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Stability and accuracy of long-term memory for musical pitch

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Stability and Accuracy of Long-Term Memory for Musical Pitch

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Abstract

Existing research gives an inconsistent picture of the nature of the cognitive processes underlying memory for musical information. A study was conducted to investigate the stability and accuracy of long-term memory for pitch amongst individuals who have not had musical training. The independent variable which was manipulated in this study was the pitch of each excerpt from a well-known pop song. Participants heard one long sequence of excerpts, each of which had been raised or lowered in pitch by one semitone, or been left unaltered. After hearing each excerpt, participants were asked to detect whether it was different from the original version of the song they remembered. The dependent variable under investigation in this study was the accuracy with which participants detected alterations in the pitch of familiar songs. Participants were significantly worse at detecting whether the pitch of an excerpt had been changed when the altered excerpt was preceded by an unaltered excerpt or vice versa, than when they heard two consecutive unaltered excerpts. This suggests that pitch memory is subject to interference from previously presented pitch information.

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Unlike other universal cognitive faculties, the ability to perceive, interpret, and enjoy music has no obvious purpose (Huron, 2001; Sacks, 2008 ; Wallin, 2000, as cited in Hyde & Peretz, 2003). Ayotte, Hyde, and Peretz (2002) proposed that neurological networks devoted exclusively to music exist within the human brain, and that we are therefore innately predisposed to musicality in much the same way as we are predisposed to language learning. Although research indicates that musical abilities are present in most people from birth, the level of sophistication and awareness of these abilities vary widely between individuals (Jackendoff & Lerdahl, 2006; Sacks, 2008). This review focuses on human perception and memory for pitch information. However, it is important to note that music as experienced in the everyday world is typically comprised of multiple elements in addition to pitch. Even something as simple as singing 'Happy Birthday' requires the singer to have internalised information about the pitch, tempo, lyrics, and melodic structure of that particular song, as well as the motor movements necessary to reproduce this information on demand (Peretz & Zatorre, 2005; Sacks, 2008).

Pitch, tempo, and timbre are perceptual characteristics of sound that allow listeners to distinguish one piece of music from another. The ability of individuals to perceive and evaluate these characteristics, and the processes which allow them to do so, have been investigated as components of general musical processing. Tempo refers to the pace of a piece of music, while timbre describes the unique 'voice' or quality of a sound (Pauws, 2003). Pitch describes how high or low a sound is, and is also involved in the interpretation of meaning in speech (Ayotte, Hyde, & Peretz, 2002; Pauws, 2003). The smallest meaningful pitch interval between two notes in Western music is one semitone. Absolute pitch (AP), the ability to identify the frequency or name (for example, B flat) of an isolated musical note, or to produce a note of a specific frequency on demand, is thought to occur in some individuals who have exceptionally stable and accurate internal pitch representations (Terhardt & Ward, 1982).

The investigation of musical processing as a distinct cognitive faculty is a relatively recent development in psychological research. Studies of working memory for pitch information and emerging research into music-specific neurological deficits provide compelling evidence that music perception and memory involve cognitive processes which are relatively independent of those related to other auditory stimuli, and that can be influenced by training (Ayotte, Hyde, & Peretz, 2002; Mohr &

Pechmann, 1992; Palmer and Schendel, 2007). Studies suggest that musical training improves the efficiency and accuracy with which pitch information is encoded into, and recalled from, both short and long-term memory. While there is consistent evidence to indicate that musicians are better than non-musicians in most tasks requiring accurate pitch discrimination and memory, researchers disagree about the extent to which these abilities are accurate and stable in untrained individuals. Some research indicates that long-term pitch memory for very well-known music is also stable and accurate among non-musicians (Levitin, 1994; Pauws, 2003). To date, many of the studies in this area have focused on working memory processes related to music, or have evaluated singing performances as an indication of various individuals' long-term memory for songs. However, this type of study is undermined by the fact that singers – particularly untrained ones – may lack the ability to accurately reproduce the pitch information they remember. Research using measures of long-term pitch memory other than singing has been less commonplace. While the body of research devoted to musical memory is growing, further investigation is still needed to clarify the extent to which long-term pitch memory is stable, accurate, and widespread among individuals without musical training.

Interference and Working Memory for Pitch Information

Working memory processes related to musical stimuli were a key focus of early music researchers. For example, Wickelgren (1966) studied the extent to which subsequently presented tonal information created interference in memory for the pitch of a single musical tone. Participants heard two tones of two, four, or eight seconds duration each, separated by an interference tone of various pitches and durations. Participants' accuracy in judging whether or not the first tone was the same as the target tone decreased significantly as the duration of the interference tone increased. Accuracy also increased modestly but steadily as the duration of the first tone increased, which Wickelgren attributed to the strengthening of the memory trace for the pitch of that tone. However, decreases in memory accuracy were considerably larger between the two and four second interference tone conditions than between the four and eight second interference tone conditions, which Wickelgren suggested indicated an asymptote effect whereby the strength of the memory trace decays to a constant level after four to eight seconds have elapsed. These findings were some of the first to indicate that storage of pitch information in working memory is subject to interference from other musical stimuli, a conclusion which has been convincingly supported by more recent research.

However, Wickelgren made little attempt to discuss and defend working memory processes which may have been responsible for his findings. This study only involved ten participants, a sample size which is inadequate to provide valid evidence of the characteristics of pitch memory in the general population. Participants were also not screened for musical training, so it is possible that musicians were included in the sample and artificially inflated the results. However, subsequent research has provided additional evidence that short-term pitch memory is subject to interference from other tonal information in both trained and untrained listeners.

While studies evaluating short-term pitch memory have often involved listening tasks like the one used by Wickelgren, many researchers investigating long-term pitch memory have evaluated participants' singing performances as a measure of the accuracy of their memory for pitch information. Vocal reproductions, though, may not always match the information the singer remembers. Further research using listening tasks, rather than production tasks, is needed to assess pitch memory without this potential confounding effect.

