group. The y-axis is a measure of the height at which clusters join; the larger the distance before two clusters are joined, the greater the difference between the clusters.*

The maximal increase in cluster height was used as the criterion for choosing an optimal cluster solution, (Everitt, 1974). This corresponded to the point at which the two-cluster structure merged into a single cluster. Thus, the two-cluster model was accepted as the optimal clustering solution for this dataset. Cluster 1 contained 11 individuals: 59% of the amusic sample (ten individuals) and 6% of the control sample (one individual);

Cluster 2 contained 23 individuals: 41% of the amusic sample (seven individuals) and 94% of controls (16 individuals). A 2 x 2 chi-square test revealed that this distribution of participant groups over the two clusters was due to factors other than chance, $\chi(1) = 10.89$, $p < .01$,[4] although analysis of the distribution of each group separately using binomial tests showed that this highly significant value was driven by the control group (Controls: $p = < .01$, Amusics: $p = .63$). There was no difference between these clusters (n clust 1 = 11, n clust2 = 23) in the average time taken to respond to the text messages, $U = 125.5$, $p = .99$.

Further analysis sought to characterize the two discrete clusters: in terms of the critical variables that described general levels of engagement (so-called key variables) and in terms of the range of reasons, effects, and activities reported (so-called summary variables). One approach may have been to follow the cluster analysis with discriminant analysis, a multivariate analysis technique that allows the key variables discriminating clusters to be identified. However, as the plan was to also carry out further analysis to determine whether amusics in cluster 2 differed either in comparison with the controls with whom they shared a cluster (an intra cluster comparison) and/or in comparison with the other amusics in Cluster 1, a univariate approach was taken for consistency.

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[4] Further chi-square tests probing group distribution consistently revealed significant differences between the control and amusic groups in cluster solutions of up to five clusters (all $p < .01$, Bonferroni corrected).

5.3.2 Between Cluster Comparisons: Performance on Key and Summary Variables

Figure 5-2 shows how the two clusters differed on four key variables: how much music listeners were exposed to, how frequently they chose to hear music, reported liking of the music, and reported attention to the music.

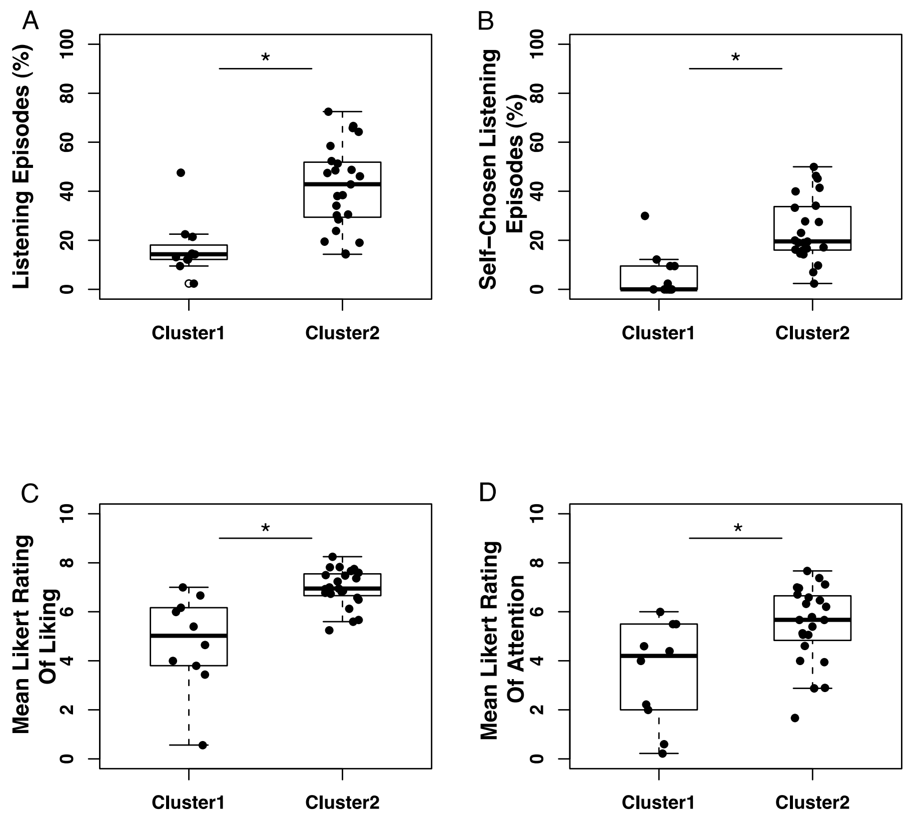

FIGURE 5-2. *Boxplots showing performance on four key variables of interest for participants in cluster 1 and 2: the percentage of episodes in which music was heard (A), the percentage of episodes in which music was chosen (B), the mean liking rating across all episodes reported by each listener (C), and the mean attention rating across all*

*episodes reported by each listener (D). The asterisk * denotes significance at p < .0125 (Bonferroni corrected).*

Tests of these contrasts of interest were conducted using Bonferroni adjusted alpha levels of .0125 per test (.05/4). Mann-Whitney U tests revealed significant differences between clusters on all four key variables: Individuals in Cluster 2 ($n = 23$) reported significantly more listening episodes, M clust2 = 41.59% ± 17.36, M clust1 = 16.75% ± 11.57, $U = 24.5$, $p < .01$, significantly greater choice over whether music was heard, M clust2 = 24.36% ± 13.24, M clust1 = 4.35% ± 5.76, $U = 11.0$, $p < .01$, significantly greater liking, M clust*2* = 6.97 ± 0.96, M clust1 = 4.77 ± 1.93, $U = 26.5$, $p < .01$, and significantly greater attention, M clust2 = 5.49 ± 1.57, M clust1 = 3.41 ± 1.99, $U = 42.5$, $p < .01$, compared with individuals in Cluster 1 ($n = 11$).

Figure 5-3 shows how individuals in each cluster were characterized on three summary variables demonstrating the range of reasons, effects, and activities of music reported. Organized by cluster group, Figure 5-4 shows the overall frequency with which each of the different reasons, effects, and activities were reported. The average number of unique reasons for listening (when chosen), effects of listening (when not chosen), and listening activities that each individual circled served as a summary measure of the degree to which they engaged emotionally with music they heard and the breadth of situations in which they heard it.

