Stability and accuracy of long-term memory for musical tempo

Avril Fairclough

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Stability and Accuracy of Long-Term Memory for Musical Tempo
Avril Fairclough
A report submitted in Partial Fulfilment of the Requirements for the Award of Bachelor of Science (Psychology) Honours, Faculty of Computing, Health and Science, Edith Cowan University.
Submitted October, 2010

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STABILITY OF LONG-TERM MEMORY FOR TEMPO

Abstract

While prior research inconclusively demonstrates how musical information is stored in long-term memory, a recent study by Hay (2009) found that interference reduced long-term memory for musical pitch. The present study extended this research to musical tempo and examined whether the stability and accuracy of long-term memory for tempo would be reduced as a result of interference from altered familiar songs. The independent variable was the tempo of excerpts from well-known pop songs, which were presented in either the original form or with the tempo increased or decreased by 10%. Participants with no formal musical training listened to a series of song excerpts and determined, using their song memories, whether they believed each excerpt had been altered. The dependent variable was participants’ accuracy at identifying tempo changes depending on the previous song’s tempo. The results were not predicted, with participants having high and low identification accuracy for unaltered and altered excerpts respectively, regardless of the preceding song’s tempo. While no evidence was found for interference, which seems to indicate accurate long-term memory for tempo, the poor identification of altered excerpts suggests a stronger possibility of poor memory accuracy and stability. The degree of tempo change and participants’ song familiarity may have been insufficient for interference to occur. Further research controlling for this or using an alternative interference-based design is necessary for a greater understanding of the affect of interference on long-term memory for tempo.

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Acknowledgements

First and foremost, my sincere thanks go to my supervisor Craig Speelman. His vast knowledge, patience and guidance have been both an invaluable asset and an inspiration.

I also wish to thank all the participants who volunteered their time for this study as well as my close friends who offered endless encouragement and understanding. In particular, a special thanks goes to Alyce Hay and David Archbold for their indispensable advice and assistance.

Last, but most certainly not least, I would like to thank my family for their unwavering support, advice and patience. The countless hours spent editing drafts and providing feedback are greatly appreciated. I could not have completed this research without you.
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>COPYRIGHT AND ACCESS DECLARATION</td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>iv</td>
</tr>
<tr>
<td>I. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Evidence for Long-Term Memory of Musical Tempo</td>
<td>3</td>
</tr>
<tr>
<td>Evidence for the Influence of Long-Term Memory on Working Memory</td>
<td>4</td>
</tr>
<tr>
<td>Evidence for a Working Memory Faculty Specifically for Musical Information</td>
<td>5</td>
</tr>
<tr>
<td>Processing and Storage Differences Between Tempo and Other Musical Information</td>
<td>9</td>
</tr>
<tr>
<td>Memory Stability and the Just Noticeable Difference Threshold</td>
<td>15</td>
</tr>
<tr>
<td>Evidence for an Adaptive Long-Term Memory for Musical Tempo</td>
<td>18</td>
</tr>
<tr>
<td>Stability and Accuracy of Long-Term Memory for Musical Tempo</td>
<td>18</td>
</tr>
<tr>
<td>Evidence for stable long-term memory for musical tempo</td>
<td>18</td>
</tr>
<tr>
<td>Evidence that long-term memory for musical tempo is not stable</td>
<td>21</td>
</tr>
<tr>
<td>Interference Research and Long-Term Memory Stability for Musical Information</td>
<td>26</td>
</tr>
<tr>
<td>Memory for Musical Tempo and Support for an Interference-Based Research Design</td>
<td>27</td>
</tr>
<tr>
<td>II. METHOD</td>
<td>30</td>
</tr>
<tr>
<td>Research Design</td>
<td>30</td>
</tr>
<tr>
<td>Participants</td>
<td>31</td>
</tr>
<tr>
<td>Materials</td>
<td>31</td>
</tr>
<tr>
<td>Procedure</td>
<td>32</td>
</tr>
<tr>
<td>III. RESULTS</td>
<td>33</td>
</tr>
<tr>
<td>IV. DISCUSSION</td>
<td>36</td>
</tr>
</tbody>
</table>
V. REFERENCES ....................................................................................... 43

VI. APPENDICES

Appendix A: List of Well-Known Songs ................................................... 51
Appendix B: Chi-Square Results.............................................................. 56
Appendix C: Participants’ Overall Percentage Accuracy ......................... 58
Stability and Accuracy of Long-Term Memory for Musical Tempo

This research investigates how stable and accurate long-term memory is for musical tempo. While previous research has been conducted in this area, the findings have been equivocal. It is possible that this is due to many of the studies presenting serious methodological confounds. Thus, the current research was designed to address these methodology discrepancies to provide a more valid investigation of long-term memory for musical tempo.

The following review focuses on how musical information, and in particular musical tempo, is both processed and stored in the human brain. There is compelling evidence to suggest memory for musical information is different from other information such as language, but whether all musical components (including tempo and pitch) are remembered in the same way is still unclear (Berz, 1995; Schendel & Palmer, 2007). Indeed, ambiguous results are also present when examining how accurately musical tempo can be remembered (Levitin & Cook, 1996; Moelants, Styns & Leman, 2006). Many of these studies require participants to vocally reproduce their memories, which may not be an accurate measure of long-term musical memories. More recently in the pitch domain, an interference methodology has been used to assess this long-term memory stability, since it addresses many of the confounds present in the earlier research. However, this design has not been extended to the tempo domain, with further investigation in this area being required before long-term memory for tempo can be adequately understood.

Music is a universal part of everyday life, requiring complex cognitive processes to be remembered and later recognised. As indicated by Levitin (2006), music is constructed of rhythm, timbre, pitch and tempo. In particular, ‘pitch’ refers to how high or low a note is relative to other notes in the musical scale, while ‘rhythm’ refers to the duration and the grouping of beats together (Levitin, 2006; Pauws, 2003). ‘Timbre’ describes the particular
sound and 'tonal colour' of different notes and instruments (Levitin, 2006; Pauws, 2003), and ‘tempo’ refers to the speed at which a piece of music is played (Levitin, 2006). It is generally agreed that human brains are physiologically structured to process this musical information (Peretz, 1996). Despite this ability, great variation exists between individuals in their abilities to process and remember musical information over a long period of time (Jackendoff & Lerdahl, 2006; Schulkind, 2009). This review focuses on human perception and long-term memory for tempo.

While decades of research has confirmed the existence of long-term memory for musical information (Bartlett & Snelus, 1980), recent research has indicated a specific working memory faculty linked with long-term memory that only contains musical information (Berz, 1995; Schendel & Palmer, 2007). The use of this faculty appears to be enhanced with musical training, however non-musicians need to devote more attention to musical information for storage in this faculty (Pechmann & Mohr, 1992). Furthermore, there is debate whether all musical information is stored together in this location, with many neurological studies indicating separate memory for different musical elements such as pitch and rhythm, while others believe these elements are combined in memory (Peretz, 1996). A third theory has also been proposed whereby memory for musical elements can be both combined and separate (Boltz & Jones, 1986; Hébert & Peretz, 1997). The lack of focus on tempo specifically, and the inconsistencies in the research literature, provide grounds for further research.

Research inconsistencies also exist between studies investigating long-term memory accuracy and stability for tempo. There is evidence that long-term memory can be stable, but it is likely that this is only for music familiar to the listener, with different studies using seemingly less familiar music showing no evidence for memory stability (Moelants et al., 2006). Furthermore, unlike previous findings for other musical stimuli, musical training does
not appear to influence this memory stability. Many studies do not adequately examine individual differences in musical experiences, and this may mask the effects of musical training. Thus, memory stability for tempo may still be different between musicians and non-musicians, but this requires further investigation. The primary method for investigating this memory stability is with vocal reproduction studies, which possess several critical confounds. Firstly, participants are unaware that tempo is being measured, and as such their focus is on accurately reproducing pitches, which may compromise the accuracy of tempo reproductions. Secondly, these studies presume that individuals have the ability to reproduce their memories. If individuals - particularly those without musical training - lack this ability, an inaccurate picture of mental stability results. Few studies have used alternative methods to examine this stability, and those that did failed to adequately examine the effect of musical experiences, which may explain the mixed memory stability results. Recent studies in the pitch domain have controlled the method and musical training confounds, however this has yet to be applied for musical tempo. Despite many conclusions formed regarding long-term memory for tempo, further research is required to determine just how stable and accurate long-term memory is for musical tempo.

**Evidence for Long-Term Memory of Musical Tempo**

There is little debate over the existence of a long-term memory that is responsible for retaining an immeasurable amount of information over a long time period. There is no known limit on the types of information stored in long-term memory, with studies such as Rubin (1977) and Mandler and Ritchey (1977) demonstrating that language, visual information, prose and verse have all been retained over many years. Music appears to be no different.