The Existence and Role of a 'Musical Loop' in Working Memory

Mohr and Pechmann (1992) examined the extent to which tonal, verbal, and visual stimuli interfered with the ability of musicians and non-musicians to hold pitch information in working memory. Mohr and Pechmann's experimental design was underpinned by Baddeley's model of working memory, which conceptualises working memory as being comprised of three separate but inter-related systems – the visuospatial sketchpad, which processes visual and spatial information, the articulatory loop, which processes verbal and auditory information, and the central executive, which co-ordinates the activity of the other two systems and the attentional resources devoted to different aspects of a task (Baddeley, 1986, and Baddeley, 1990, as cited in Palmer & Schendel, 2007). Baddeley suggests that auditory information must be continually rehearsed to be retained in the working memory store, and Mohr and Pechmann proposed that it is this rehearsal which is affected by interference from other stimuli. They also proposed that musical training may lead to the development of a sub-system in the articulatory loop which deals exclusively with musical stimuli, and therefore that musicians' processing of tonal and verbal stimuli would be subject to different levels of interference from subsequently presented tonal and verbal information, while non-musicians should experience similar levels of interference for both types of information. A second aim of Mohr and Pechmann's study, then, was to assess whether the amount of attention devoted to the pitch comparison task affected the accuracy of a listener's memory.

Fourteen musicians and 13 untrained listeners heard two tones that were either identical, or a semitone apart, and asked to judge whether they were identical. In the five second interval between the notes participants heard a series of musical tones, single syllable nouns, or silence. In a fourth condition, they saw black and white grids in the interval between tones. In half the conditions, participants were instructed to ignore the stimuli between the two target tones, while in the other half they attended to the intervening stimuli as part of a secondary task. Both groups made significantly more correct judgements in the verbal and tonal attended conditions in which the target tones were identical, than those in which they were non-identical. While the memory of non-musicians for the pitch of the first tone was subject to interference from all types of stimuli tested, their performance was most significantly impaired by other tonal stimuli. Tonal stimuli were also the only kind which created significant interference for musicians' memory for the pitch of the first tone. The authors suggest that the markedly worse performance by musicians in the tonal condition was due to a form of interference specific to tonal stimuli, whereby the initial tone was overwritten by subsequent tonal information in a process that was automatic and almost uninfluenced by expertise or increased attention.

The results of this study suggest that divided attention also impairs recognition memory among non-musicians, even when the comparison and intervening stimuli are presented in different modalities. Mohr and Pechmann (1992) propose that while a tonal loop may exist in the working memories of both groups, untrained listeners must devote more attention in order to encode pitch information into it, a difference that leads to memory impairments for untrained musicians when they perform a distractor task in between comparing tones. Participants were also significantly more accurate when comparing identical tones than non-identical tones across all conditions. The authors suggest that the comparison tone in the identical pair reactivates the stored representation of the first tone and reduces the 'blurring' introduced by the intervening stimuli. The findings of this study provide support for Mohr and Pechmann's proposition that a tonal loop exists in working memory which is particularly efficient in trained musicians, allowing them to rehearse and retain tonal information relatively independently of other auditory stimuli, and with greater ease than non-musicians. This theory may also account for the superior pitch memory of musicians in comparison to non-musicians that has been observed by other researchers, for example Pauws (2003), Dalla Bella, Giguére, and Peretz (2007). However, musicians in this study were labelled as such only if they currently played an instrument, a classification system that could have masked wide inter-individual variation in musical skill and experience and so may have confounded the results.

Palmer and Schendel (2007) conducted three experiments to determine the effect of articulatory suppression on participants' ability to remember musical and verbal information, in an effort to establish whether Baddeley's model of verbal working memory processes was applicable to musical stimuli. Palmer and Schendel postulated that if this model were accurate, then the processing of auditory verbal material by the phonological store could occur directly and would not be impaired by articulatory suppression. Conversely, visually presented verbal material would have to be translated into an auditory form by the articulatory control process before it could be rehearsed. Articulatory suppression would disrupt this translation, and therefore impair participants' memory in tasks involving visually presented stimuli.

Trained musicians heard two four-item sequences of musical notes or spoken numbers, or saw similar sequences in which the notes and numbers were written rather than presented auditorily. The two sequences in each pair were separated by a 4900 millisecond interval. In the control condition participants remained silent during the interval, while in the two experimental conditions they were asked to repeat the word 'the', or to sing the syllable 'la' at a constant pitch. In the visual stimuli conditions, participants saw a comparison sequence after the interval and were asked to identify whether it matched the target sequence. They undertook a similar recognition memory task in the auditory stimuli conditions, with the comparison stimuli being presented in the form of tones played through headphones. Verbal ('the') suppression caused significantly greater impairment of musicians' memory for visually presented digits than verbally presented digits, a finding which is consistent with Palmer and Schendel's (2007) proposition that the conversion of visual stimuli into an auditory form for rehearsal is impaired by articulatory suppression. However, musical suppression ('la') did not significantly impair musicians' memory for visually or verbally presented notes, a puzzling finding that contradicts the earlier results. If a similar interruption of conversion was occurring as that created by verbal suppression, then recognition memory for notes should be impaired. If the visually and auditorily presented notes as well as the 'la' production task were all processed by the same musical loop, then interference should also be evident. The authors offer insufficient explanation for this trend. The finding that verbal suppression caused greater memory impairment for visual than verbal information is also inconsistent with Mohr and Pechmann's (1992) research, which found that auditory material between two comparison tones could interfere with musicians' memory for the pitch of the tones, while visual material did not.

When interpreting the results of the first experiment in their study, Palmer and Schendel (2007) assumed that participants were converting visually presented information into an auditory form before rehearsing it, rather than using other cues such as the visual appearance of the note sequences to aid memorisation. To test this assumption, the authors replaced articulatory suppression with a visual interference task. In the interval between sequences in this task, participants were not required to make any sounds. Instead, they saw a black and white grid which appeared in the same place as the written notes or numbers had just been presented. Squares on this grid which fell in the positions previously occupied by written numbers or notes were blacked out. Participants' memory for visually presented notes was significantly impaired when they saw this grid in the interval between the presentation of note sequences. However, no such impairment occurred when visually presented numbers were interpolated by the grid, a finding that the authors interpret as evidence that musicians translate visually presented digits into an auditory form before rehearsal, but do not do so for written music. If participants were encoding the printed scores visually then the information was presumably processed by the visuospatial sketchpad, a system within working memory that is believed to be largely independent of the articulatory loop. Therefore, visually presented information should not be affected by interference from verbal information, which is processed by the articulatory loop. The findings of the first experiment, that neither verbal nor musical suppression significantly impaired musicians' memory for visually presented notes when the comparison stimulus was also visual, support this assertion.