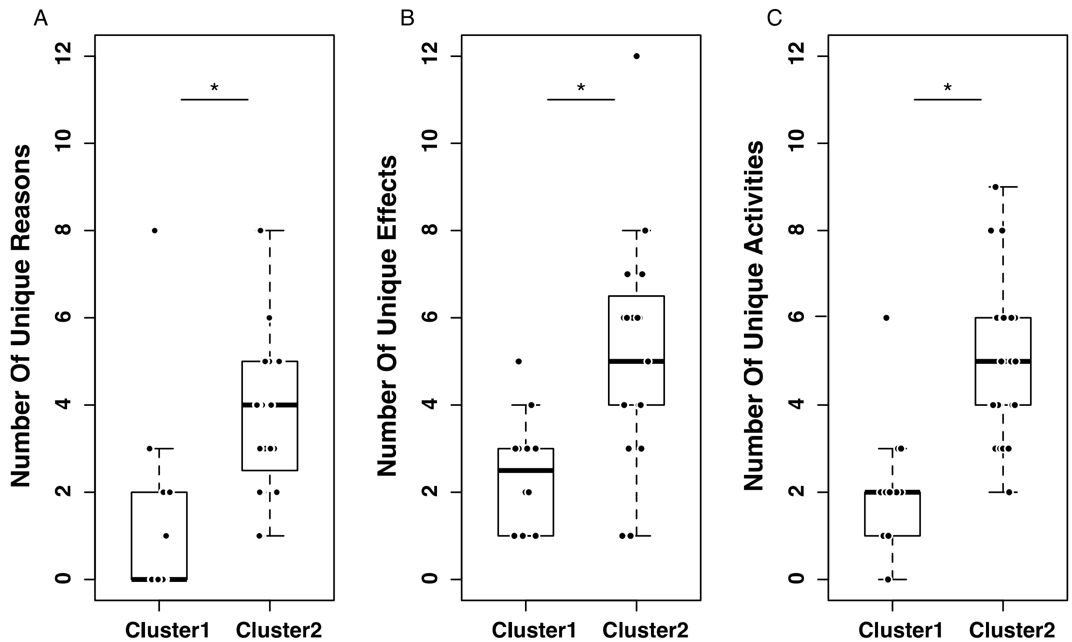

FIGURE 5-3: *Boxplots showing performance on summary variables for participants in cluster 1 and 2: number of unique reasons for listening (A), unique effects of listening (B), and unique activities during which music was heard (C). The asterisk * denotes significance at p < .017 (Bonferroni corrected).*

Mann-Whitney *U* tests, with adjusted alpha levels of .017 per test (.05/3), revealed significant differences between the individuals in the two clusters on all three variables. Individuals in Cluster 1 (n = 11) reported significantly fewer unique reasons and effects of listening compared to individuals in Cluster 2 (n = 23): Reasons: M clust1 = 1.18 ± 1.66, M clust2 = 3.87 ± 1.89, U = 34.5, $p < .01$; Effects: M clust1 = 1.73±1.74, M clust2 = 4.09 ± 2.35, U = 46.0, $p < .01$. The effects that individuals in Cluster 1 did report tended to be negative: of the four most common effects of music (when not chosen) for individuals in Cluster 1, three of these were negative: "*it negatively changed my mood*", "*it hindered my concentration*," and *"it created the wrong atmosphere."* For individuals in Cluster 2, the four most common effects were uniformly positive: "*it positively changed my mood," "it helped create the right atmosphere," " relaxation*," and "*it matched my mood*" (see Figure 5-4).

Further, individuals in Cluster 1 reported significantly fewer unique activities compared to individuals in Cluster 2, M clust1 = 2.09 ± 1.30, M clust2 = 4.96 ± 1.80, U = 43.0, $p < .01$, with the former failing to incorporate music listening into common everyday activities including getting dressed, bathing, reading, and studying. Also shown in Figure 5-4 is the overall frequency with which each cluster reported hearing music in the presence of different company types. While the pattern of reports were highly similar across clusters, an interesting observation is that individuals in Cluster 1 did not report hearing music in the presence of friends to the same extent of individuals in Cluster 2.

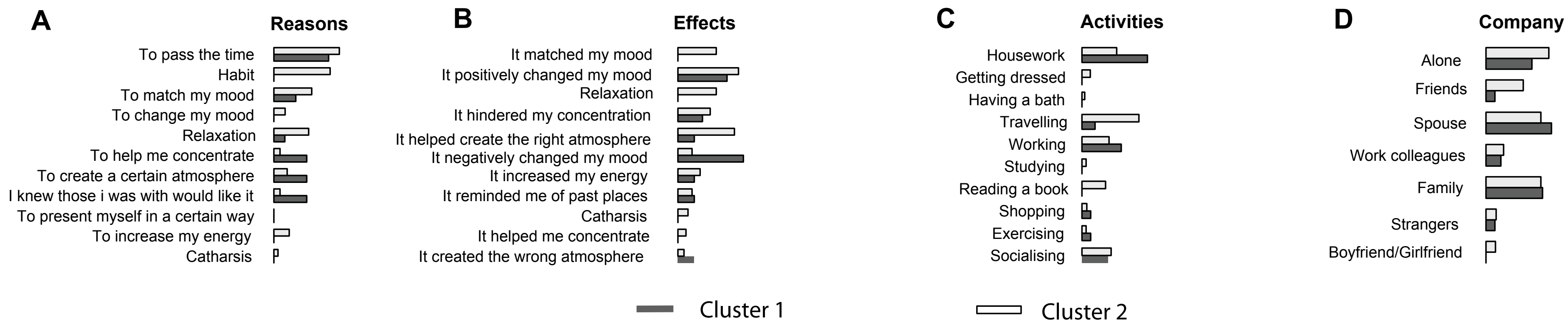

FIGURE 5-4: *List of reasons (A), effects (B) and activities (C) reported by members of cluster 1 (black) and cluster 2 (grey) as well company types in which music was heard (D). The length of the bars indicate the relative frequency with which each reason, activity, effect and company type was selected, scaled as a proportion of number of episodes in which music was chosen, the number of episodes in which it was imposed, and number of episodes in which it was heard (for activities and company type), respectively.*

The previous analysis reveals that individuals in Cluster 1 showed reduced engagement with, and appreciation of music in everyday life compared to individuals in Cluster 2. Since all but one of the control participants were in Cluster 2, this cluster may be taken to represent the listening profile typical of the normal population. The inclusion of a sizeable subgroup of amusic individuals in this group motivates a comparison of the listening profiles of these individuals with both the non-amusic individuals within the same cluster as well as the amusic individuals in Cluster 1. Thus, as with the comparison between Clusters 1 and 2, the following analysis characterized the amusic and control subgroups in terms of their performance on key and summary variables that described levels of music engagement and appreciation.

5.3.3 Amusic Subgroup Comparisons: Performance on Key and Summary Variables

Figure 5-5 shows how the three different groups: amusic individuals in Cluster 1 (clust1A, $n = 10$), amusic individuals in Cluster 2 (clust2A, $n = 7$), and control individuals in Cluster 2 (clust2C, $n = 16$) differed on the four key variables. Kruskal-Wallis tests demonstrated an unequal profile on all four key variables across the three groups: Music heard: $H(2) = 17.26$, $p < .01$; Music chosen: $H(2) = 20.99$, $p < .01$: Liking: $H(2) = 13.60$, $p < .01$, Attention: $H(2) = 8.41$, $p = .02$.

Follow up post-hoc Mann Whitney *U* tests using a Bonferroni adjusted level of .025 (.05/2) were conducted for each key variable to test whether Cluster 2 amusics differed either in comparison with the Cluster 2 controls with whom they shared a cluster and/or in comparison with the other amusics in Cluster 1. The former group of tests confirmed that amusic individuals in Cluster 2 were not significantly different from control individuals in the same cluster in terms of how frequently they heard music, *M* clust2A = 37.38% ± 17.72, *M* clust2C = 43.44% ± 17.45, $U = 44.0$, $p = .45$, how frequently they chose to listen to music, *M* clust2A = 17.02 ± 15.64, *M* clust2C = 27.58 ± 11.10, $U = 23.5$, $p = .03$, reported liking for the music they heard, *M* clust2A = 6.48 ± 0.78, *M* clust2C = 7.18 ± 0.69, $U = 26.0$, $p = .05$, and reported attention to the music, *M* clust2A = 5.02 ± 2.08, *M* clust2C = 5.69 ± 1.33, $U = 46.0$, $p = .52$. The comparisons between amusic individuals in Cluster 1 and amusic individuals in Cluster 2 revealed that amusic individuals in Cluster 1 heard music more frequently, *M* clust1A = 13.66% ± 5.67, $U = 6.0$, $p < .01$, and had chosen to listen to music more frequently, *M* clust1A = 3.36% ± 4.97, $U = 7.5$, $p < .01$, although the two groups failed to show significant differences in the levels of liking and attention reported, Liking: $U = 48.0$, $p = .09$; Attention: $U = 47.0$, $p = .11$.