The ease of recalling a song heard years before, and the ability to pass songs between generations, is evidence for long-term memory for musical information (Lord, 1982 as cited in Calvert & Tart, 1993; Sloboda, 1985). This is further shown through music studies
examining memory recall and recognition between musicians and non-musicians (Hébert & Peretz, 1997; Levitin, 2006; Levitin & Cook, 1996), and different songs styles including folk (Halpern, 1988; Levitin & Cook, 1996), classical (Geringer & Madsen, 1984), jazz (Collier & Collier, 1994) and pop music (Brennan & Stevens, 2006; Hay, 2009; Levitin, 1994; Levitin & Cook, 1996).

Evidence for the Influence of Long-Term Memory on Working Memory

A number of studies have used working memory to demonstrate long-term memory for musical information (Berz, 1995). Working memory, as proposed by Baddeley and Hitch (1974), is the memory system where information from both the environment and long-term memory is held and processed by three different, but inter-related systems. The 'phonological loop' (or 'articulatory loop'), and the 'visuospatial sketchpad' are the storage systems processing auditory and language information and visual and spatial information respectively (Baddeley, 1986; Baddeley, 1990 as cited in Schendel & Palmer, 2007). The third system, the central executive, co-ordinates and processes the information held in the two storage systems (Baddeley, 1986; Baddeley, 2003). Recently, a fourth 'episodic buffer' system has been proposed, which performs the actual processing of the information (Baddeley, 2000; Baddeley, 2003), but further research is required to confirm this system.

According to Baddeley and Hitch (1974), long-term memory and working memory are interconnected, with working memory retrieving information from long-term memory to assist with short-term processing (Ruchkin, Grafman, Cameron & Berndt, 2003). Multiple music studies have demonstrated this interaction, including Attneave and Olson (1971) who investigated participants' abilities to transpose intervals. An interval is the specific distance between two pitches, which remains the same when the pitches are changed (known as 'transposition') provided the pitches are the same distance apart (Attneave & Olson, 1971). Subjects with greater long-term memory of intervals were found to be significantly better at
transposing the melodies than those with limited interval knowledge, indicating the relationship between working memory performance and long-term knowledge. Six participants do not adequately represent the population though, so these findings should be applied carefully. However, other music studies have also found this relationship. Indeed, participants with enhanced long-term musical memory have been found to have better immediate recall of melodies (Sloboda & Parker, 1985) and enhanced recognition memory for both tones (Cuddy, 1971; Dewar, Cuddy & Mewhort, 1977) and tonal sequences (Deutsch, 1980).

Many of these studies focused on musicians because they have enhanced musical long-term memory resulting from musical training, thus they are prime subjects for these studies (Cuddy & Cohen, 1976). Furthermore, few studies examined the relationship between long-term memory and working memory for isolated musical elements, including tempo. It is expected these results would also apply to tempo, as it is often presented with other musical elements (particularly in short melodies).

**Evidence for a Working Memory Faculty Specifically for Musical Information**

It is apparent from many working memory studies that memory for music may be determined by a specific cognitive faculty, distinct from memory systems for other information, such as language (Pechmann & Mohr, 1992). While there is still debate in this area, research has indicated that, for musicians at least, different musical elements can be remembered separately. Martin, Wogalter and Forlano (1988) demonstrated the memory differences between verbal and musical information using interference with background music. Interference refers to the reduced ability to remember an item when another similar item is presented around the same time, due to both items using the same memory storage system (Anderson & Neely, 1996). Baddeley (2000) proposed that the information must be rehearsed to remain stored, and during rehearsal is when interference occurs. Thus, if verbal
and musical items are similar, they would be rehearsed and stored in the same location and when presented together, interference would occur. Indeed, Martin et al. (1988) tried to assess the difference between verbal (auditory) and musical memory using interference. Participants were instructed to read a text passage, with the expectation that the text would be internally spoken and stored as verbal information, and would suffer interference from other verbal, but not musical, information. At the same time participants were exposed to one of six auditory background conditions: 1. silence; 2. instrumental music; 3. random sequences of tones; 4. white noise; 5. random speech; 6. continuous speech. Participants were told to ignore the background sounds. Participants then completed an interpolated task before answering comprehension questions about the passage they read. As predicted, there was significant interference between the background speech conditions and reading the passage, with significantly fewer correct answers for the speech condition compared with the quiet control condition (64% and 72% respectively). This confirms prior studies that verbal information competes for the same storage place. However, the subjects still performed reasonably in the speech condition, which may indicate that while interference did occur, the similarity between the items (and the resulting interference) was not enough to produce extremely low comprehension performance.

It was also apparent that the comprehension performance with musical background stimuli (70%) was no different to the control, but was significantly better than the verbal conditions. This provides strong support that there is no interference between verbal and musical information and thus, musical information is likely to be stored separately. This study did not examine the proportion of musically trained subjects, however. If only musicians store musical information separately, high numbers of musicians may have artificially inflated the results. Furthermore, it cannot be concluded that verbal background information only interferes with a written (or read) primary task; verbal background stimuli
may interfere with any primary task.

Martin et al. (1988) conducted a second experiment where the primary task was musical. If interference occurred solely for musical information, this would further support the separate storage of verbal and musical information. Musically trained participants were required to read written notation to identify the song. It was expected that the written musical notation would be converted and stored as auditory musical information. Participants were given a pilot test to verify if they knew similar songs and could perform the task, and only three background conditions were used (continuous speech, instrumental jazz and silence).

The results were opposite to the first experiment. Performance on the musical task was significantly worse in the music condition (27%) than both the control (66%) and verbal conditions (46%), indicating interference between the music task and the background music and demonstrating separate musical information storage. However, there was a significant difference between the verbal and control condition performances that was not apparent in the previous experiment between the music and control conditions. This may be due to the musical task requiring verbal identification of song titles, and is therefore likely to have suffered interference from verbal background information. The interference does not seem to be as great as with musical stimuli. Thus it is probable that musical information is stored separately to verbal information, but there is some interaction during processing to link the verbal information to the musical information for recall, with this being where interference occurs. The degree of this interaction (and the resulting interference) remains to be determined. Further investigation into different primary musical tasks with and without verbal requirements is also needed to explore the true interaction between these two information types. There is evidence suggesting verbal and musical information are stored separately in musicians. More investigation into non-musicians is still necessary.

While the existence of separate memory systems for verbal and musical information
has been supported by studies utilising the background-music interference methodology (Madsen, 1987), further studies with more direct interference between music and verbal stimuli have yielded similar results (Deutsch 1970, 1975; Schendel & Palmer, 2007). As in Martin et al. (1988), the majority of these studies could only examine musicians’ memory as non-musicians cannot read or perform music adequately. Thus memory for musical information in non-musicians has been consistently neglected.

Pechmann and Mohr (1992) addressed this neglect with their study examining differences between musicians and non-musicians for tonal, visual and verbal stimuli. It was hypothesised that musical training leads to the development of a special storage location in the phonological loop specifically for musical stimuli. Musicians would therefore process musical information separately, and without interference from other verbal and visual information. Non-musicians, on the other hand, who would not have developed this specialised musical storage will therefore experience interference between the different stimuli. To test this, 14 musicians and 13 non-musicians heard two tones separated by five seconds of interference, and were asked to determine whether the tones were the same or different (one semitone apart). The interference was either silence, a sequence of musical tones, single syllable nouns read aloud or presented images of black and white grids. It was found that all subjects made more errors identifying non-identical tones (17%) than identical tones (8%) for both the verbal and tonal conditions. It is apparent that musicians only had significantly poorer memory for the first tone when there was tonal interference, with this effect being found for non-musicians too. However, unlike musicians, they also had poor memory for all methods of interference but tonal interference had the greatest effect.

Pechmann and Mohr (1992) believed that tonal interference was the greatest for both the musicians and non-musicians because all tones are retained in the same storage location (whether they are stored in a separate musical faculty or not), and multiple tones will
interfere with each other regardless of their storage location or the individuals’ musical training. However, since the non-musicians also experienced interference from all types of stimuli while musicians did not, suggests that music, at least in trained individuals, can be stored in a separate location that is only interfered with by tonal stimuli.