In the third experiment, Palmer and Schendel (2007) attempted to force participants to translate visually presented notes into an auditory form to rehearse them by presenting the printed score as the target stimulus and the auditory version of the same note sequence as the comparison stimulus. In this visual-auditory condition only, musical suppression did impair memory for visually presented notes. Palmer and Schendel concluded that this study provides evidence that musical training develops a working memory subsystem within the phonological loop that processes music independently of other auditory input, but that processing by this subsystem does not occur by default for musical stimuli that is not auditory. The authors posit that the tonal sub-loop is capable of processing musical information which is presented in score form, but only when the viewer is forced to convert it into an auditory form. This assertion is consistent with the findings of the study. However, Palmer and Schendel's study is one of relatively few that investigate the role of the tonal loop in processing musical information that is not solely auditory, and further research is needed to validate their claims. This study provide evidence that having to produce tones of a different pitch to an initial tone interferes with musician's ability to hold the pitch of the first tone in working memory. This is consistent with the findings of Wickelgren (1966) and Mohr and Pechmann (1992), which indicate that hearing tones of a different pitch immediately after hearing a target tone creates interference in memory for the first tone. The authors also interpreted their results to indicate that while training can improve memory for musical stimuli, memory for other verbal material will always be more accurate. They attributed this difference in accuracy to differences in experience – specifically, that over the course of day-to-day life even musicians use verbal memory more often than musical memory, and through continual use verbal memory will become the more accurate and efficient of the two. However, the average amount of musical training accrued by participants in this study was only six years – a period that is probably insufficient to develop true musical expertise. It is possible that musical memory might be more accurate among musicians who have had more training and experience, and further studies of such individuals are necessary to investigate this issue. This and other studies described here have been conducted in a laboratory setting using isolated, decontextualised musical stimuli – most often, single tones. Most of the music an individual is exposed to throughout life will be complex and comprised of simultaneous melodic, rhythmic, timbral, and often linguistic and emotional components (Peretz & Zatorre, 2005; Sacks, 2008). Therefore, the understanding of music-related working memory processes gleaned through studies that utilise single tones may not be especially meaningful.

Evidence for Pitch Perception and Memory as Discrete Cognitive Processes

In one of a series of studies that investigated the existence and nature of neurological impairments specific to music, Ayotte, Hyde and Peretz (2002) assessed the proficiency of 11 adults with apparent processing deficits across a range of musical domains - a profile of deficits the authors term 'congenital amusia'. Participants were assessed for their ability to process metre, scale, interval, and pitch contour information, to keep time to a rhythm, and to remember novel music, using a battery which has been widely validated for identifying musical deficits in brain damaged individuals. All participants who had been identified as amusic performed significantly below average in at least two of the battery subtests, with the most pronounced deficits evident in pitch discrimination test scores. Amusic participants were significantly worse than controls at identifying one semitone alterations in familiar and unfamiliar melodies, discriminating consonant tunes from dissonant tunes, and inferring the 'mood' of a melody from the key (major or minor) that it was played in. However, they performed slightly better in this last test than in the others, which the authors attribute to amusics using tempo (fast or slow), rather than pitch information, to determine the mood of the piece.

In order to establish whether the pitch processing problems experienced by amusics also affect their processing of speech sounds, the researchers asked participants to interpret the inflection (questioning or statement) of sentences in which the pitch of the last word had been raised six semitones, or lowered two semitones. Participants were also asked to identify the emphasised word in sentences in which the pitch of one word had been raised by eight semitones. Amusics performed only negligibly worse than controls in both these tasks. However, once the sentences were edited so that all linguistic information was removed and all that was left was a speech analogue to musical humming, amusics were significantly less accurate at identifying emphasised words, or whether the sentence was a statement or a question, than control participants. The authors interpret this to mean that amusics may rely on linguistic information more heavily than non-amusics when perceiving and interpreting speech prosody.

Taken together, the findings of this study provide some evidence for Ayotte, Hyde, and Peretz's (2002) assertion that an as yet unknown proportion of the population are affected by neurological deficits that almost exclusively affect music, and which impair performance across a range of musical domains including rhythm, pitch, and musical memory. The authors also argue that this indicates the existence of neurological processes that are unique and specific to music. However, the difficulties their participants had in interpreting the inflection of sentences and speech patterns with linguistic information removed are inconsistent with this claim. While the most pronounced difficulties experienced by amusic participants did involve musical stimuli, their pitch processing problems also slightly impaired their speech perception. This finding supports Levitin and Menon's (2003) assertion that human language and music share common neurological processes. Furthermore, there was considerable variation in the profile of difficulties experienced by each amusic participant. The authors cite these inter-individual differences as evidence that music-related neurological difficulties may exist on a continuum, or that the congenital amusia described may in fact be a general class of deficits comprised of a range of specific and discrete musical processing disorders. However, music-specific processing deficits have received relatively little attention from researchers (Peretz & Zatorre, 2005). More research is needed in this area before the existence of musical disorders can be verified.

Accuracy of Long-Term Pitch Memory in Vocal Production Tasks

Levitin (1994) differentiated between pitch memory and pitch labelling – a listener's ability to assign a name to the pitch of a note they hear, for example F sharp. He proposed that while possessors of absolute pitch have both abilities, the majority of listeners without AP may also possess stable internal pitch memory, but lack knowledge of the labels to describe pitch information. To test the accuracy of pitch memory among non-musicians who presumably lack pitch labelling skills, Levitin had 46 amateur singers sing or hum two different popular songs which they selected from a range of choices as songs they knew well. Their performances were compared with the versions of each song recorded by the original artist. Forty per cent of participants were able to sing familiar songs accurately to within one semitone in at least one trial, and 12 per cent were able to do so in both trials. Forty-four per cent of participants sang within two semitones of the accurate pitch on both trials. Levitin's definition of accuracy was fairly broad – participants could sing a full semitone sharp or flat and still be classified as correct. This is likely to have led to an overestimation of untrained singer's pitch accuracy when reproducing familiar songs from memory. The results of this study provide some support for Levitin's proposition that pitch memory is moderately accurate among untrained listeners. However, participants were allowed to begin singing from any point in the song they chose, and only the first three notes each singer produced were compared with the performance of the recording artist. This small sample provides a very limited representation of the overall accuracy of the pitch information stored in each singer's memory. Analysing the pitch of a number of notes from various points throughout the song, or of a greater number of successive notes, would provide a more valid impression of the characteristics of pitch memory. Furthermore, this study is underpinned by the assumption that vocal reproduction accurately reflects the representation of a song held in memory. Pauws (2003) found significant variability in the pitch of successive singing performances of the same song by untrained singers, which suggests that amateur singers are not particularly consistent when performing songs from memory. Therefore, the accuracy estimates of pitch memory gained through studies that rely on analysis of participants' singing may not be valid, and further research is needed that uses data other than sung performance to convey remembered pitch information.