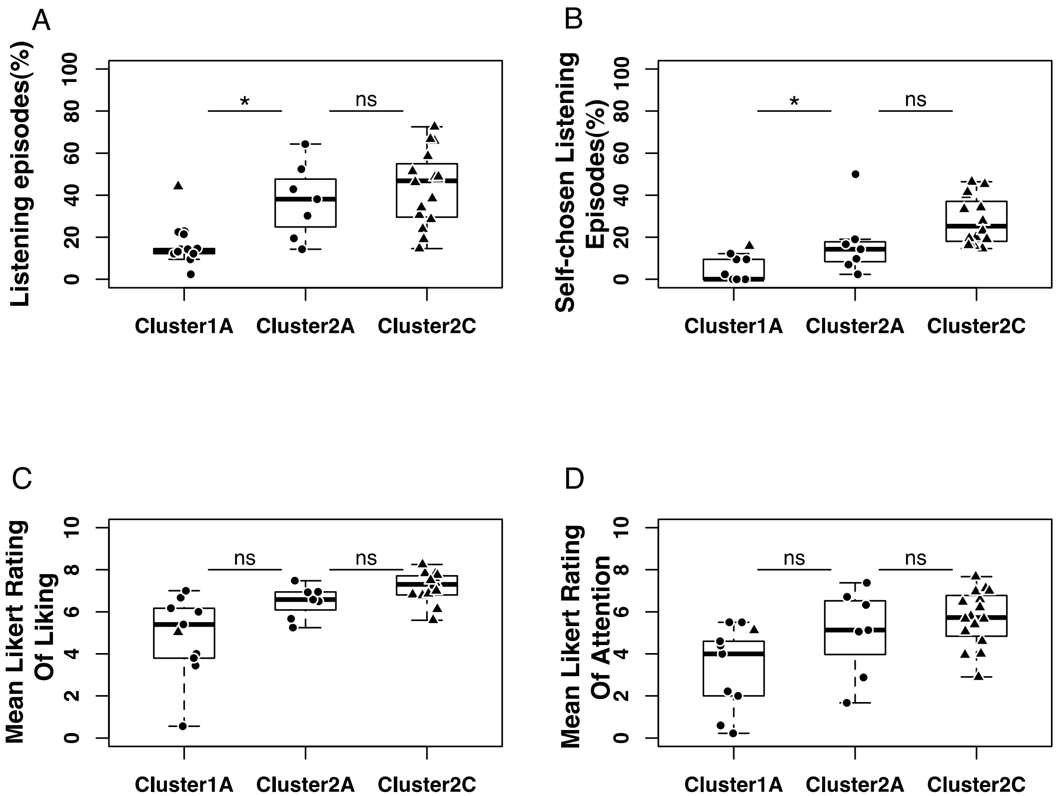

FIGURE 5-5: *Boxplots showing performance on four key variables of interest for the two amusic subgroups and controls in cluster 2: the percentage of episodes in which music was heard by listeners (A), the percentage of episodes in which listeners had chosen to hear music (B), the mean liking rating across all episodes reported by each listener (C), and the mean attention rating across all episodes reported by each listener (D). Individual data points for the amusic participants are shown using circles while those for controls are shown using triangles. Note that the data of the single control in Cluster 1 is shown as a single triangle in the Cluster 1A boxplots but is not included in this group in the statistical comparisons reported in the results section. The asterisk * and ns denote significance and non significance, respectively, at $p < .025$ (Bonferroni corrected).*

Figure 5-6 illustrates how the three different groups differed on summary variables. Once again Kruskal-Wallis tests revealed significant differences across clusters, Reasons: $H(2) = 17.88$, $p < .01$; Effects: $H(2) = 16.39$, $p < .01$; Activities: $H(2) = 18.17$, $p < .01$. Follow up post-hoc Mann Whitney U tests using a Bonferroni adjusted level of .025 (0.05/2) revealed that amusic individuals in Cluster 2 were not significantly different from the control individuals in Cluster 2 on the number of unique reasons, M clust2A =3.00 ± 2.38, M clust2C = 4.25 ± 1.57, $U = 85.0$, $p = .05$, unique effects, M clust2A = 4.14 ± 1.57, M clust2C = 4.06 ± 2.67, $U = 52.0$, $p = .81$, and unique listening activities reported, M clust2A = 5.29 ±1.60, M clust2C = 4.81 ± 1.91, $U = 45.5$, $p = .50$, while in contrast, they were significantly different from amusics in Cluster 1 in these three respects, Reasons: M clust1A = 0.80 ± 2.38, $U = 11.5$, $p = .02$, Effects: M clust1A = 1.30 ± 1.06, $U = 4.0$, $p < .01$, Activities: M clust1A = 1.80 ± 0.92, $U = 1.0$, $p < .01$.

The range of reasons, effects, and activities reported by the amusic subgroups (clust1A and clust2A) were very similar to those shown by the original clusters, which they shared with control participants (Cluster 1 and Cluster 2). While amusics in Cluster 2 reported listening to music for reasons like "*relaxation*," "*to increase energy.*" and "*catharsis,*" amusics in Cluster 1 did not report using music for reasons related to arousal. In contrast, amusics in Cluster 1 unlike amusics in Cluster 2, reported listening to music because of others "*I knew those I was with would like it*" and also reported using it "*to create a certain atmosphere*" to a greater extent than Cluster 2 amusics. For amusics in Cluster 1, the most commonly reported effect was "*it negatively changed my mood,*" where for amusics in Cluster 2, this was "*it positively changed my mood*." Of the top five effects reported, only two were positive for amusics in Cluster 1 while for amusics in Cluster 2, all but one were positive. Finally, amusics in Cluster 1 failed to incorporate music listening into solitary activities such as bathing, studying, reading a book and exercising where amusics in Cluster 2 reliably did so.

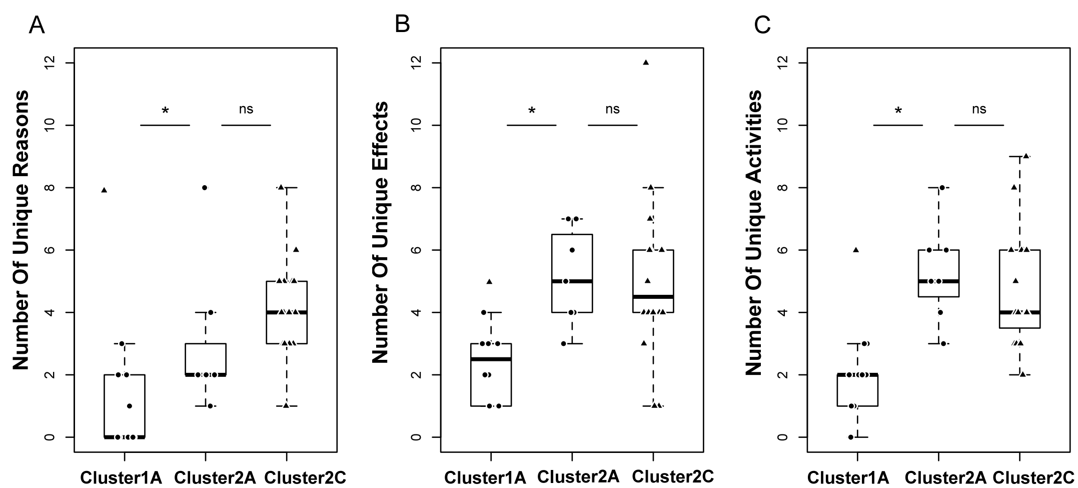

FIGURE 5-6: *Boxplots showing performance on summary variables for the two amusic subgroups and controls in cluster 2: number of unique reasons for listening (A), unique effects of listening (B), and unique activities during which music was heard (C). Individual data points for the amusic participants are shown using circles while those for controls are shown using triangles. Note that the data of the single control in Cluster 1 is shown as a single triangle in the Cluster 1A boxplots but is not included in this group in the statistical comparisons reported in the results section. The asterisk * denotes significance at p < .025 (Bonferroni corrected).*