Pechmann and Mohr (1992) hypothesised that all individuals are likely to be able to store musical information separately, but that divided attention may be responsible for the differences between musicians and non-musicians use of this storage facility. The more attention that can be devoted to musical stimuli, the greater the storage in the music faculty and the less interference from other types of stimuli. Non-musicians, who are likely to have reduced attention to musical stimuli, may not encode musical information in the musical facility as strongly as musicians. Consequently, their memory may be more subject to interference from other types of information, with this explaining their worse memory performance. Additionally, Pechmann and Mohr (1992) believed that the reason for the identical tones being remembered better than the non-identical tones was due to the second identical tone reactivating the tonal image from the first note, and reducing the ‘blurring’ that occurred form hearing other notes in-between. This study may therefore help to explain why musicians have been found to have better memory than non-musicians for musical information (Cuddy & Cohen, 1976; Dalla Bella, Gigüere & Peretz, 2007; Pauws, 2003).

However, the research neglects to examine musical elements beyond pitch, and while some studies have found differences between musicians and non-musicians for tempo and other musical elements (Madsen, 1979; Sheldon, 1994), further investigation into a cognitive faculty for all musical stimuli is essential to form a more concrete understanding of specific musical memory.

**Processing and Storage Differences Between Tempo and Other Musical Information**

While musical memory may involve separate systems to memory for other
information, considerable research has investigated whether all musical elements are
remembered together or separately. Of particular focus here are differences between memory
storage for tempo and pitch. There is a great paucity of research examining these two
elements specifically, with most research comparing rhythm and melody. Rhythm
encompasses beat duration, beat position and tempo, while the melodic component refers to
pitch, intervals and melodic contour (the pattern of pitch changes). When tempo is
investigated through rhythm, there is evidence that tempo is remembered separately from
melodic information.

The strongest evidence for separate melody and rhythm storage comes from
Peretz (1996) investigated the case of C.N., a 40-year-old non-musician with music agnosia,
who only had impairments associated with musical stimuli. In particular, C.N. could
recognise and comprehend speech and non-musical stimuli normally, but was unable to
recognise, name and memorise musical tunes or judge the familiarity of a piece of music.
C.N. did not appear to show any rhythmic impairments however, as she could identify
differences in rhythmic patterns and recognise familiar tunes based on rhythmic components.
This suggests that rhythmic and melodic processing may involve separate neural systems, as
C.N. had no difficulties with rhythm while she did for melodic information. Peretz and
Kolinsky (1993) also explored C.N.’s music agnosia and reached a similar conclusion; C.N.
was able to perform better than chance on identifying rhythmic variations than melodic
variations, indicating separate melodic and rhythmic processing. As with many neurological
deficit studies, the impaired individuals’ perception and memory for melodic information
may be influenced by their pre-deficit musical abilities. While it was assumed that C.N.
previously had normal musical abilities from personal accounts and screening procedures, it
cannot be confirmed that there were no previous deficits (music or otherwise) that influenced
these results. Furthermore, neurological deficit studies alone cannot confirm memory
differences between rhythm and pitch, as it is possible that the change creating the
neurological deficit may have altered the functioning of the brain and the memory for these
musical elements.

Several studies have therefore examined rhythm and melody processing and memory
in normal individuals. When looking at different brain processing locations, Helmuth and
Ivry (1996, as cited in Levitin & Cook, 1996), indicated that tempo may be controlled via the
cerebellum with a central timing mechanism, while pitch is initially perceived in the cochlear
before further processing in the auditory cortex (Levitin & Cook, 1996). These studies only
focus on isolated musical elements though. It is possible that despite different musical
elements being seemingly processed in different locations, there may be some interaction in
memory that cannot be identified via analysis of single musical elements. Palmer and
Krumhansl (1987a, 1987b) performed a study that investigated the likely interaction of
temporal and melodic components in memory, with participants determining how ‘correct’
different phrases sounded when only specific musical elements were varied. They found that
temporal and melodic information could be recognised and sound correct in isolation, and
this judgement was not dependent on this information being presented together.
Consequently, it can be concluded that perception for temporal information and melodic
information can be separate. Using judgements for a correct sounding phrase does not
necessarily indicate different memory for musical elements however, merely that they are
likely to be perceived differently.

The greatest limitation for all research supporting separate pitch and tempo memory is
their lack of sufficient explanation as to why musical dimensions are so often recalled
together, such as when remembering songs. Thus, many researchers have proposed that
musical information is stored together rather than separately. Researchers have, therefore,
investigated whether song recognition is best when musical elements are combined together, or when musical elements are presented separately. If melodies are remembered better using a combination of elements, this would be indicative of combined processing and memory of musical elements. Many studies appear to show support for this theory, with Boltz and Jones (1986) finding recall of melodies was greatest when the timing of beats corresponded with the melodic contour. Deutsch (1980) also found this, with melody memory being better when temporal segments were aligned with pitch (the pitch fell on a strong beat), than when they were separate. Other studies have reported similar findings for increased song recognition from combined temporal and pitch information (Dowling, Lung & Herrbold, 1987; Jones, Boltz & Kidd, 1982; Monahan, Kendall & Carterette, 1987). Like most studies in this area however, little emphasis is placed on memory differences between tempo and other musical information. Nor do they differentiate between non-musicians and musicians, who, as previously indicated, may have different musical memory abilities. Furthermore, these studies only used short unfamiliar melodies that were memorised during short testing periods. There is little evidence to suggest that the assisted recall of melodies from combined information can occur over a very long-term.

As in previous studies, Hébert and Peretz (1997) explored the influence of different musical elements on song recognition, but used familiar songs to explore long-term memory, and also differentiated between musicians and non-musicians. Thirty-two subjects (approximately one-third were musicians) were presented with either a melodic version of a familiar song with no tempo or rhythmic variation, or the rhythmic version of the song with one pitch. For each song, participants had to identify the song and rate, on a scale of 1 to 5 (with 5 being very familiar), how well they recognised the song. In a control condition, participants then heard and had to name the unaltered version of the song (with combined musical elements). It was found that subjects correctly identified the unaltered songs very
accurately (91% accuracy), suggesting high song recognisability when all musical elements were used together as a memory cue. However, decreased memory accuracy was found with separate melodic (49.2% accuracy) and rhythmic (9% accuracy) versions, indicating better memory from the cue with multiple musical variables. For song recognisability, participants perceived songs in the rhythmic condition to be generally unfamiliar (average of 1.5), while subjects indicated better song familiarity in the melodic condition (average of 3.5). It is possible that subjects may have responded better for the control condition because they had previously heard either the rhythmic or melodic cue, but a separate study by Hébert and Peretz (1997) found that subjects performed just as well when they heard the songs in isolation without hearing the rhythmic and melodic-altered songs beforehand. Thus, the results from this study support the notion that memory for songs is considerably better when all musical elements are used to cue memory recognition.

Hébert and Peretz (1997) found that rhythm was not a very good cue for song recognisability compared with the melodic variation. As neither condition assisted song recognition as greatly as songs using all musical components, it is still likely that temporal information and melodic information are encoded together in memory; rhythm may just be remembered more poorly than melodic components. Furthermore, unlike other studies in this area, Hébert and Peretz (1997) examined the difference between musicians and non-musicians, but found no significant effect of musical training. It is likely that the high familiarity of songs may mean musicians no longer possess an advantage from musical training, as non-musicians know the songs as well as musicians. As this study cannot be conducted without familiar songs, studies with different methodologies are important to assess differences between musicians and non-musicians.

In light of the conflicting literature regarding the memory storage of pitch and tempo, Peretz and Kolinsky (1993) investigated a dual-theory memory model, where musical
information can be stored both separately and together. They performed a study similar to the stroop task, but which used musical elements instead of verbal material. The 'stroop effect' refers to the difficulty in identifying the colour of a word when there are differences between a word and the visual colouring of that word. If reading words and identifying colours were processed entirely separately, there would be no interference. Peretz and Kolinsky (1993) applied this theory to musical stimuli, with the assumption that if the melodic information was processed similarly to the temporal information, subjects would exhibit interference from melodic information when trying to determine if rhythms were the same or different. Both control subjects and C.N. (as previously described in Peretz's (1996) research), were used in this study. It was anticipated that C.N., who is thought to have separate processing of rhythmic and melodic information, would not suffer interference from melodic information. Control subjects, however, would have reduced rhythm discrimination from melodic information interference if they process all musical information together.

As predicted, C.N. performed consistently well and showed no presence of interference with 82% correct rhythm identifications. On the contrary, the control subjects performed significantly worse on trials where there was melodic interference compared to when melodic information was controlled (with 67% and 89% correct rhythm identifications respectively), which indicates some interference from melodic information. This study therefore provides important evidence that musical information can be processed and retained separately, as C.N. had no problems with rhythmic information. Additionally, however, the normal subjects indicated that at some stage, musical elements must be processed together. Provided C.N.'s impairments indicate true brain functioning, there is evidence for both separate and combined processing for musical elements. This study did not attempt to determine where the separation or integration takes place, but merely demonstrated that both are likely to occur. More research is required to confirm that C.N.'s results are representative
of normal brain functioning. Also, there is no indication of how many control subjects were used in this study or their musical experience, so the applicability of these results is questionable. If, like Pechmann and Mohr (1992) suggested, divided attention plays a role in how well people can perform musical tasks, it is possible that a non-musician may have had far more interference in this ‘musical stroop task’, and may in fact process the information differently. The lack of research in the area of dual processing for musical information, and for tempo in particular, leaves a large gap in the research that requires further attention before the complex issue of memory for different musical elements can be resolved.