Pauws (2003) compared the abilities of 18 trained and amateur singers to accurately reproduce the pitch, tempo, and intervals between notes in songs they knew well. He hypothesised that the song performance of trained singers, who have been taught to discriminate subtle pitch and tempo information in the music they hear and to integrate this into their performance, would improve after hearing the song played aloud, while untrained singers would not improve. He also proposed that singers in both groups should be able to accurately reproduce pitch and tempo information from memory, particularly for familiar songs, and that trained singers should be able to produce more correct intervals than untrained singers. Participants were presented with the titles of two songs by The Beatles that they had nominated as very familiar to themselves, and of two with which they were less familiar. They were asked to choose and sing a passage from each song twice without using the lyrics (i.e., just the melody), and then, after hearing the song played on a CD player, to sing the same passage a third time. These performances were recorded, and the recordings manually and computer analysed to create transcriptions of the melody produced by each singer. These transcripts were compared with the 'correct' scores corresponding to the passages participants had chosen, as performed by The Beatles. These scores were drawn from published songbooks containing transcriptions of The Beatles music. The use of such written scores as a basis for comparison with the performance of other singers is problematic. Musicians performing in a recording studio sometimes improvise or otherwise deviate from the score of the song they are currently singing. Therefore, the pitch and tempo information represented in the written scores may not have exactly matched the information produced by The Beatles on the CD participants heard, or on other renditions of the song they had heard which formed the basis of their memory for that particular song.

All participants sang each song in the uncued condition twice, in order to establish whether they could replicate their performance. While trained singers accurately reproduced the first note approximately 16 per cent of the time in both trials, the pitch production accuracy demonstrated by the untrained singers differed significantly between the first and second times they sang each melody – eight per cent and five per cent, respectively. However, these tests involved only a single note, the first of each song. Analysing the pitch accuracy of several notes, either consecutive or at different points throughout the song, would have given a more accurate impression of each singer's accuracy. While these results, like those obtained by Dalla Bella, Giguére, and Peretz (2007), suggest that trained musicians are significantly more accurate when recalling pitch information than untrained individuals, the accuracy scores for singers in both groups were markedly lower than those obtained by other researchers (for example, Levitin, 1994; Schellenberg & Trehub, 2003).

In Pauws' (2003) study, pitch production accuracy improved significantly for both trained and untrained singers when they sang immediately after hearing the original recording of that particular song. Trained singers reproduced the pitch of the first note of each melody in 47 per cent of trials, or produced a note which was a single semitone above or below the correct pitch. Untrained singers were accurate in 23 per cent of trials, and sang within one semitone of the correct pitch on 40 per cent of trials. The significant improvement by both groups is at odds with Pauws's hypothesis that cueing should enhance performance only for trained singers. This finding suggests that both trained and untrained singers are able to discriminate and remember subtle pitch and tempo information, and to evaluate and alter their own performance to better reflect this information. Trained singers were also more accurate at singing intervals than untrained participants. They correctly produced 62 per cent of the intervals across trials in the uncued condition, while untrained participants were accurate 56 per cent of the time. Both groups produced significantly more accurate intervals when singing very familiar songs in the uncued condition than when singing less familiar songs. Pauws suggests this as evidence that, for both musicians and non-musicians, pitch information for well-known songs is more stable and accurate than for less well-known songs. This conclusion is consistent with the findings of this study, and is further supported by Levitin's findings that pitch memory for very familiar songs is accurate even amongst individuals with no musical training.

Participants from both groups were able to sing significantly more correct intervals of less familiar songs in the cued condition than the uncued conditions. Pauws interprets this improvement as indicating that hearing a song played acts as a cue that activates the representation of that song stored in the listener's memory, allowing them to sing it with greater accuracy. This conclusion is also consistent with research conducted by Herbert and Peretz (1997), who noted an improvement in participants' singing performance after hearing the song aloud. However, it is also possible that participants were simply reproducing the information they had memorised from the most recent playing of the song, which they heard immediately before singing. A fundamental flaw in this experimental design is that it is impossible to distinguish whether the most recent memory of the song or a more stable, long-term memory is guiding their singing. No significant difference was found between the pitch production accuracy for the first note of less familiar songs in the cued and uncued conditions for either group of singers. Production of the initial note and of intervals both rely on the singer's internal representation of pitch information, so it seems odd that the presence of a cue should improve reproduction of the latter and not the former. All the trained singers in this study had at least five years of formal music education. As with the study conducted by Palmer and Schendel (2007), singers at this level of training are likely to be proficient, but may not have attained genuine expertise. Therefore, it is possible that more experienced singers might exhibit different levels of accuracy.

Dalla Bella, Giguére, and Peretz (2007) analysed the singing performance of untrained singers along similar dimensions as those investigated by Pauws (2003). Participants' a capella renditions of a familiar folk tune were also judged by their peers for overall proficiency. Twenty participants performed in a laboratory, while the remaining 42 sang outdoors while unaware that they were being recorded. Five professional singers were also recorded performing the song. Ten university students who had no musical training heard the recordings of the performances by the professional and untrained singers, and were asked to rate the 'overall accuracy' of each singer's rendition. This is a very general and ill-defined instruction which could have been interpreted differently by various raters, and which may have reduced inter-rater reliability. A computerised acoustical analysis was conducted to assess the tempo and pitch accuracy of each performance. Only syllables containing vowels were analysed, an approach the authors justify by citing Murayama's (2004, as cited in Dalla Bella, Giguére, & Peretz, 2007) finding that these syllables carry the majority of voicing and stable pitch information when sung. Tempo variation between singers was found to be related to the majority of their errors and lower peer judgements, with many participants singing at a faster pace, and a smaller but still significant number producing more incorrectly pitched intervals, than were evident in the recordings of professional singers.

However, their pitch errors were usually small. The researchers found that when 15 of the participants were explicitly asked to sing the song at a slower pace than the one they had been using, peer ratings of their proficiency became approximately equal to their ratings of professional singers. This study is one of few involving untrained singers in which the researchers demonstrate that the guided alteration of one aspect of sung performance can improve a singer's overall accuracy in reproducing a melody from memory. The authors suggest that the substantial improvements made by amateur singers once they slowed the speed of their singing indicate that pitch information is actually recalled from memory with a high level of accuracy, and that some pitch production errors may be a reflection of timing difficulties. It is impossible to determine whether these singers made timing errors because they had difficulty producing the song to match the version they remembered, or whether the remembered tempo itself is incorrect.