5.3.4. *Influence of Choice and Company on Liking and Attention*

Further analysis sought to evaluate whether the three groups differed in the extent to which there was an effect of choice on liking and attention ratings. Wilcoxon signed rank tests using an adjusted alpha level of 0.017 (0.05/3) revealed that both controls and Cluster 2 amusic individuals reported significantly greater liking for music that was self chosen as opposed to music that was imposed upon them: For example, music heard while in a public place, clust2C: M chosen = 7.75 ± 0.88, M not chosen = 6.14 ± 0.14, W = 105.0, n = 16, $p < .01$; clust2A: M chosen = 7.46 ± 1.28, M not chosen = 5.56 ± 0.76, W = 28.0, n = 7, p = .02. In contrast, no modulating effect of choice was seen in the liking ratings of Cluster 1 amusics, M chosen = 6.33 ± 0.70, M not chosen = 4.72 ± 2.24, W = 1.0, N = 10, p > .99. All three groups reported paying greater attention when they had chosen the music but attention ratings were significantly modulated by choice only in controls, M chosen = 6.21 ± 1.44, M not chosen = 4.86 ± 1.50, W = 82.0, N = 16, p = .01.

There was no difference between the three groups in how likely they were to be listening alone versus in company, M clust1A = 33.5% ± 27.38, M clust2A = 33.74% ± 24.4, M clust2C = 45.12% ± 23.88, $H(2) = 1.78$, p = .41. Further analysis was conducted to evaluate whether the presence of others had an influence on liking and attention ratings as reported by any of the three groups. Wilcoxon signed rank tests using an adjusted alpha level of 0.017 (0.05/3) revealed that liking and attention ratings were significantly higher for control participants when music was heard alone than in company, Liking: W = 108.0, n = 16, $p < .01$, Attention: W = 107.0, n = 16, $p < .01$. However, neither of the amusic groups showed this effect: in both cases, liking and attention ratings were not significantly modulated by the presence or absence of others.

In summary, amusic individuals in Cluster 1 demonstrated significantly lower levels of music appreciation and engagement than Cluster 2 individuals on a number of key variables. In contrast, amusic individuals in Cluster 2 showed only slight evidence of differing from the controls with whom they shared a cluster, suggesting that these amusic individuals possess broadly typical levels of music engagement and appreciation.

5.3.5 Music Styles

Analysis sought to investigate whether there were any differences between clusters and amusic subgroups in the types of music that was heard. No difference was found between clusters (*n* clust1 = 11, *n* clust2 = 23) in terms of the frequency with which music with lyrics was heard, *M* clust1 = 52.80 ± 0.23, *M* clust2 = 74.10 ± 0.44, $U = 88.5$, $p = .31$. Nor was there a difference between the amusic subgroups (*n* clust1A = 10, *n* clust2A = 7) in this respect, *M* clust1A = 50.90 ± 0.46, *M* clust2A = 72.60 ± 0.22, $U = 24.5$, $p = .49$. With regard to styles of music heard, pop music was the most commonly reported in both clusters (Cluster 1 = 50%, Cluster 2 = 34.5%) followed by folk (16.7%) and golden oldies (14.8%) in Cluster 1 individuals, and classical (14.2%) and rock (13.4%) music in Cluster 2 individuals. For amusic individuals in Cluster 1, the most frequently reported genres were pop (45.5%) and golden oldies (15.2%) while in Cluster 2, they were pop (37.60%) jazz (12.9%) and rock music (9.9%).

5.3.6. Relationship with MBEA and Demographic Factors

Given the evidence for distinct subgroups of amusic individuals, further analysis sought to identify factors that might differentiate amusic individuals displaying low versus typical levels of engagement with music. Figure 5-7 plots the MBEA scores and demographics of the two amusic subgroups (*n* clust1A = 10, *n* clust2A = 7). Neither performance on the pitch-based subtests of the MBEA [Scale: *M* clust1A = 18.90 ± 3.18, *M* clust2A = 19.86 ± 1.95, $U = 26.0$, $p = .40$; Contour: *M* clust1A = 18.90 ± 3.73, *M* clust2A = 21.57 ± 2.23, $U = 21.0$, $p = .19$; Interval: *M* clust1A = 17.70 ± 2.63, *M* clust2A = 19.00 ± 2.16, $U = 22.0$, $p = .22$; Pitch composite: *M* clust1A = 55.50± 7.58, *M* clust2A = 60.43 ± 3.26, $U = 22.0$, $p = .32$] nor performance on the rhythm subtest [*M* clust1A = 23.50 ± 4.62, *M* clust2A = 23.57 ± 2.23, $U = 35.0$, $p > .99$] could account for the difference between the amusic subgroups. There were also no differences in the mean age of the two groups, *M* clust1A = 49.10 ± 11.45, *M* clust2A = 40.71 ± 12.02, $U = 50.0$, $p = .16$, their years of education, *M* clust1A = 16.56 ± 2.55, *M* clust2A = 14.71 ± 3.25, $U = 43.5$, $p = .21$, or their gender, clust1A: two male, eight female; clust2A: three male, four female; $\chi(1) = 1.04$, $p = .31$. Furthermore, there was no difference in the years of music training reported by the two subgroups, *M* clust1A = 0.45 ± 0.96, *M* clust2A = 1.71 ± 2.75, $U = 27.5$, $p = .42$. A chi-square analysis revealed that any difference in the way those individuals with at least some music training were distributed over the two amusic subgroups was simply due to chance, $\chi(1) = 0.30$, $p = .59$, and an additional cluster analysis including only those participants with no music training experience (11 amusics, ten controls) produced largely similar results. Thus, in terms of the MBEA and demographic variables the two amusic subgroups from Cluster 1 and 2 appeared to be indistinguishable.