**Memory Stability and the Just Noticeable Difference Threshold**

Memory stability for tempo has also been substantially researched. Music stability refers to how accurate and consistent memories are over time (Kledzik-Malkiewicz, 2008; Lapidaki, 2000; Levitin & Cook, 1996). Before musical accuracy and stability is considered here, it is important to discuss the ‘just noticeable difference’ (JND) for tempo, which puts stability studies in context. The JND refers to the degree of tempo change required for the change to be detected. If individuals can identify very small differences in the tempo between songs (a small JND), their memory for the correct tempo must be very stable and accurate (Levitin & Cook, 1996; Pauws, 2003).

Despite substantial conflict regarding the JND for tempo, the lowest found JND is approximately 3.5% (Perron, 1994 as cited in Levitin & Cook, 1996). Perron (1994) measured the accuracy and stability of drum machines and sequencers to test the common assumption that they produce tempo exceptionally accurately, but found tempo deviations of up to 3.5%. However, individuals hearing drum machine tempos may have learnt songs with unstable tempos, and this may affect their performance on memory stability studies.

Studies specifically measuring individuals' tempo thresholds have been more plentiful, with different methodologies finding alternative JNDs. Indeed, Povel (1981) found
a JND of 3-4% when subjects were required to tap in synchrony with a pulse. Allen (1975), who required subjects to tap the pulse of a song even after the pulse had stopped, found varying JNDs of 7-11%. It is difficult to know whether this was an accurate representation of perception and memory, since subjects may be physically incapable of reproducing their memories accurately. Other studies with different methods have required subjects to listen to two excerpts with either varying or specific tempo differences, and determine whether they can detect that difference. Geringer and Madsen (1984) found that the JND must be greater than 12%, as subjects could not detect a tempo change of this amount or smaller. Kuhn (1974) only looked at differences of 16% between excerpts, and found that subjects could accurately detect this change, with the JND appearing to be less than 16%. Another methodology was conducted by Reed (in preparation, as cited in Reed, 2003), where subjects were played a song that either continued at the same tempo or changed tempo in increments of 3%, 5% and 10%. The results suggested that no subjects could detect a 3% change, while a change of 5% was detected better than chance, and approximately 80% of individuals could identify the 10% change. The JNDs for the other 20% of subjects remained undetermined. It is possible that the JND of some subjects may be very high, as a result of limited musical training (Drake & Botte, 1993).

Very few of these studies examined differences between musicians and non-musicians, with musical expertise possibly contributing to individuals’ JNDs for tempo. Both Geringer and Madsen (1984) and Povel (1981) accounted for the influence of musical training on individuals’ JND, but found no effect. The task of tapping along to a beat, as used by Povel (1981), is often performed by both musicians and non-musicians everyday though, so it is likely that even if musicians did have smaller JNDs, non-musicians may have similar abilities for a tapping task.

Drake and Botte (1993) found contradictory findings, with subjects’ JNDs depending
on musical training. Drake and Botte (1993) conducted a study using unfamiliar music where both musicians and non-musicians heard two sequences with different tempi, and had to identify the faster song. The tempo difference between the two songs was lowered 1% if participants were correct for four consecutive trials, and raised by 1% if participants were incorrect for one trial. Four trials were presented before reducing the tempo difference to control for guessing. Each session examined 11 different starting tempos, with each tempo occurring three times in a counterbalanced design. The results indicated a significant difference between musicians and non-musicians, with JNDs of 6.2% and 8.8% respectively. It was also found that non-musicians had small JNDs when the sequences presented were at medium speeds, while the musicians had smaller JNDs at both medium and fast speeds.

Drake and Botte (1993) hypothesised that musicians may have a lower overall JND due to improved processing abilities, which allows them to determine smaller differences in tempo. Additionally, it was suspected that musical training leads to the development of a wider window for detecting tempo changes, which justified why musicians detected changes better at fast speeds than non-musicians, but not at moderate speeds. The difficulty in detecting changes at lower speeds was possibly due to many ‘current’ songs having medium to fast tempos, so participants had less accurate tempo memories to use to detect changes in slow songs. Sheldon (1994) offered a different hypothesis for musicians’ increased accuracy, with musicians having developed more specific and accurate internal beat concepts that are used for detecting small tempo changes. Thus non-musicians, without these concepts, would have larger JNDs.

It is possible that the discrepancy between the results of Drake and Botte (1993) and Geringer and Madsen (1984) is that the latter did not examine the familiarity of songs used in the study. While Drake and Botte (1993) used unfamiliar sequences of beats, Geringer and Madsen (1984) used popular songs which participants were likely to be familiar with. As
Geringer and Madsen (1987) and Pauws (2003) have demonstrated, memory for tempo appears to be more accurate for familiar songs, regardless of musical training (Lapidaki, 2000). Thus, it is likely that the non-musicians may have been very familiar with the songs, eliminating musical training advantages, and resulting in similar tempo discrimination accuracy for musicians and non-musicians. Repeating Geringer and Madsen’s (1984) study with familiarity controlled would be necessary before true differences between musicians and non-musicians can be confirmed. Thus, more research is needed in the tempo JND domain to further identify a specific JND for tempo, or to determine what underpins the JND variability between studies (such as musical training or song familiarity). Currently though, the JND for tempo appears to be between 3% and 16% of the original song tempo, but this result should be used cautiously.

Evidence for an Adaptive Long-Term Memory for Musical Tempo

Many studies have suggested that adaptive memory exists for music, with adaptive memory referring to the traces of songs and musical information that are retained in memory and allow for song recognition even after certain musical elements have been altered. Indeed, adaptive memory has been found for musical dimensions such as pitch, with studies including Dowling and Bartlett (1981) finding that songs remain recognisable after the pitches within a song have been transposed (all pitches are moved up or down to the same degree) (Attneave & Olson, 1971; Drayna, Manichaikul, de Lange, Snieder & Spector, 2001). Adaptive memory has also been noted for musical tempo, with many studies demonstrating the same song can be recognised when played at multiple speeds (Dowling, Bartlett, Halpern & Andrews, 2008; Halpern & Müllensiefen, 2008).

Stability and Accuracy of Long-Term Memory for Musical Tempo

Evidence for stable long-term memory for musical tempo. While there is consensus for adaptive memory’s existence, there is still indecision regarding the stability of
musical memories. On one hand, studies such as Levitin (1994) have found stable memory for pitch. Levitin (1994) required subjects to reproduce any two songs from a list of songs generally identified as ‘familiar’, and then compared the produced pitches with the pitches sung in the original song. Participants were found to replicate the original pitches with surprising accuracy, and Levitin (1994) proposed that memory, while adaptive, can also be stable. Other studies, including Schellenberg and Trehub's (2003), have similarly found this result; pitch memory can be stable over time.

A wealth of research has also found stable long-term memory for tempo. Indeed, Levitin and Cook (1996) used a similar methodology as Levitin (1994), but extended the previous research on stable pitch memory to examine musical tempo. Forty-six university students with a range of musical skills were asked to select two familiar songs from 600 contemporary popular or rock songs, which had been previously identified as well-known. These songs had only been produced in one version, which was essential to make sure participants had a specific song memory against which memory stability could be measured. Participants in the study were instructed to simply reproduce the tones of the two well-known songs, and were unaware that tempo was being investigated. The reproduced tempo was then compared with the tempo of the original song. It was found that participants could accurately reproduce songs within 4% of the original tempo, with 72% and 40% of participants demonstrating this for the first and second reproductions respectively. When Levitin and Cook (1996) examined tempo reproductions with less than 8% deviation, 89% and 60% of subjects reproduced tempo accurately for the first and second reproductions respectively. To put this result in context using JND studies, JNDs of 4% and 8% have both been identified as difficult to detect, despite 8% being detected more often than 4%. These JND findings support Levitin and Cook's (1996) theory that individuals have very accurate and stable long-term memory for tempo as participants could reproduce songs very closely to a change that is
only just detectable. Furthermore, this finding was for both non-musicians and musicians, which may indicate stable memory for all individuals. As there was no discrimination of results for those with different musical training, if musicians do have more accurate memories, their performance may have masked the performance from non-musicians, preventing non-musicians' true memory accuracy being evident. Therefore, further studies examining musicians or non-musicians specifically are crucial to determine the influence of musical training on the stability of long-term memory for tempo.