Folk songs are a useful stimuli for studies of musical memory because they are typically well-known to both trained and untrained singers. However, their lack of a single standard version makes it difficult to generalise findings gathered from one group of singers to a broader population. Songs such as 'Happy Birthday' are performed using a wide range of instruments and key signatures on different occasions, and often by amateur performers who use varying pitches and tempos (Levitin, 1994). While they have heard and sung the song hundreds of times, the version one singer – or in this case, peer rater - has encoded may differ substantially from the version encoded by another. It is difficult to accurately assess tempo and pitch errors in a folk song because there is no true 'correct' version. This shortcoming in the chosen stimuli casts doubt over whether the findings of Dalla Bella, Giguére, and Peretz's (2007) study accurately reflect the characteristics of musical memory among untrained singers. Two participants made large numbers of pitch errors. However, when they completed a listening task that required them to identify the incorrectly-pitched note in a short melody, these two participants performed very accurately. Dalla Bella, Giguére, and Peretz suggest that this poor singing performance in the apparent absence of a pitch perception problem indicates the existence of a purely vocal form of tone deafness, although the scarcity of participants who had this difficulty seems inadequate to support such a proposition. It is possible that these people performed poorly not because they were unable to hear that they were singing at the incorrect pitch, but because they were unable to accurately produce the pitches they were aiming for.

Accuracy of Long-Term Pitch Memory in Listening Tasks

Terhardt and Ward (1982) investigated the accuracy of pitch memory in trained musicians. Forty-seven musicians heard several versions of the first five seconds of a Bach piano piece commonly learned by pianists during training, which had been shifted up or down one, four, six, or seven semitones in pitch. Participants also saw a simplified version of the correct score, which is likely to have provided an additional cue for the memory of the pitch of the piece. Five participants claimed to possess absolute pitch (AP). While all five performed extremely well and accurately identified pitch altered excerpts in over 92 per cent of trials, several other participants who had not claimed to have AP performed equally well. All but four of the participants were able to judge whether the excerpt had been altered at a rate significantly better than chance. Participants' judgements were less accurate when the excerpt had been altered by only a semitone, although they were still moderately accurate. This suggests that even among musicians, fine-grained pitch differences of one semitone are below some people's threshold of absolute discriminability. Participants, including those who claimed to possess AP, reported feeling that they were guessing in a number of the one semitone trials. Their accuracy rate in these trials, however, suggest that it is possible for musicians to have excellent fine-grained pitch discrimination without being aware of it. Although the authors offer little explanation for this, the presence of four participants who performed significantly worse than the other participants and were unable to correctly discriminate even large alterations in musical key suggests that there may be some individuals in the population who suffer from marked pitch perception deficits. This is consistent with later research by Ayotte, Hyde, and Peretz (2002).

The results of Terhardt and Ward's (1982) study indicate that pitch memory exists at high levels of accuracy amongst musicians, but that even extensive musical experience does not lead to perfect pitch discrimination abilities. However, there is insufficient support in the results for the authors' claim that the high accuracy of almost all participants in this study indicates that AP is relatively widespread among the musically trained population. True AP possessors should, at least in theory, have made no errors at all. As the authors note, however, all but one of the supposed AP possessors made some errors, most often in the one semitone alteration condition, which suggests that even individuals with almost 'perfect' pitch have some difficulty discriminating very fine-grained pitch differences. Furthermore, the authors' failure to screen participants for AP beyond asking them to self-identify means that more or fewer of the participants than reported may have had this ability. Therefore, the results achieved by these individuals may not reflect the real accuracy of pitch memory among AP possessors. Studies of individuals who have been definitively identified as having AP would provide more accurate information about the unique characteristics of this type of pitch memory in comparison to that possessed by the general population.

In a study investigating the accuracy of long-term memory for the pitch of well-known melodies, Schellenberg and Trehub (2003) played pairs of excerpts from television theme tunes to a group of college students who did not have extensive musical training, and who claimed to be very familiar with each of the tunes presented. While the excerpts in each pair were taken from the same tune, one had been raised or lowered by one or two semitones. The participants were able to identify which excerpt had been altered in 58 per cent of trials in which the alteration was one semitone, and in 70 per cent of trials in which the excerpt had been altered by two semitones. This experimental design has the same flaw as that used by Pauws (2003) – namely, that it is impossible to determine whether participants were comparing the altered song to the relatively recent memory of the correct version played immediately beforehand, or to the representation which had been stored in memory for a much longer period, and which had been developed through repeated exposure. Therefore, it is uncertain whether their results reflected the accuracy of the older or more recent memories of each song.

Schellenberg and Trehub (2003) attempted to remove these possible cueing effects in a second experiment, in which participants heard each excerpt in isolation. Participants could judge whether the excerpt had been altered significantly more accurately in the first trial in this condition than in subsequent trials, although they performed significantly above chance in all trials. The authors suggested that this particular finding suggests that the recall of stable, long term memory for songs is subject to interference from similar musical stimuli. They proposed that the decline in participants' recall accuracy in later trials suggests that cumulative exposure to altered excerpts starts to interfere with memory for the original pitch level of subsequent songs, which appears to be a valid conclusion. However, when participants heard excerpts from unfamiliar melodies paired with identical excerpts which had been raised or lowered in pitch by one or two semitones, they were no better than chance at identifying which excerpts had been altered. This suggests that memory for novel musical information – in this case, pitch – is relatively inaccurate in individuals without musical training. However, research by Levitin (1994), Drayna, Manichaikul, de Lange, Snieder, and Spector (2001), Pauws (2003), and Dalla Bella, Giguére, and Peretz (2007) indicates that while the process by which musical information is encoded into memory may be more efficient in musicians than untrained listeners, untrained listeners are able to accurately recall the pitch characteristics of songs they have heard many times. Further investigation is needed to determine the role song familiarity plays in the accuracy of pitch recall.