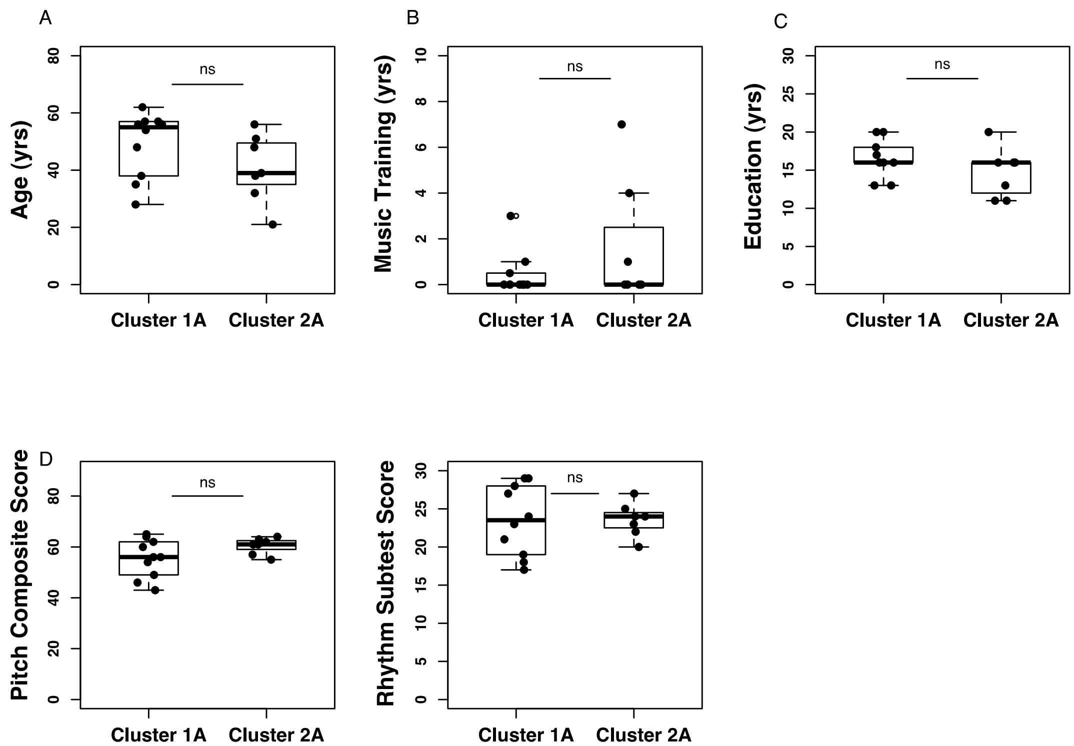

FIGURE 5-7: *Boxplots showing how amusic subgroups differed on age (A), years of music training (B), years of education (C), MBEA pitch composite score (D), and MBEA rhythm subtest score (E). ns denotes non significance at p < .05.*

5.4. DISCUSSION

The present study aimed to determine to what extent abnormal levels of music engagement and appreciation accompany the disordered musical listening capacity that amusics exhibit. An experience sampling approach was used to gather information about music listening behavior and appreciation as this method allows researchers to probe experiences "*in the moment*" (Larson & Csikszentmihalyi, 1983), and thus provides a level of ecological validity that is lacking from retrospective reports. Specifically, in the context of the present study, this approach provided an objective measure of the degree to which individuals with amusia are exposed to music in everyday life as well as the extent to which they voluntarily choose to hear it. In addition, it allowed the collection of nuanced information on individuals' motivations for and effects of listening and permitted evaluation of the roles of contextual and social factors on music listening behavior and appreciation.

The detailed and multifaceted nature of the data provided by ESM necessitated the use of multivariate statistical techniques that allowed the consideration of patterns of behavior (music listening profiles) rather than performance on individual items. Hierarchical cluster analysis highlighted similarities in music listening profiles in a data driven way. This statistical approach is blind to the status of an individual as amusic or control. Clusters were formed purely on the basis of the similarity of profiles. This feature of the analysis presented an interesting possibility to determine to what degree the real world musical listening behavior of amusics was similar or different to controls.

The results of analysis yielded a nuanced picture: a two-cluster solution, with 59% of the amusic sample and 6% of controls in one cluster and 41% of the amusic sample and 94% of controls in the second cluster. Thus, while the majority of individuals with amusia showed profiles that were dissimilar to controls, a sizeable subgroup showed profiles that were largely similar to controls. This finding is consistent with previous work (McDonald & Stewart, 2008) as well as with anecdotal reports presenting a mixed picture of how individuals with amusia feel about music, with some claiming music sounds like "*banging*" and "*noise*" and others reporting deriving considerable pleasure from it (Stewart, 2006, 2008). The current findings also build on previous work, by showing that critical factors that define and differentiate these distinct amusic subgroups include the extent to which individuals voluntarily expose themselves to music and incorporate it into a range of everyday activities to achieve a range of psychological states.

As with previous attempts, it was difficult to attribute the heterogeneity in music appreciation seen in the amusic sample to differing levels of perceptual ability. In particular, there was no support for the view that amusic individuals showing typical levels of engagement simply have a less severe case of amusia. Neither the performance on any of the MBEA pitch subtests, nor performance on the rhythm subtest could account for the differences in appreciation found between the groups.

It was also difficult to account for these differences in terms of demographic factors. McDonald and Stewart (2008) reported a significant relationship between age and levels of engagement, such that younger amusic individuals reported greater engagement than older amusic individuals. However, the current study failed to replicate this effect and it was not possible to account for the differences observed in the amusic subgroups with respect to years of music training.

The finding here of potentially intact emotional responses to music in the absence of normal music perception ability is not unprecedented. Indeed a number of such cases have been reported in the acquired amusia literature (Griffiths et al, 2004; Peretz, Gagnon, & Bouchard, 1998). Neuroimaging studies in typical listeners have associated the emotional responses generated by music with emotion and reward neural circuits comprising, specifically, the amygdala, the insula and ventral striatum (Blood & Zatorre, 2011, Koelsch, Fritz, Cramon, Muller & Friederici, 2006). More recently, a study combining positron emission tomography (PET) scanning and fMRI provided compelling evidence for the role of dopamine in mediating emotional responses, with release in the dorsal striatum (caudate) associated with the anticipation of 'chills', the sensation sometimes referred to as "shivers down the spine and release in the ventral striatum (nucleus accumbens) associated with the sensation itself (Salimpoor, Benovoy, Larcher, Dagher & Zatorre, 2011). While the current study did not explicitly enquire as to whether listeners experienced chills, one could speculate that the different subgroups of amusics seen in the current study may reflect differences in dopaminergic mediation in the mesiolimbic system. Given that differences in musical abilities, as indexed by the MBEA, could not account for the differences seen between the two groups in terms of musical engagement, an interesting question then would be what drives this dopamine mediation.

In addition to potential differences in biological factors, it is also worth considering consider whether music's extrinsic properties play a significant role in explaining the observed amusic subgroups. Indeed a number of factors may result in individual differences in music appreciation demonstrated by amusic individuals with similarly impaired music ability. Music is a highly prized part of many important social and cultural events and there may be some individuals for whom full participation in such events is of paramount importance. Such individuals might, regardless of their power to process it fully, willingly choose to immerse themselves in musical environments.

Further, personality types have been shown to predict musical preferences (Rentfrow & Gosling, 2003) and it is possible that sensation seeking individuals who are keen to extract enjoyment out of as many daily activities as possible will choose to engage with music despite an impaired ability to process it relative to normal listeners. The degree to which individuals can tolerate music may also influence their predisposition to be in environments where music may be heard or to have music in the background while they carry out their daily activities. Specifically the presence of background music has been shown to influence the performance of introverted and extroverted individuals differently (Furnham & Bradley, 1997; Furnham & Strbac, 2002). Introverts are generally more negatively affected by background noise, and it is thus conceivable that those amusics who show less engagement with music are more introverted and thus avoid situations in which music may be heard.

In addition to individual differences in personality, differences in individuals' lifestyles may lead to differences in the contexts in which they experience music. It is plausible that those individuals having greater exposure to music in the presence of friends and family would have built up more positive associations with music than those individuals whose musical experiences are limited to contexts deemed less enjoyable in general (e.g. imposed music in public places).

In conclusion, the current study, exploring the everyday uses, effects, and functions of music in individuals with amusia, reveals that a difficulty in melody recognition and discrimination does not necessarily result in a lack of musical appreciation. As a sizeable subgroup of the amusic sample showed levels of musical engagement and appreciation that were similar to controls in many respects, one can conclude that a simple one to one mapping of music perceptual abilities to appreciation does not exist.

CHAPTER 6

SUMMARY OF FINDINGS: IMPLICATIONS, LIMITATIONS AND FUTURE DIRECTIONS

In this section, the experimental Chapters 2,3,4 and 5 are summarised. Limitations with respect to experimental design and consequently interpretation of results are highlighted and ways to address these issues are proposed. Next, the main implications and contributions of the current findings are discussed in relation to the previous literature. Finally the scope for future research into congenital amusia research is discussed.