Furthermore, like Levitin's (1994) study, this research is dependent upon participants being able to accurately produce the songs as they are retained in memory. If participants lack the ability to accurately reproduce these memories, a false representation of their long-term memory will result. This leads to further questioning of the differences between musicians and non-musicians, with musicians often having more developed skills in physically producing music than non-musicians (Dalla Bella et al., 2007). As a result, musicians may have better song reproductions than non-musicians, and could incorrectly appear to have more stable memory. Thus, studies with song reproductions should be questioned, and research with alternative methodologies is essential to determine true long-term memory stability and accuracy for tempo. However, participants were only instructed to reproduce pitch, deflecting their focus from accurately reproducing the tempo of songs. If pitch and tempo memories are retained together in the same processing component (as indicated by Boltz and Jones (1986) and Deutsch (1980)), the memory of one element, such as tempo, may be compromised for the increased recall of pitch. Repeating the study, but specifically asking participants to focus on the speeds of music would help to eliminate this problem.

More studies have found evidence of stable long-term memory for tempo (Reed, 2003), with Collier and Collier (1994) investigating the memory of jazz musicians, due to
their seemingly exceptional tempo abilities. Like Levitin and Cook (1996), memory was found to be exceptionally stable, suggesting that musicians - at least in the jazz domain - have both specific and stable memories for tempo, and exceptional reproduction abilities. Evidence for memory stability has similarly been found using listening tasks, such as Bergeson and Trehub (2002), who found memory stability in infants (Trainor, Wu & Tsang, 2004). As infants have had little musical exposure compared with adults, the applicability of this study to other age groups is limited. Despite this, there appears to be evidence for the existence of stable long-term memory for tempo.

Evidence that long-term memory for musical tempo is not stable. There is also evidence from recent studies, including Moelants et al. (2006), that tempo memory is not stable. Moelants et al. (2006) performed a study similar to Levitin and Cook’s (1996) where seventy-two subjects with various musical education were required to select songs from a list (of 30 possible songs) that they thought were imitable and had to imitate 10 of them. The tempo and pitch reproductions were then compared with the corresponding sections in the original songs. It was found that subjects’ imitations were generally faster than the original tempo (an average of 9.81% faster). Only 27% of individuals accurately reproduced songs within a deviation of 4%, while 51% reproduced songs within 8% deviation. Compared to Levitin and Cook’s (1996) study, this performance is remarkably poor and does not demonstrate stable long-term memory for tempo. Even after subjects were played the actual song, and could use this as a memory cue, subjects did not indicate stable memory, despite improved memory accuracy. Pitch memory results were considerably worse than Levitin’s (1994) study too, questioning whether stable long-term memory exists for any musical element.

One explanation for the differences between Moelants et al.’s (2006) study and Levitin and Cook’s (1996) may be attributed to the song selections and hence song
familiarity. In Levitin and Cook’s (1996) study, participants had a very large selection of 600 songs to choose from, so it is likely that participants could select songs with which they were highly familiar. Consistent findings have indicated that increased familiarity leads to increased song rehearsal in memory and improved memory accuracy (Baddeley, 2000; Pechmann & Mohr, 1992). This may explain why Levitin and Cook (1996) identified stable memory, with participants choosing highly familiar songs to sing. Moelants et al. (2006) only offered a small range of songs from which to select, so poorer memory may have been due to less song familiarity than no memory stability. Additionally, the first song reproduction by each participant in Levitin and Cook’s (1996) study was significantly more accurate than the second. It is likely that the song with the greatest familiarity was chosen first, which would explain the greater accuracy on this trial compared with the second. Hence, familiarity may be significantly related to memory stability, but the extent of this contribution is unknown and requires continued study.

Familiarity may not be the only element accounting for differences in these studies, as indicated by significant differences in long-term memory for pitch and tempo in Moelants et al. (2006). If familiarity was the only factor influencing memory, pitch and tempo would be remembered with similar accuracy for a highly familiar song. While this seems to indicate differences in memory for pitch and tempo, these differences could be due to separate abilities being required to reproduce pitch and tempo. Individuals may lack the memory representations. Therefore, true differences between pitch and tempo cannot be determined. The inconclusive research on tempo and pitch differences offers little support as to whether the differences found in this study are representative of other research findings. A greater understanding of long-term pitch and tempo differences is necessary to adequately explain these findings and identify the specific factors influencing memory stability.

Unlike Levitin and Cook’s (1996) research, Moelants et al. (2006) differentiated
between musicians and non-musicians but found no significant differences between their results. This was unexpected, due to several previous studies finding improved processing and memory for musicians (Attneave & Olson, 1971; Pechmann & Mohr, 1992). However, as previously explained, the familiarity of the songs may also have played a role in the lack of difference found between musicians and non-musicians (Geringer & Madsen, 1984). Thus, it is possible that only a certain degree of familiarity is required to eliminate the advantage of musical training, while substantial familiarity is required to have stable memory. As neither this study or Levitin and Cook's (1996) controlled for familiarity, the hypothesis cannot be confirmed. Additionally, the allocation of subjects into the 'musical' or 'non-musical' categories may have affected the results. While the 'non-musical' category included individuals with no musical training, the musical category included individuals with at least a very basic musical understanding. As indicated by Pechmann and Mohr (1992), the amateur musicians may not have developed special musical processing to enhance memory stability, and consequently, their memory stability may resemble non-musicians more than musicians. This may explain why the musical group showed similar memory to non-musicians. Further studies that do not examine vocal reproductions and sufficiently account for familiarity and musical training are therefore crucial to develop a more specific representation of memory stability.

Both Strauss and Vitouch (2009) and Strauss et al. (2006) used a different methodology to Moelants et al. (2006), but found a similar result; long-term memory does not appear to be stable for musical tempo. These studies examined whether hearing extreme versions of songs would alter long-term song memories. If the memories were unstable, hearing the extreme version of the song would change the long-term memory. Thus, when presented with an altered version of the song participants would identify this song as 'correct' more often than the original version since the altered version matches the new long-term
memory (that is, the extreme version of the song) more closely. When no extreme version is presented, there would be no change to long-term memory and participants should therefore identify the original version more accurately. As hypothesised, when presented with the extreme song version participants detected the changed songs significantly better than the originals, and vice versa when the original song version was presented instead of the extreme version. Thus, poor long-term memory stability is apparent. This study does not sufficiently prevent short-term memory effects though, as the interference used to prevent memory rehearsal was a mere 3 seconds of pink noise. It is possible that the memory trace from hearing the song for the first time was retained in short-term memory and this cued the perception of the song when it was repeated. These results may then indicate short-term memory rather than long-term memory, and should be interpreted cautiously.

Lapidaki (2000) investigated memory stability using a different listening methodology and also found no evidence for stable long-term tempo memory. Participants were played a song beginning with different speeds and adjusted the tempo until the song sounded "right." The results indicated that subjects could not correctly identify the song tempi, and also that the initial speed of the song profoundly influenced subjects' perceptions of the correct tempo. If memory stability existed, participants should correctly identify the tempo without the initial tempo interfering with memory accuracy. Indeed, several studies including Thomas (2007) and Kuhn (1974) have demonstrated that the speed of the song interferes with how well the tempo can be remembered (Kledzik-Malkiewicz, 2008; Wang & Salzberg, 1984), with these studies offering further support that memory for tempo is not stable.

This study did find that some individuals (mostly musicians) were remarkably consistent at identifying the correct tempo for the same songs across trials. Lapidaki (2000) hypothesised that this exceptional accuracy may be the result of tempo being processed
differently for individual songs, with stable long-term tempo memory being song-specific. However, only a very small number of individuals showed song stability, with the question remaining as to why no other individuals exhibited memory stability. As it was mainly musicians who showed song-stability, the influence of musical experience must once again be questioned. It may be that musical training provides greater exposure to music on a daily basis or increased exposure to certain types of music. This would explain why some non-musicians had seemingly stable memory for some songs too, despite not having any musical training; they may have had comparable musical exposure. The lack of differences found between the other participants, may also indicate a similar level of musical experience between the musicians and non-musicians. Repeating this study but taking more musical experience factors into account may shed light on why this seemingly song-specific long-term memory stability occurred for tempo.