Herbert and Peretz (1997) investigated the relative salience of pitch and tempo as long-term memory codes for musical information. Participants heard excerpts from popular songs which had been altered so they had either the original pitch variations but different rhythms, or the original rhythm but the melody played at a constant pitch. In a third condition, the rhythm of one song was paired with the melody of another. Participants were able to correctly name the tune significantly more often in the original pitch with altered rhythm condition, and reported higher 'feeling of knowing the song' ratings for this condition in comparison to the others. The authors interpret this to mean that pitch relations (i.e., melody) give rise to a particularly strong and salient memory code, and can be used more readily than rhythm to identify excerpts which have had other elements altered. This conclusion is consistent with their findings. The results also indicated that when participants saw a song title at the beginning of the song being played in the original rhythm with constant pitch condition, they correctly judged whether the song matched the title more quickly than when the title was presented at the beginning of songs in the original melody with altered rhythm condition. While their other results indicate that rhythm is a relatively weak memory code in comparison to pitch information, Herbert and Peretz propose that the improvement in listener's ability to quickly and correctly identify songs in the unaltered rhythm condition suggest that rhythmic information is in fact encoded quite accurately, and is simply less salient during uncued recall. Herbert and Peretz propose that seeing the title triggers top-down processing, whereby the representation of the song matching the presented title is activated in a participants' memory, and they compare the subsequently heard song against this activated memory representation. In the presence of the same cue, recall for pitch is inferior to recall for rhythm. This explanation is consistent with the findings of this study, and is further supported by the findings of Schulkind (2004), which suggest that top-down processing plays a role in recall for familiar songs. These results suggest that the experimental circumstances under which individuals recall musical information can significantly influence their performance, and therefore the accuracy of the conclusions researchers draw about the characteristics of musical memory. However, participants in this study were not screened for musical training, which may have masked significant differences in memory processes between musicians and non-musicians within the group.

Overall Accuracy of Pitch as a Memory Code, and the Possible Impact of Interference on Long-Term Memory for Pitch Information

There is some evidence to support the applicability of Baddeley's model of working memory to music processing, and the existence of a tonal loop which, with training, can process musical stimuli almost independently of other auditory information. Pitch information appears to be a particularly stable and salient code in both long and short term memory, in comparison to other musical characteristics such as tempo. However, some studies suggest that the presence of a cue such as a song title or hearing the song played aloud can temporarily strengthen recall of tempo information. There is also substantial evidence that suggests that long-term memory for pitch information is moderately stable and accurate among both musicians and non-musicians. However, estimates of the accuracy of pitch memory vary considerably between studies. While many studies indicate that trained musicians outperform untrained individuals in tests of long and short term pitch memory, particularly those tasks which involve novel musical information, the discrepancy between the two groups is less pronounced when the task involves recall of well-known songs. This suggests that while non-musicians may need more exposure to musical information in order to memorise it accurately, non-musicians are eventually able to encode and recall pitch information accurately. The inconsistencies between studies indicate that research is needed to further clarify the nature of memory for pitch information, and the extent to which familiarity with a piece of music interacts with musical training to influence the accuracy of pitch recall. The predominance of studies that evaluate pitch memory by analysing singing performances also suggest a need for additional research that assesses this type of memory in other ways, to avoid the potential confounding effects of mismatches between the pitch information participants remember, and that which they are capable of producing.

The existence of interference has been widely validated by psychological research, and has been shown to affect memory for a range of different types of information. A number of researchers have examined the impact of interference on working memory for musical and non-musical auditory information (Mohr & Pechmann, 1992; Palmer & Schendel, 2007; Wickelgren, 1966). This research provides compelling evidence that when an individual is asked to recall a particular piece of auditory information, various types of other auditory information presented close to the time of recall do interfere with their ability to remember the target information accurately. Given the existence of interference in memory for other types of auditory information, it is likely that such interference may also affect memory for music. However, little research exists to support or dispute the existence of interference in long-term memory for music. Further study is needed to largely overlooked aspect of music cognition. This study is designed to test the hypothesis that among listeners who do not have musical training, the pitch of a previously heard excerpt from a well-known pop song will impair an individual's ability to accurately recall the pitch of the next excerpt they hear.

Method

Research Design

This study utilised a repeated measures design. The independent variable, which had nine levels, was the pitch of each excerpt. In the control condition participants heard two unaltered excerpts. In condition two, participants heard an unaltered excerpt followed by an excerpt lowered by one semitone. In condition three, participants heard an unaltered excerpt followed by an excerpt raised by one semitone. In condition four, participants heard two excerpts lowered by one semitone. In condition five, participants heard an excerpt lowered by one semitone, followed by an excerpt raised by one semitone above the original pitch. In condition six, participants heard an excerpt lowered by one semitone, followed by an unaltered excerpt. In condition seven, participants heard two excerpts raised by one semitone. In condition eight, participants heard an excerpt raised by one semitone, followed by an unaltered excerpt. In condition nine, participants heard an excerpt raised by one semitone, followed by an excerpt lowered by one semitone. All participants were tested at all levels of the independent variable. The dependent variable under investigation was participants' accuracy in detecting pitch alterations in familiar songs.

Participants

Participants in this study were 20 undergraduate students from Edith Cowan University and 10 individuals from outside the university. Included in the group were 22 females and eight males aged between 18 and 48 years ($M = 26.97$, $SD = 8.55$).

Participants were recruited opportunistically through face-to-face requests, and through snowballing techniques whereby participants were asked to provide the contact details of acquaintances who would be interested in taking part in the research. These individuals were asked to indicate whether they had past musical training, and only those who had never had music lessons were invited to participate in the study.

Materials

Songs considered for inclusion as stimuli in this study were selected from the top 100 best-selling singles charts from the United Kingdom, the United States of America, and Australia over the last 20 years. The researcher also asked acquaintances and fellow university students of various ages to suggest song titles that they thought were likely to be well known among other university students, that were classified as pop or soft rock, and that had lyrics as well as music. A shortlist of 130 songs was compiled, and digital files of these songs were circulated via email among university students who were acquaintances of the researcher. The students were asked to identify which songs on the list they were familiar with. Songs that were recognised by at least five individuals in this informal pilot test were selected for inclusion as stimuli in this study. Pop songs were chosen as the stimuli because usually only one version of a song, performed by one artist or group, is heard multiple times by listeners, and always at the same pitch (Levitin, 1994). Such repeated exposure to the same stimulus increases the likelihood that participants will have formed strong memories for the songs they hear in the study. CD recordings of these songs were converted to a digital format and copied into the music editing software Audacity version 1.2.6. This software program was used to extract excerpts from the recording of each song, and to raise or lower the pitch of some excerpts by one semitone. The excerpts were played to participants through the computer program Superlab 4.0, over Sony MDR E818 headphones. Participant responses were recorded using an RB-830 response box.