6.1. INTRODUCTION

Research into developmental disorders seeks to explain why basic abilities that are acquired effortlessly by most humans prove difficult for others. The capacity to make sense of music is one such example. While music is recognised as a fundamental human trait (Blacking, 1995), individuals with amusia fail to reach a normal level of ability with it. In recent years, the disorder has been linked to difficulty with the perception and discrimination of fine-grained pitch changes and poor memory for pitch. More recently, it has also been suggested that the condition may be more accurately described as a disorder of awareness.

An overarching aim of the current thesis was to further clarify the nature of the disorder from different perspectives and within a context of real world music listening. Critically, the current questions were motivated by previous research regarding which mechanisms and processes are necessary for normal music cognition in typical listeners. In short, the current thesis sought to contribute towards an integrated account of amusia, by addressing outstanding questions related to the nature of the disorder's underlying deficits while characterising it with reference to what is known about typical musical development. The previous four chapters, which constitute the experimental work in this thesis, are summarized below.

6.2. SUMMARY OF FINDINGS

6.2.1. Amusic individuals can internalise musical regularities

The first study in the current thesis took as a starting point the notion that typical individuals' facility in perceiving music is built upon long-term schematic knowledge that is gained incidentally over a life-time of exposure to the statistical properties of their musical culture (Tillmann et al., 2000). Its precise aims were to distinguish between two possibilities: namely, that amusics exhibit pervasive and lifelong difficulties with music because they have inadequate learning mechanisms for acquiring this knowledge, or that they have intact learning mechanisms, but that these are rendered less effective owing to an insensitivity to small pitch changes.

By giving amusic individuals and matched controls an equal opportunity to learn the regularities present within novel tonal materials containing intervals that were supra-threshold for discrimination, the state of learning mechanisms in individuals with amusia could be assessed and compared with those in typical listeners. Further, by giving them the opportunity to learn the structure of tonal materials containing small intervals, which may be considered sub-threshold for their perception, the extent to which fine-grained pitch discrimination ability should be seen as a limiting factor in the acquisition of musical knowledge in amusia could be examined. Finally, by giving them the opportunity to learn the structure within structured linguistic materials, the domain specificity of the pitch-processing deficit shown by amusics could be assessed.

The main finding from this study was that amusics have no difficulty in internalizing the regularities in structured linguistic and tonal materials, even when pitch intervals in the latter are smaller than have been shown to be discriminable by them. This finding is important because it suggests that an insensitivity to pitch is unlikely to account for the difficulties amusics experience at a higher level of musical listening. Another important finding was that amusic individuals differed in the levels of confidence they showed when required to judge the decisions made in the forced choice task. This lack of confidence may, in part, explain why amusic individuals generally show higher pitch discrimination thresholds in the context of tasks that are not criterion-free (Kershaw, 1985; Macmillan & Creelman, 2001). Finally, although neither group could be said to have acquired full explicit knowledge of the structure of the tone sequences, an interesting finding was that while a significant association existed between the levels of awareness shown by controls and the levels of performance they achieved, this association was absent in amusics. This finding is important as it hints at the dissociation between implicit and explicit knowledge in amusia, which has previously been alluded to in the literature (Peretz et al., 2009).

6.2.2. Amusic individuals can form implicit musical expectations but are impaired at reporting them explicitly.

The ability to form expectations is generally thought to result from implicit learning mechanisms that allow the extraction of rules and regularities present in the structured systems that one is exposed to (Reber, 1992; Seger, 1994). Given the evidence that amusic individuals may be able to internalize the regularities in tonal materials, the first experiment in chapter 3 asked whether these individuals are also able to use the knowledge that they might have thus accumulated to form expectations as to how a given piece of music would unfold. In the first experiment, participants were required to make speeded timbral discrimination judgments for notes that were high or low in terms of information content, given the preceding melodic context, and were informed as to the precise points in the melody where a judgment was required using a visual cue as the melody unfolded. Faster processing time for low versus high IC notes (high and low probability respectively) presented in the same timbre as the context (piano) was taken as evidence of intact implicit expectations. In the second experiment, an analogous paradigm to that used in experiment 1 was employed, whereby participants gave subjective ratings regarding how unexpected on a scale of 1 to 7 they found the cued target notes. In contrast to the implicit task of experiment 1, where only automatic processing was investigated, the paradigm in the experiment 2 assessed the ability of participants to consciously reflect on the perceived expectedness of target pitches given the melodic context.

Results from experiment 1 showed that amusics were generally slower and less accurate than controls in their timbre discrimination responses but like controls were facilitated in terms of response time for low IC relative to high IC piano notes- demonstrating evidence of implicit expectations. Additional analysis showed that amusic individuals were also, like controls, more accurate in identifying low IC relative to high IC notes. Importantly, these results contrasted with those of experiment 2 where amusic participants were shown to significantly differ from controls in terms of their ability to use explicit expectedness ratings to distinguish between points of high and low IC in the context of a melody, demonstrating evidence of impaired explicit processing abilities.

The findings here confirmed that the degree to which amusic individuals show evidence of the ability to form melodic expectations is dependent on the way in which these expectations are probed. Thus it parallels the work of Tillmann and colleagues (2007) who showed a similar pattern of results in a single acquired amusic individual. It also parallels a more recent study from Tillmann and colleagues (2012), which examined harmonic priming in a speeded phoneme discrimination task, and showed that amusic individuals, like controls, displayed a priming effect: significantly faster reaction times to target phonemes sung on tonic rather than subdominant chords. Most importantly, however, it provided further evidence that amusics have internalized the regularities in the western tonal musical system and offered strong direct support for the notion that amusia should be considered a disorder of awareness.

6.2.3. The neural basis of impaired explicit processing in amusia may lie in impaired early mechanisms for detecting pitch deviations.

Results from chapter 3 had demonstrated a dissociation between the implicit and explicit music anticipatory capacities of those with amusia. With the aim of exploring the neural correlates of this dichotomy, electrophysiological recordings were collected from a sample of amusic and control participants as they listened to real world melodies previously used in chapter 3. Results revealed an effect of note IC that was highly comparable in both groups: high IC notes reliably elicited a delayed P2 component relative to notes with low IC, suggesting that amusic individuals, like controls, found these notes more difficult to evaluate. However, high IC notes were also characterized by an early frontal negativity in controls that was attenuated, although present, in amusic individuals in line with evidence of a close relationship between the amplitude of such a response and explicit knowledge of musical deviance.

Based on these findings, it was put forward that both the present, although attenuated, early negative response and the delayed P2 effect may be taken as markers of intact implicit knowledge of melodic structure in individuals with amusia. In contrast, it was suggested that the lack of sensitivity to musical violations shown by individuals with amusia may be related precisely to the attenuation seen in the obligatory response to high IC notes. This proposal is supported by evidence in the literature relating the robustness of early pre-attentive mechanisms to the degree of conscious awareness of a deviant a listener shows (e.g. Koelsch et al., 1999; Koelsch et al., 2002; Koelsch et al., 2007; Miranda & Ullman, 2007). It is also supported by previous studies from the congenital amusia literature, showing the absence and attenuation of negative deflections (similar in timing and topography to those observed here) to veridical melodic deviants (Braun et al., 2008) and out of key notes in the context of a melody (Peretz et al., 2009).