Lapidaki (2000) also offered an alternative explanation for their finding of person-specific memory stability; these individuals may possess ‘absolute tempo’ (AT). AT refers to the ability to remember and identify specific tempi without external tempo indicators (Kledzik-Malkiewicz, 2008; Lapidaki, 2000). This explanation is controversial however, as subjects being considered as possessing AT only had stable memory for some songs. If true AT was present, these participants should have had exceptional performance on all trials. There is a significant void of research investigating the notion of AT, with only one apparent study by Kledzik-Malkiewicz (2008) exploring this. Kledzik-Malkiewicz (2008) asked participants to listen to two versions of the same song and determine if tempo was the same or different (with an 8% tempo change). If participants selected ‘different’, they also had to select the direction of the change (faster or slower). With familiarity, musical experience and confidence being accounted for, there was no evidence found for memory stability or AT. Participants were found to perform at chance level and with 61% accuracy for the first and
second trials respectively. It is possible that the 8% degree of change was not detectable, as a JND of this amount was not consistently identified. On the other hand, some studies found this was detectable, and if so, memory stability therefore appears to be poor. Individuals with AT would be expected to have a very low JND, and so perform well on this task. As no individuals performed exceptionally, AT seems unlikely. Kledzik-Malkiewicz (2008) hypothesised that absolute tempo does not exist because tempo is often measured on a continuous scale rather than as different notes (like that of pitch), with no specific markers for tempo differences being retained for specific tempo identification. However, if AT is like that of absolute pitch, very few individuals are likely to possess this ability and it is unlikely that the 22 subjects in Kledzik-Malkiewicz’s (2008) study will be adequate to find an AT possessor. This study would need to be repeated with more participants to determine the presence of AT. While this study is one of the first to examine AT it does indicate, like previous studies, that long-term memory stability for tempo is unlikely to exist.

Interference Research and Long-Term Memory Stability for Musical Information

Despite the discrepancies between studies using vocal reproduction methodologies, other studies have examined memory stability using interference methodologies instead. As previously indicated, when two similar items are being simultaneously processed in working memory, interference can prevent the memory of either one or both of these items. If memory is stable and accurate for information, there should be little or no interference. Indeed, many interference studies have demonstrated the lack of memory stability for a range of stimuli including verbal, visual and auditory information (Anderson & Neely, 1996; May, Hasher & Kane, 1999). Carbon and Leder (2005) in particular, demonstrated that when extreme versions of well-known faces were presented followed by the original faces, subjects had significant impairments in recognising the original faces. Long-term memory for familiar faces does not seem to be very stable. However, considerably less research has been
conducted on the role of interference on long-term memory for musical stimuli. While many studies, including Pechmann and Mohr’s (1992), have researched the effect of interference on memory for tones and short phrases, the effect of interference on memory for longer pieces of music has only been examined minimally.

Hay (2009) looked at the role of interference on how accurate and stable long-term memory is for musical pitch using familiar songs. Thirty participants with no previous musical training heard a series of excerpts which had either been unaltered or altered (raised or lowered by one semitone), and were asked to identify if the song was the original version. The results indicated that participants’ memories of a song were susceptible to interference from the song preceding it, with participants being particularly poor at identifying the original version when an unaltered excerpt was preceded by an altered excerpt (55% accuracy), or vice versa (35% accuracy). On the contrary, participants performed better for the control condition where two unaltered excerpts were presented in succession (79% accuracy). These findings suggest that long-term pitch memory is not particularly stable or accurate, since the long-term pitch memories were being affected by interference. This study only examined the influence of musical pitch, so it is possible that interference may only demonstrate the stability of long-term memory for musical pitch rather than other musical stimuli.

Memory for Musical Tempo and Support for an Interference-Based Research Design

Baddeley’s model of working memory has been applied to the domain of music processing and memory, indicating the possible existence of a memory faculty devoted specifically to musical stimuli. There is, however, considerable disagreement as to whether different musical components, particularly pitch and tempo, are remembered together with this faculty or separately. Some research (predominantly concerning neurological deficits) seems to suggest separate memory systems (Peretz, 1996), but this is undermined by the
notion that memory recall is best when all musical elements are combined together, thus one musical memory system is more likely (Boltz & Jones, 1986; Hébert & Peretz, 1997).

However, a dual-theory has also been proposed, with both separate and combined processing during different cognitive stages (Peretz & Kolinsky, 1993). More research is necessary in this area to determine the most likely method of remembering specific musical elements.

With many inconsistencies between studies, long-term memory stability for tempo also appears to be unclear. Indeed, memory for tempo has been found to be stable (Levitin & Cook, 1996), but may only be so when highly familiar music is used, as studies using seemingly less familiar music found no memory stability (Moelants et al., 2006). Unlike what previous research has indicated, this result does not appear to be different between musicians and non-musicians, which may be due to many studies either focusing solely on musicians (without comparison to non-musicians), or a lack of differentiation in results based on musical training. Consequently, the high accuracy of musicians may artificially inflate non-musicians’ accuracy results. Furthermore, there are discrepancies between how much musical training is required to class an individual as a ‘musician’, with those who have very little training often being termed ‘musicians’. As musical training is thought to develop musical processing abilities, the abilities of amateur musicians may be too limited to demonstrate memory accuracy. Thus, ‘musicians’ overall may incorrectly appear to have similar memory stability to non-musicians, so it is possible that musicians may have increased overall memory stability, but without studies using better discrimination between musically and non-musically experienced individuals, memory stability cannot be adequately determined.

Furthermore, the predominant methodology used to assess memory stability is questionable, as it requires the vocal reproduction of songs. Participants may inaccurately reproduce tempo while they are focusing on pitch reproductions. Additionally, participants (most likely those with limited musical training) may be unable to accurately reproduce their memories,
providing an inaccurate representation of how stable their memories really are. However, the few studies that have used alternative methods still provide unclear conclusions, as they do not adequately account for musical experience.

Interference has been considerably well researched for multiple types of information, and has been found to notably influence working memory for auditory stimuli (Hay, 2009; Martin et al., 1988). Research suggests there will be reduced memory for a specific piece of auditory information if another similar piece of information is presented at, or close to, the time of recall. Interference provides an important method for assessing memory stability, as a memory that is stable will be accurately recalled despite interference. This is a credible strategy for investigating the memory stability for musical stimuli. However, only one study utilising this design appears to have investigated musical memory, specifically examining musical pitch. Consequently, there is a large gap in the literature examining the influence of interference on memory for other musical information, such as musical tempo.

The present study was designed to investigate whether individuals with no musical training would have a reduced ability to recall tempo information for a familiar song excerpt after having heard a song excerpt with a different tempo beforehand. Thus, participants heard a series of different song excerpts and identified whether or not each song excerpt sounded like the original version of the song. Pairs of excerpts were then analysed and the number of correctly identified second excerpts (that is, the second excerpt in each ‘pair’) was determined. It was expected that if long-term memory for tempo is not stable, the tempo from the previous song would affect participants’ abilities to detect changes in each song excerpt, and the percentage of correctly identified second excerpts would be low. On the other hand, if long-term memory for tempo is stable, there would be little or no interference from the preceding song’s tempo and the participants would have high accuracy in detecting tempo differences for the second excerpt in each pair.
Method

Research Design

This research was approved by the Edith Cowan University Faculty of Computing, Health and Science Human Ethics Subcommittee.

This study utilised a repeated measures design, with the nine-level independent variable being the tempo of each musical excerpt. For each level (condition), participants heard two consecutive excerpts of either the same or different tempo. The tempo of the excerpts used in each condition can be seen in Table 1. The dependent variable for this study was participants' accuracy at detecting tempo changes in familiar songs depending on the tempo of the previous song.

Table 1

<table>
<thead>
<tr>
<th>Condition</th>
<th>Excerpt 1</th>
<th>Excerpt 2</th>
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<tr>
<td>1 (Control)</td>
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<td>2</td>
<td>Unaltered</td>
<td>Decreased by 10%</td>
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<td>3</td>
<td>Unaltered</td>
<td>Increased by 10%</td>
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<td>4</td>
<td>Decreased by 10%</td>
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<td>6</td>
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<td>7</td>
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<td>8</td>
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<tr>
<td>9</td>
<td>Increased by 10%</td>
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</table>
Participants

This study had 17 male and 23 female participants, aged 18 to 62 ($M = 26.25$, $SD = 11.95$) with a range of educational levels. All participants reported having no formal musical training. Recruitment was opportunistic via face-to-face interactions and through emailing the researcher's acquaintances. Snowballing was also used, whereby participants provided the contact information of individuals they knew who had no formal musical training and may want to participate in the research.

Materials

The songs used for this study were those selected by Hay (2009) using an informal pilot test (See Appendix A). These songs were released in the last 20 years and appeared in the top 100 best-selling singles charts for Australia, the United Kingdom and the United States of America. All the songs chosen were from the pop genre, as these songs generally only existed in one version, performed by only one group or artist. This meant the songs were always heard at the same pitch and tempo outside of the study (Levitin, 1994). Thus, the participants' song memories are likely to be stronger due to repetitive exposure to the same version of each song. These songs were accessed on compact disc (CD) and then converted into a digital format of the song. The digital songs were copied into Audacity (version 1.2.6) music editing software. Excerpts from each of the songs, starting from the first chorus heard in the song, were then extracted with versions created where the tempo was adjusted to be either 10% faster or slower than the original song.