Procedure

In each trial, participants heard a 30 second excerpt of a well-known pop song. They then had ten seconds to make a judgement about whether or not the song they heard was different from the original recording of that song, and to press buttons on a response box to indicate a judgement of yes or no, or to indicate that they had never heard the song. The next trial began immediately after they had entered a response, or after ten seconds had elapsed. No feedback about the correctness of the response was provided. Each participant performed 100 trials in a single session of approximately 66 minutes duration. The order of presentation of all trials was manually randomised by the experimenter, and five versions of the experiment were produced in which the songs occurred in different orders. Participants were divided into groups of six, and each group completed one version of the task. Although there were a minimum of five pairs of songs belonging to each condition in every version of the experiment (for example, five pairs consisting of one unaltered excerpt followed by an excerpt raised by one semitone, for a total of ten excerpts in the unaltered – raised condition), the different song order in each version meant that there were different numbers of additional pairs in each condition in each of the five versions. Participants completed between fourteen and 28 trials for each experimental condition depending on which version of the experiment they completed, and ten additional trials. These occurred at random intervals, and did not conform to the sequence governing the order in which the rest of the songs are heard. The inclusion of these 'filler trials' was intended to prevent participants from guessing the pattern underlying the order in which songs were presented.

Results

The correct responses participants gave for every second excerpt (i.e., the second song in each pair) in each of the pitch pairing conditions were converted to a percentage total for that condition. Trials in which participants indicated that they had never heard the song before were excluded from the analysis, as were results from the filler trials and those in which the participant entered no response. A one-way repeated measures Analysis of Variance (ANOVA) was conducted to compare the group's mean pitch alteration detection scores for the second excerpt in each of the pairs they heard, in each of the nine pitch conditions. Normality screening identified participant seven as an outlier. This individual performed significantly better than the other participants in all conditions, and their mean score fell more than three standard deviations above the group mean. Data from this participant were therefore excluded from further analysis. The ANOVA indicated a significant main effect of the pitch of the previous song on participants' ability to accurately detect whether or not the pitch of the second excerpt in a pair of pop songs excerpts had been altered, $F(8, 224) = 22.155, p < .05$. Tukey's Honestly Significant Difference (HSD) comparisons were conducted to identify the location and size of differences between the group's mean scores in each of the conditions. These differences are illustrated in Table 1, with the significant differences ($ps < .05$) underlined.

	Unaltered - unaltered	Unaltered - raised	Unaltered - lowered	Lowered - unaltered	Lowered - raised	Lowered - lowered	Raised - raised	Raised - unaltered	Raised - lowered
Unaltered - unaltered	-	-	-	-	-	-	-	-	-
Unaltered - raised	38.5	-	-	-	-	-	-	-	-
Unaltered - lowered	48.24	9.74	-	-	-	-	-	-	-
Lowered - unaltered	29.03	9.47	19.31	-	-	-	-	-	-
Lowered - raised	25.08	13.42	23.25	3.95	-	-	-	-	-
Lowered - lowered	40.83	2.33	7.52	11.8	15.75	-	-	-	-
Raised - raised	45.61	7.11	2.81	16.58	20.53	4.78	-	-	-
Raised - unaltered	18.49	20.01	29.67	10.54	6.59	22.34	27.12	-	-
Raised - lowered	27.26	11.24	21.02	1.77	2.18	13.57	18.35	8.77	-

Table 1. Absolute differences between non-musicians' mean correct pitch alteration judgements in each pitch condition.

Tukey's HSD comparisons indicated significant differences between the means of the control condition (M = 78.71%, SD = 17.24) and all other conditions. Significant differences were also found between the means of the unaltered excerpt followed by a lowered excerpt condition (M = 30.47%, SD = 14.27) and the lowered excerpt followed by a raised excerpt (M = 53.63%, SD = 17.97), raised excerpt followed by an unaltered excerpt (M = 60.22%, SD = 16.97), and raised excerpt followed by a lowered excerpt (M = 51.45%, SD = 22.68) conditions. Further significant differences were found between the means of the unaltered excerpt followed by a raised excerpt condition (M = 40.21%, SD = 18.74) and the raised excerpt followed by an unaltered excerpt conditions, the lowered excerpt followed by an unaltered excerpt condition (M = 49.68%, SD = 27.01) and the raised excerpt followed by a raised excerpt condition (M = 33.10%, SD = 18.53), the lowered excerpt followed by a raised excerpt condition (M = 53.63%, SD = 17.97) and the lowered excerpt followed by a lowered excerpt condition (M = 37.88%, SD = 16.20), the lowered excerpt followed by a raised excerpt condition and the raised excerpt followed by a raised excerpt condition, the lowered excerpt followed by a lowered excerpt condition and the raised excerpt followed by an unaltered excerpt condition, the raised excerpt followed by a raised excerpt condition and the raised excerpt followed by an unaltered excerpt condition, and the raised excerpt followed by a raised excerpt condition and the raised excerpt followed by a lowered excerpt condition. No other significant differences between conditions were observed. These results provide some evidence that hearing a musical excerpt at a particular pitch can interfere with untrained listeners' ability to accurately recall the pitch of musical excerpt presented immediately afterwards.

Discussion

The results of this study indicate that hearing a familiar song that has had its pitch altered by one semitone impairs participants' ability to detect altered pitch in a subsequent song. Participants were particularly inaccurate at judging the pitch of an excerpt which had been lowered by one semitone when it was preceded by an unaltered excerpt. This suggests that hearing a song at a pitch that matches their stored representation for that song creates significant interference in a listener's ability to accurately recall the pitch of a song they hear shortly afterwards, and to detect that is a semitone lower than the version they remember. However, participants were not markedly inaccurate at detecting pitch alterations in the unaltered excerpt followed by a raised excerpt condition. This may indicate that listeners have more difficulty detecting subtle pitch variations from their stored representations of music when the variation involves lowering rather than raising the pitch of the remembered song. Participants were also moderately inaccurate at detecting pitch alterations when they heard an excerpt which had been raised one semitone in pitch preceded by another raised excerpt, which suggests that hearing altered pitch information creates some interference in listeners' ability to accurately recall the pitch of a subsequent song when its pitch has been altered in a similar direction, and to detect that this alteration has taken place.