6.2.4. There is not a simple mapping between music appreciation and music perceptual deficits.

The fourth and final study in the thesis used ESM to examine and compare the patterns of music-related behavior seen in a group of individuals with amusia and matched controls. A multivariate analysis technique, cluster analysis, was used to group individuals according to the similarity of their behavior, regardless of their status as amusic or control. At least two possibilities were envisaged regarding the extent to which individuals with amusia would be found to show typical levels of engagement with music in everyday life. One view, based on the premise that engagement with and appreciation of music depends upon having intact perceptual processing, predicted that amusics and controls would form largely independent clusters, with amusic individuals exhibiting little evidence of engaging with or appreciating music and control individuals showing high levels of both. In contrast, another view, based on ethnographic, psychological and sociological research, proposed that music's extrinsic properties afford a sufficient number of reasons for amusic individuals to choose to engage with and appreciate music in their everyday lives even if listeners are limited in the extent to which they can process it. This latter view suggested that amusics, if probed, would be largely indistinguishable from controls with respect to everyday music listening habits.

In fact, analysis yielded a more nuanced picture: a two-cluster solution with one cluster comprising 59% of the amusic sample and 6% of controls and the other comprising 41% of the amusic sample and 94% of controls. Comparisons of the two clusters in terms of specific aspects of music listening behavior revealed differences in levels of music engagement and appreciation, revealing that amusic individuals may be split into at least two subgroups: those with normal levels of engagement and appreciation and those with reduced levels of both. Importantly, neither performance on the MBEA pitch-based or rhythm subtests were able to predict membership in these clusters, suggesting that the relationship between perceptual ability and appreciation is complex and multifaceted

6.3. IMPLICATIONS OF THE THESIS

Findings from the current thesis, as briefly summarised above, make a number of contributions, both towards an integrated account of amusia in the framework of typical musical development, and also towards the more general fields of music cognition and auditory cognitive neuroscience.

Firstly, with respect to the former, the finding that insensitivity to small intervals is not a limiting factor in the internalisation of a tonal system's statistical regularities has important implications for what should be considered the underlying deficit of congenital amusia. Specifically, this finding refutes the idea that the disorder is simply one of fine-grained pitch discrimination (Hyde & Peretz, 2004). This idea was suggested due to the observation of fundamental pitch discrimination deficits in a cohort of amusic individuals who had been required to monitor a sequence of five monotonic piano notes for a possible change in pitch at the fourth note (Hyde & Peretz, 2004). The authors reported that whilst controls were able to detect pitch intervals as small as a quarter of a semitone, amusic individuals were unable to detect a pitch change of a semitone or less. It was speculated that an inability to perceive intervals of a semitone would preclude the learning of rules of key membership and ensure that amusic individuals were unable to carry out tonal encoding of pitch (Peretz et al., 2003). Critically, the finding here that amusics can learn the structure in tonal systems containing intervals as small as a semitone, suggests they may also have internalized the structure of key membership in real scales and calls for a reappraisal of this initial account of the disorder.

A broader implication of this first study is its demonstration of the power of criterion-free tasks (Kershaw, 1985; Macmillan & Creelman, 2001), where individuals are forced to make a choice between a number of options and are not simply allowed to favour a conservative no-change response as is possible, for instance, when same-different judgments are required. The results of this study in which individuals with low confidence in their ability nevertheless perform at a comparable level with typically developed individuals clearly demonstrate the importance of considering the way in which knowledge is probed before drawing conclusions regarding the levels of such knowledge within a special population. This need to consider the way in which knowledge is probed is most clearly demonstrated in the results of chapter 3 which assessed the presence of melodic expectations in amusia. It has been increasingly suggested that amusic individuals may be able to process aspects of musical structure that they are not able to report and an important contribution of this study is its strong support for this notion.

Findings from the third study (chapter 4), employing an ERP approach contributed towards a functional account of the lack of explicit knowledge amusics show when faced with musical violations. By demonstrating a potential deficit in early pre-attentive mechanisms as indexed by a diminished early frontal negative response to high IC notes, the study exhibited parallels with a range of other ERP studies showing a relationship between the strength of these pre-attentive mechanisms as reflected by similar early negative deflections (two examples being the MMN and the ERAN) and the degree of musical expertise a listener has. One case in point is a study showing that the superior ability of musicians to consciously detect slightly mistuned chords in a chord sequence was reflected in their having a larger MMN than novices who are less able to detect these deviants (Koelsch, 1999). Another is that individuals who were more accurate at identifying harmonically inappropriate chords in a chord sequence also elicited a larger ERAN response to such chords than those individuals for whom detection rates were lower (Koelsch et al., 2002; Koelsch et al., 2007)

Notably, association of the impaired explicit knowledge demonstrated in Chapter 3 with the abnormal pre-attentive components of the auditory evoked potential, demonstrated in Chapter 4, has implications that go beyond music processing alone. In fact, these findings provide support for the more general notion that robust sensitivity of early pre-attentive mechanisms is critical for normal conscious perception of auditory deviance in general. Specifically, Rinne and colleagues (2006) suggested that pre-attentive mechanisms generally increase the probability that a stimulus change in the environment will be consciously perceived while it has similarly been proposed that pre-attentive mechanisms possess attention-triggering properties (Naatanen, 1990; Winkler, 2007) that permit the emergence of conscious perception of less probable events in the auditory environment (Naatanen, 1990).

Finally, the finding that there is no clear relationship between the extent to which amusic individuals use and engage with music and their levels of musical ability, as indexed by the MBEA, raises important questions concerning the critical factors that drive musical appreciation, both in those with impaired musical ability and in the typical population, more generally.

6.4 LIMITATIONS OF THE CURRENT STUDIES AND PROPOSED EXTENSIONS

Here, outstanding issues related to each of the experiments are discussed in turn along with ideas about how they may be addressed in the future.

6.4.1. Chapter 2

It was concluded from the statistical learning experiment reported here that amusics have the requisite tools for acquiring musical knowledge. However, the internalization of statistical regularities from real-world music is likely complex compared with the first-order transitional probabilities used in the present study. Specifically, higher-order transitional probabilities or relational probabilities between non-adjacent tones (Creel et al., 2004; Gebhart et al., 2009) may be more relevant to the acquisition of knowledge required to support an understanding of melodic and harmonic structure (Jonaitis & Saffran 2009; Tillmann et al. 2000).

Future studies might assess the ability of amusic individuals to internalise the rules guiding more complex musical grammars (Loui, Wessel & Kam, 2010; Rohrmeier, Rebuschat, & Cross, 2010) as these may show deficits which were not apparent using the present stimuli. However, it should be borne in mind that performance on artificial grammar learning tasks simulating more complex musical systems may be limited by the short-term memory deficits shown by many individuals with congenital amusia (Gosselin, Jolicoeur, & Peretz, 2009; Williamson & Stewart 2010; Williamson et al., 2010). Thus any future experiments to this end would have to be careful not to confound established memory deficits with potential learning deficits.

6.4.2 Chapter 3 and 4.

Typical listeners learn about the statistical distribution of pitches and pitch intervals in music through incidental exposure in everyday life and it was concluded that findings of intact implicit processing in chapter 3 may be taken as confirmation that individuals with congenital amusia have also internalized music's regularities. An alternative explanation, however, is that the observed facilitation amusics show for low IC events may be accounted for by general cognitive and perceptual predispositions that are not specific to music processing (Thompson & Schellenberg, 2002). Indeed it has been suggested that innately specified Gestalt principles of grouping might influence the formation of musical expectations (e.g., Narmour, 1990). According to this view, for example, the fact that pitches preceded by small intervals are more expected is a universal property of the auditory system.