A tempo change of 10% was selected based on previous research and an informal pilot test. This was to ensure that participants could identify a change between the original version of the song and the altered version (which would require using their long-term memory) but not to the extent that the alterations were too obvious and would be unaffected by interference. The informal pilot test used 57 non-musicians who heard a random
combination of two unaltered and two altered song excerpts, with the songs used being the same as those of the main study. The altered songs had tempo changes (either increased or decreased) of 4%, 6%, 8%, 10%, or 12%, since previous research has found these changes to be detectable to some extent, but no consistently detectable change had been found for non-musicians. The playing of each song excerpt was separated by both a long pause (more than one minute) and discussion about non-research related topics to reduce the likelihood that hearing the first song would cause interference with the second. The ideal tempo change was found to be 10%. This change was detected by approximately 70% of participants, indicating that the songs had been sufficiently altered so that most participants could detect a change, but that the change was not too obvious (which would yield close to 100% detection). The pilot participants were not tested in the main study.

The song excerpts in the main study were heard using the Superlab 4.0 computer program, with Sony MDR E818 headphones. As participants responded, their responses were recorded using an RB-830 response box.

Procedure

Each participant listened to 100 pop-song excerpts over the course of approximately 66 minutes. For each trial, the participants were played a 30-second song excerpt followed by a 10 second pause. In this pause, they were asked to press one button on the response box - labelled as 'do not know' - if they did not recognise the song, otherwise, to press one of two buttons to indicate whether they thought the excerpt was either the original version of the song (labelled as 'same') or an altered version (labelled as 'different'). When the participant had responded or 10 seconds had elapsed, the next song excerpt was played until all the excerpts had been heard. Participants were not told whether their responses were correct.

Five different versions of the experiment were created, with eight participants being randomly allocated to complete each version. These versions presented trials in a manually
randomised order to ensure that each condition was presented a minimum of five times (total of 90 trials). Ten additional trials were also placed in different locations for each experimental version to prevent participants guessing the pattern the trials were being presented in. The 'additional' trials were not placed between a pair of trials based on a specific condition. For example, if the condition had one altered excerpt before an unaltered excerpt, the additional trial was placed either before the altered excerpt, or after the unaltered excerpt but not between the two. Depending on their location, the 'additional' trials altered the number of times different conditions were presented. If the extra trial was an unaltered excerpt and was presented after an altered trial (i.e., the second trial in the condition with two altered excerpts), this would create an additional altered-unaltered condition. Thus, the number of times conditions were presented varied between versions, but each condition was presented a minimum of five times.

Results

The number of correct identifications of the second excerpt in each pair of trials was converted into a percentage total for each condition. Where participants did not enter a response for a trial, this was recorded as an 'incorrect' identification. If participants indicated that they did not know the song, the trial was excluded from the analysis. Two participants were excluded from the analysis due to not knowing at least 25% of the songs, as it was likely that if participants did not know this many songs they could be responding incorrectly or may not be musically aware. One participant was excluded from analysis because they failed to respond to more than 50% of the trials, which was an insufficient number of button presses. Normality screening did not find any outliers.

A one-way repeated-measures Analysis of Variance (ANOVA) was conducted to compare the mean number of correctly identified tempo alterations of the second excerpt in each pair for each of the nine tempo conditions. Mauchly's test identified that the sphericity
assumption had been violated, $\chi^2(35) = 125.47, p < .05$, and hence, the degrees of freedom were corrected for using the Greenhouse-Geisser sphericity estimate ($\varepsilon = .45$). The results found a significant main effect for tempo, with the tempo of the first song excerpt in each pair of songs influencing participants' abilities to detect whether the second song excerpt had been altered, $F(3.62,130.31) = 30.05, p < .05$.

Bonferroni comparisons were conducted to identify where the differences were between the group mean scores for each condition. The group mean scores and standard errors for each condition are shown in Figure 1. The Bonferroni comparisons indicated that in the conditions with an unaltered second excerpt (conditions 1, 6 and 8), participants correctly identified these excerpts significantly more than all other conditions. No other significant differences were found.

![Figure 1](image)

*Figure 1.* Mean Percentage (%) Correct for Each Condition. Error bars represent standard errors.
These results did not clearly support or disprove the hypothesis and may be a result of participants not knowing whether the excerpts had been altered or not. Hence, participants may have responded by guessing and randomly selecting the ‘same’ and ‘different’ button responses.

A chi-square analysis was conducted for each participant (see Appendix B) to determine how many of the participant’s correct excerpt identifications were the result of guessing whether or not the song had been altered. The number of times participants’ pressed each button (‘same’ or ‘different’) was compared with the number of button presses expected if participants were guessing (half ‘same’ and half ‘different’ button presses). All the trials where participants did not respond or indicated that they did not know the song were excluded from analysis. The results suggested that 22 out of 37 (59%) of subjects responded significantly differently to the ‘guessing’ response. The data from the 15 subjects who were likely to have responded by chance were therefore removed, and the initial analysis was repeated with a one-way repeated measures ANOVA. Once again, Mauchly’s test indicated the sphericity assumption had been violated, $\chi^2(35) = 90.31, p < .05$, and the Greenhouse-Geisser sphericity estimate was used ($\varepsilon = .42$). A significant main effect was found for tempo, with the tempo of the first song excerpt influencing participants’ ability to identify tempo alterations for the second excerpt, $F(3.39, 71.14) = 36.56, p < .05$. Bonferroni comparisons were then conducted like the previous analysis. The group mean scores and standard errors for each condition are shown in Figure 2.

Like the previous analysis, the number of correctly identified second excerpt alterations was significantly higher for all the conditions where the second excerpt was unaltered (conditions 1, 6 and 8).

Overall accuracy percentages were also calculated for those participants whose results were significantly different to chance (see Appendix C), to determine each participant’s
ability to accurately detect tempo alterations across the nine conditions. Two participants had an accuracy of 70% or higher, with participants 21 and 30 performing with 80% accuracy. A further 10 participants had between 50% and 70% accuracy, and the remaining 10 scored below 50%.

![Figure 2](image.png)

*Figure 2. Mean Percentage (%) Correct for Each Condition. Error bars represent standard errors.*

**Discussion**

The results from this study demonstrate that participants were significantly better at identifying the nature of each musical excerpt when the second excerpt of each pair was unaltered, as opposed to altered. This was similarly found when the analyses were repeated after omitting the participants who were likely to have responded by guessing. The results were not predicted by any of the hypotheses considered in the design of the experiment.
There is no apparent evidence suggesting that interference was present in this study, whereby participants would be less accurate at identifying the nature of a familiar song excerpt after having heard a song excerpt with a different tempo immediately beforehand. Indeed, irrespective of the preceding song's tempo, participants performed consistently well for the conditions with an unaltered excerpt and consistently poorly for conditions with an altered second excerpt. These results were different to Hay (2009), who found evidence suggesting interference influenced long-term memory for musical pitch. That is, when an altered song excerpt preceded an unaltered song excerpt the performance was significantly poorer than when two unaltered song excerpts were presented in succession. Hay (2009) therefore concluded that since memory for pitch could be interfered with, long-term pitch memory is not stable.

Nonetheless, despite the present study finding no effect for interference using tempo, this should not necessarily be considered as evidence in support of stable tempo memory. The participants did not demonstrate high overall identification accuracy and scored poorly when the second excerpt in each pair was altered, which suggests that long-term memory may not be very stable. Furthermore, a high proportion of participants was suspected to have guessed their responses and, even after their omission, only two subjects performed with an accuracy of 80% or higher. With so few participants performing with this high degree of accuracy it can be inferred that, for most non-musicians, long-term tempo memory is poor.

It is possible that the high number of correctly identified unaltered excerpts resulted from a response bias for pressing the ‘same’ button, regardless of whether or not this was the correct response. However, this bias is unlikely since participants were told that some of the excerpts would be changed while others would be the same as the original. Thus, it is expected that they would have selected a combination of the ‘same’ and ‘different’ button responses rather than being biased towards one. Furthermore, several participants still
correctly identified a number of the altered excerpts, indicating that when participants believed the songs were different, they selected this option accordingly. Hence, it is more probable that the high percentage of correctly identified unaltered excerpts was due to participants selecting the 'same' button because they genuinely believed the songs were the same as the original. That is, they could not tell when the tempo of some of the songs had been changed.