Participants were particularly good at detecting that the pitch of an unaltered excerpt had not been changed when it was preceded by an excerpt which had been raised by one semitone. This suggests that hearing a song at a higher pitch than the version of that song they have in memory prior to hearing an unaltered song does not create interference to the same degree as hearing a lowered excerpt prior to an unaltered song. Participants were moderately accurate at detecting pitch alterations in both the raised excerpt followed by a lowered excerpt and the lowered excerpt followed by a raised excerpt conditions, which suggests that listeners are slightly more accurate at detecting deviations from the representations of pitch information they have in memory when the size of the pitch alteration separating two consecutively heard songs is two semitones instead of one.

Several participants had never heard a number of the songs used as stimuli in this experiment, and were therefore unable to make a valid judgement about whether or not the pitch of these songs had been altered. While the exclusion of these trials from the calculation of individual participants' overall accuracy rate in detecting pitch alterations was deemed necessary, it is possible that this may have artificially raised or lowered their overall scores for conditions in which they were unfamiliar with multiple songs. One participant performed unusually well, achieving an accuracy rate of over 70 per cent in each condition. Although this participant was identified as an outlier and therefore had their results excluded from the final analysis, her high accuracy scores suggest that there are some individuals who have extremely accurate and stable pitch memory and pitch discrimination skills, even without having had musical training.

This study provides some evidence that the long-term pitch memory of individuals who have not had musical training is not particularly stable or accurate. It also suggests that, like memory for other auditory stimuli, recall for music is vulnerable to interference from more recently presented stimuli. While various differences between the way musicians and non-musicians process musical information have been extensively researched, few researchers have examined the impact musical training has on interference in long-term memory for music. Studies of short-term memory suggest that musician's memories for musical information are more resistant to interference from non-musical auditory stimuli than those of untrained listeners (Mohr & Pechmann, 1992). However, some research indicates that subsequently presented musical tones can also interfere with musicians' ability to recall the pitch of an initial tone, sometimes to almost the same extent as they do for non-musicians (Mohr & Pechmann, 1992; Palmer and Schendel, 2007). Further research is necessary to establish whether the interference in long-term pitch memory created by hearing differently pitched songs close to the time of recall of another song, as identified in this study, is evident among musicians as well as untrained individuals.

Many past studies of long-term pitch memory have required participants to sing or listen to a number of familiar songs one after the other in a short space of time (for example, Levitin, 1994; Pauws, 2003; Terhardt & Ward, 1982). The accuracy with which participants are able to perform pitch judgement tasks involving these songs, or to sing them at the correct pitch, is presumed to reflect the accuracy of their memory for pitch information. However, if the interference researchers (Mohr & Pechmann, 1992; Palmer & Schendel, 2007; Wickelgren, 1966) have identified in studies of short-term musical memory also affects the encoding and recall of pitch information in long-term memory, then it is possible that past studies that have utilised multiple musical stimuli presented in quick succession have underestimated the accuracy of long-term pitch memory among both musicians and non-musicians. To determine whether interference does represent a confound in experimental designs of this nature, future research should be conducted to compare the accuracy of participants' pitch memory in singing or listening tasks that involve multiple songs presented close together in time, with their accuracy when there is a long interval separating the presentation of each song.

This study provides some of the first evidence that long-term pitch memory among individuals without musical training is subject to interference from previously presented pitch information. This finding has significant implications for existing research into pitch memory, some of which may have underestimated the accuracy of pitch recall as a result of the interference created when participants were required to recall pitch information for multiple songs in quick succession. More studies are needed to determine whether the findings of this study can be replicated in other untrained populations, as well as to investigate the impact interference has on trained musicians' ability to remember pitch information.

References

Ayotte, J., Hyde., K., & Peretz, I. (2002). Congenital amusia: a group study of adults afflicted with a music-specific disorder. *Brain, 125,* 238-251.

Baddeley, A. (1986). *Working memory.* Oxford: Oxford University Press.

Dalla Bella, S., Giguére, J.-F., & Peretz, I. (2007). Singing proficiency in the general population. *Journal of the Acoustical Society of America, 121(2),* 1182-1189.

Drayna, D., Manichaikul, A., de Lange, M., Snieder, H., & Spector, T. (2001). Genetic correlates of musical pitch recognition in humans. *Science*, *291*, 1969–1972.

Herbert, S., & Peretz, I. (1997). Recognition of music in long-term memory: are melodic and temporal patterns equal partners? *Memory & Cognition, 25(4),* 518-533.

Huron, D. (2001). Is music an evolutionary adaptation? *Annals of the New York Academy of Sciences, 930,* 43-61.

Hyde, K. L., & Peretz, I. (2003). What is specific to music processing? Insights from congenital amusia. *Trends in Cognitive Sciences, 7(8),* 362-367.

Jackendoff, R., & Lerdahl, F. (2006). The capacity for music: What is it, and what's special about it? *Cognition, 100,* 33-72.

Levitin, D. J. (1994). Absolute memory for musical pitch: Evidence from the production of learned melodies. *Perception & Psychophysics,56(4),* 414-423.

Levitin, D. J., & Menon, V. (2003). Musical structure is processed in "language" areas of the brain: a possible role for Brodmann area 47 in temporal coherence. *Neuroimage, 20(2), 142-152.*

Mohr, G., & Pechmann, T. (1992). Interference in memory for tonal pitch: Implications for a working-memory model. *Memory & Cognition, 20(3),* 314-320.

Palmer, C., & Schendel, Z. A. (2007). Suppression effects on musical and verbal memory. *Memory and Cognition, 35(4),* 640-650.

Pauws, S. (2003). Effects of song familiarity, singing training, and recent song exposure on the singing of melodies. Retrieved July 7, 2009, from http://ismir2003.ismir.net/papers/Pauws.PDF

Peretz, I., & Zatorre, R. J. (2005). Brain organization for music processing. *Annual Review of Psychology, 56,* 89-114.

Sacks, O. (2008). *Musicophilia: Tales of music and the brain* (Rev. ed.). New York: Vintage Books.

Schellenberg, E. G., & Trehub, S. E. (2003). Good pitch memory is widespread.

Psychological Science, 14(3), 262-266.

Schulkind, M. D. (2004). Conceptual and perceptual information both influence melody identification. *Memory and Cognition, 32(5),* 841-851.

Terhardt, E., & Ward, W. D. (1982). Recognition of musical key: Exploratory study. *Journal of the Acoustical Society of America, 72*, 26-33.

Wickelgren, W. A. (1966). Consolidation and retroactive interference in short term recognition memory for pitch. *Journal of Experimental Psychology, 72(2),* 250-259.