In chapters 3 and 4, the computational model of statistical sequence learning was supplied with representations of scale degree (pitch relative to a tonic) and pitch interval. The model was used to select target types differing in their probability of occurrence, given the preceding context, at a given point in a melody. As a result, the target types (low and high IC notes) differed in terms of both tonal stability and the size of the preceding interval, such that high IC events were, on average, more tonally unstable and more likely to be preceded by a large interval. While the comparable strength of facilitation shown by the amusic and control participants in the implicit task suggests the influence of both these measures (scale degree and pitch interval) in driving expectations across members of the two groups, such a claim may not be made based on the current data and further studies may seek to control for the effects of pitch interval in order to establish whether amusic individuals are as sensitive to tonal influences on expectation as controls. In a similar vein, future studies using the Pearce and Wiggins model would benefit from separate experiments in which probe points are selected based on outputs from the long term and short term model separately in order to determine whether the memory deficits previously shown in amusics (e.g. Williamson et al, 2010) play a role in their ability to form musical expectations.

However with regard to the current study, it must be noted that pitches preceded by small intervals are also more prevalent in music, so one can argue that any advantage shown for processing proximate tones is simply a result of the frequency with which they occur in the environment. Indeed, it is very difficult to tease apart whether expectations arise from statistical learning or innate mechanisms: an observation which has led Schellenberg, Adachi, Purdy and McKinnon (2002, p. 533) to suggest that the *"effects of nature (a predisposition for gestalt principles) and nurture (exposure to stimuli following these principles) are perfectly confounded."*

6.4.3 Chapter 5

It was concluded from chapter 5 that levels of music appreciation may not be simply accounted for by musical competence, however, it important to note that the competencies tested here were not exhaustive and it remains possible that the observed differences between the amusic subgroups in terms of musical engagement may relate specifically to additional (untested) factors.

The first of these concerns is the implicit processing of musical structure. As shown by findings from the musical expectation tasks in chapter 3, even though individuals with congenital amusia show impairment in tasks (such as the MBEA) where explicit responses (e.g., same/different judgments) are required, they may nevertheless show comparable performance to controls when their knowledge is probed using implicit methods. Critically, such implicit knowledge of musical structure may allow individuals with amusia to build pitch expectations as they listen to music, an activity that is proposed to be a rich source of music appreciation (Huron, 2006). The observed differences in the extent to which amusic individuals show musical engagement in chapter 5 may therefore be due to individual differences in the extent to which they have acquired knowledge of musical structure over a lifetime of exposure. Unfortunately there was little overlap between the participants that took part in these studies, making it impossible to test this possibility. However, a future study addressing these issues would provide an important insight into the degree to which levels of appreciation are dependent on levels of implicit melodic pitch knowledge.

In addition to differences in the extent to which amusics choose to or are able to implement their knowledge of the pitch based aspects of music at an implicit level, there may also be differences in the extent to which rhythmic cues are processed in the low versus typically engaged amusic subgroups revealed in this chapter. While no difference was seen across groups in performance on the MBEA rhythm subtest, this subtest provides only a partial indication of the degree to which rhythmic processing may be intact, and the findings here allow for the possibility that those amusic individuals who showed typical music engagement were engaging with the rhythmic dimension of the music to a greater extent than those who did not. Specifically, the finding that the amusic subgroup with typical levels of engagement reported using music for reasons such as "*relaxation*" and "*to increase my energy*" while the non-appreciating subgroup did not, suggests that the former subgroup may be using the rhythmic and temporal aspects of music to modulate arousal. The additional finding that jazz music was the second most popular genre after pop music in these individuals is also worth noting. Further evidence that rhythm may provide a sufficient and rich source of musical appreciation comes from some cochlear implantees who, despite having a coarse perception of pitch, report enjoying listening to music, most likely owing to their normal ability to hear rhythm and tone duration. These reports of enjoyment are most common among patients who are born deaf and have never experienced melodic pitch patterns (Drennan & Rubinstein, 2008; Lassaletta, Castro, Bastarrica, Pérez-Mora, Madero, De Sarriá, & Gavilan, 2007).

Finally, notwithstanding the need to investigate whether differences in implicit processing of pitch, harmony and rhythm are the source of the contrasting attitudes to music seen in the results of chapter 5, future studies using the experience sampling methodology could be improved in at least two respects. First, a larger sample size would allow a more thorough investigation (as was permitted in the study of North and colleagues (2004)) into how reasons and effects of listening are contingent on concurrent activities and company types present, with such analyses having the potential to present a clearer picture regarding the influence of contextual factors on motivations and listening habits. Secondly, while the current study presented in chapter 5 did not require any further detail on contact episodes where no music was heard, a future study collecting data on contextual factors in such situations would allow a better characterization of individuals' listening habits specifically as they relate to their individual lifestyles and the degree of musical listening afforded.

6.5 CLOSING STATEMENTS

The current thesis sought to inform understanding of a subgroup of the population who fail to develop normal musical ability despite normal intelligence and otherwise normal cognitive functioning. Motivated by the belief that a sound theory of cognenital amusia has both specific and broad implications, the current thesis focused on elucidating critical and outstanding questions related to the nature of the disorder. In doing so, it not only contributed towards an integrated account of the disorder, by showing that the disorder may be more accurately described as a disorder of awareness than of fine grained pitch discrimination, but it also made interesting observations that may have broader implications for music cognition. These include demonstrating the power of criterion-free tasks and implicit methods for revealing latent abilities, the importance of early preattentive mechanisms in the conscious evaluation of musical structure, and finally the lack of a simple relationship between music perception and appreciation.

APPENDIX: CHAPTER 5

A Sheet From the ESM diary

Date.................... Time when message was received………. Time when questionnaire was filled out……….

Are you listening to any music at the moment, or have you heard any in the past 30 minutes? **YES / NO**

IF NO THERE IS NO NEED TO CONTINUE.
IF YES PLEASE CONTINUE WITH THE QUESTIONNAIRE

(These questions relate to your most recent listening episode. If you are not currently listening to music but have been in the past 30 minutes, please cast your mind back to what you are doing and how the music made you feel)

Are you alone? **YES / NO**

If no, who are you with? **(PLEASE CIRCLE)**
friend(s), spouse/partner, work colleague(s), family member(s), stranger(s), boyfriend/girlfriend, other (please specify)

Did you choose to listen to this music yourself? **YES / NO**

If yes, why did you choose to listen to this music? (**PLEASE CIRCLE**)
to pass the time, habit, to help me concentrate, to match my mood, to change my mood, to create a certain atmosphere, relaxation, I knew those I was with would like it, to present myself in a certain way, increase my energy, catharsis, to remind me of past people and places, other (please specify)

If no, what effect has the music had on you? **(PLEASE CIRCLE)**
it matched my mood, positively changed my mood, negatively changed my mood, increased my energy, relaxation, reminded me of past places, catharsis, helped me concentrate, hindered my concentration, helped create the right atmosphere, created the wrong atmosphere, other (please specify)

How would you rate your liking of this music? 0-10 (0 = hate it, 10 = love it) …….

How much attention are you paying to the music? 0-10 (0 = ignoring it, 10 = attending to it fully) ..…..

What are you doing whilst listening to this music? (**PLEASE CIRCLE**)
housework, getting dressed, having a bath, travelling, working, studying, reading a book, shopping, exercising, socialising, other (please specify)

Does the music you are listening to contain lyrics? **YES / NO**

What style of music is it? (**PLEASE CIRCLE**)
pop, rock, indie, rap/hip hop, dance, heavy metal, punk, blues, golden oldies, classical, jazz, r n' b, gospel, soul, world, folk, country, other (please specify)

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