It is possible that these tempo changes were not detected because the degree of change was smaller than many of the individuals’ just noticeable difference (JND) thresholds. However, the degree of tempo change used in this study was carefully selected using an informal pilot test and previous research to maximise the likelihood that participants could detect the tempo changes. However, only 70% of participants in the informal pilot test noticed the tempo change of 10%, which indicates that a number of participants were likely to have a JND threshold greater than 10% that prevented them from detecting this change. Performing the study using tempo changes specific to each individuals’ JND threshold would be necessary to eliminate this discrepancy.

A greater issue for this study, however, is to determine at which point – if such a point exists – there is enough tempo change to be detected and interfered with, but not so much change that the alteration becomes too obvious and interference is unlikely to occur. If the tempo change is detected too easily and no interference occurs, memory would appear stable when in fact it may not be. Furthermore, any study that uses this design and finds no evidence for memory stability could argue that the degree of change was not great enough to be detected. Repeating the experiment with this conceptual paradox resolved would be essential to determine whether interference influences long-term memory for tempo. Alternatively, using a different design that examines the influence of interference and memory stability is necessary.
Regardless, the results show that even when the tempo was changed as much as 10%, the percentage of correct identification of song alterations was low. This suggests that long-term memory for musical tempo may not be as absolute or accurate as Levitin and Cook (1996) indicated, with their findings demonstrating very accurate long-term tempo memories (with greater than 70% accuracy) with tempo changes as small as 4% and 8%.

The differences between the results of the present research and Levitin and Cook’s (1996) may be explained by differences in participants’ familiarity with the songs presented. Despite the songs for this research being selected via Hay’s (2009) informal pilot test to maximise familiarity across individuals, it is possible that many of the songs that were responded to were not highly familiar and consequently, participants’ song memories were not as high or accurate as they could be. For Levitin and Cook’s (1996) study however, the participants may have had exceptionally high song familiarity due to the subjects specifically selecting the songs they knew well. Thus, a fairer test of Levitin and Cook’s (1996) claims may require altering this study’s design to measure each participant’s familiarity with the songs presented. Alternatively, it might require pre-selecting and using highly familiar songs specific to each individual or manipulating participants’ exposure to new songs, such that familiarity of the songs can be controlled across participants. However, these strategies require different research designs to the current experiment.

Moreover, it cannot be discounted that some non-musicians may have more accurate and stable long-term memory for tempo than other non-musicians. Indeed, two participants were able to correctly identify song tempo alterations considerably more than the other non-musicians. As Lapidaki (2000) hypothesised, it is possible that these high performing participants might possess absolute tempo, or the ability to remember tempo exceptionally well without external tempo guides (Kledzik-Malkiewicz, 2008). Thus, they would be very good at identifying tempo changes, since their memory of the correct song tempo would be
exceptionally accurate. However, while these participants did perform better than the other non-musicians, their accuracy was still not exceptional (as would be expected by an absolute tempo possessor), with incorrect responses on close to 20% of the trials. It is therefore unlikely that these individuals possess absolute tempo, and thus, this theory inadequately explains the higher performance accuracy from these two participants. Despite this, further research exploring the existence of absolute tempo is necessary before this hypothesis can be refuted.

A more likely explanation for the more accurate performance by the two participants may be related to these participants having a greater degree of musical exposure and experiences than the other non-musicians. As indicated by Lapidaki (2000), this musical exposure may lead to increased memory for music, including an improved memory for tempo. These memories may give certain participants an advantage when trying to detect tempo changes for songs, since they have stronger and more accurate tempo memories to compare with the songs they heard in the study. To date, the role of musical experiences and exposure has been largely overlooked, with the predominant explanation for memory differences between individuals being related to musical training. As musical training cannot account for the differences found between the non-musicians in this study however, further research examining the role of musical exposure and experiences is necessary to identify the underlying factors responsible for the differences in non-musicians’ long-term tempo memory.

However, the role of musical training cannot be ignored, with previous studies debating whether musical training enhances long-term memory stability. Since the current study’s interference design provides evidence against memory stability in non-musicians - and this design has not been extended to musical populations - continued research using interference with musicians is required to understand whether musical training enhances
memory stability for musical information.

It is also likely that there are differences in the long-term memory of pitch and tempo, with Hay’s (2009) study finding that interference affected pitch memory, while this study found no interference with tempo memory. There is a possibility that the degree of change necessary for pitch and tempo changes to be detected and affected by interference is not comparable; that is, a tempo change of 6% may be more difficult to detect, and be subject to less interference, than a pitch change of one semitone (the equivalent of a 6% tempo change). Indeed, the tempo change of 10% in this study did not demonstrate any effect of interference while the smaller pitch change of 6% did. The number of pitch and tempo change cues present throughout a song may explain these differences, with the number of cues being directly related to the strength of the memory for the musical element and the speed and ease of detecting the change. Pitch change cues, which occur each time the melody of the music changes pitch, often occur very frequently throughout a song. Tempo change cues, on the other hand, occur less often because they are formed from sequences of musical notes, rather than individual changes in pitch.

Consequently, with more pitch change cues than tempo cues, pitch changes are likely to be remembered better and detected sooner than tempo changes. In order for the tempo change to be detected as well as the pitch change, the tempo change would need to be considerably greater. Therefore, Hay’s (2009) 6% pitch change, despite being less than the 10% tempo change used in the present study, may have been sufficient for interference to occur while the tempo change was not. Further research examining the differences between pitch and tempo change detection is necessary before this conclusion can be confirmed. Furthermore, with so few studies examining long-term memory for pitch and tempo using interference designs, this direction of research must be explored further to investigate whether there are true differences between pitch and tempo long-term memory.
The findings from the present study suggest that the human brain – particularly in non-musicians – may be more accepting of tempo changes than has been previously believed. It appears likely that long-term memory for tempo is a more volatile construct than other musical dimensions (such as pitch), with tempo changes throughout songs often being unnoticed and accepted as the original song version. Indeed, musicians have been found to be unaware of their own tempo changes, despite their alteration of the tempo in certain sections of their songs to provide emotional expression and enhance the ‘feel’ of a piece of music (Sloboda, 1994). This begs the question of whether stable memory for tempo is even necessary, since tempo changes are so often unnoticed and outside conscious awareness. Despite this, it is still important to determine whether the human brain is capable of storing musical information in a stable form.

While this study is one of the first to investigate long-term memory for tempo using interference from the previously presented song, it remains to be seen whether memory for tempo is affected by interference, and if so, how stable long-term memory is for musical tempo. It seems likely that long-term memory for musical tempo may not be accurate or stable, however further research using a revised interference methodology is essential before the true nature of long-term memory for musical tempo – in both musicians and non-musicians – can be established.
STABILITY OF LONG-TERM MEMORY FOR TEMPO

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Appendix A

List of Well-Known Songs

1. ABBA - Dancing queen
2. ABBA - Money money money
3. Alanis Morisette - One hand in my pocket
4. Alanis Morrisette - Ironic
5. Amy Winehouse - Rehab
6. Angels - Am I ever gonna see your face again?
7. Aqua - Barbie girl
8. Arethra Franklin - Respect
9. B-52s - Love shack
10. B-52s - Roam
11. Beach Boys - Good vibrations
12. Beach Boys - Surfin' USA
13. Beatles - Eleanor rigby
14. Beatles - With love from me to you
15. Ben Lee - Catch my disease
16. Billy Idol - White wedding
17. Billy Joel - Piano man
18. Bon Jovi - It's my life
19. Britney Spears - Oops!...I did it again
20. Bruce Springsteen - Born in the USA
21. Bryan Adams - Summer of 69
22. Bryan Ferry - Let's stick together
23. Buddy Holly - Peggy sue
24. Carly Simon - You're so vain
25. Cat Stevens - (Remember the days of the) Old school yard
26. Cat Stevens - Moonshadow
27. Cheap Trick - I want you to want me
28. Choir Boys - Run to paradise
29. Chris Isaak - Baby did a bad bad thing
30. Christina Aguilera - Genie in a bottle
31. Cold Chisel - Khe sanh
32. Coldplay - Clocks
33. Coldplay - Yellow
34. Crowded House - Don't dream it's over
35. Crowded House - Weather with you
36. Culture Club - Karma Chameleon
37. Cyndi Lauper - Girl's just wanna have fun
38. Dave Dobbyn - Slice of heaven
39. Don McLean - American pie
40. Eagles - Hotel California
41. Eagles - Desperado
42. Elton John - Rocket man (I think it's going to be a long long time)
43. Elton John - Tiny dancer
44. Elvis Presley - Hound dog
45. Eric Clapton - Layla
46. Eurythmics - Sweet dreams
47. Goo Goo Dolls - Iris
48. Guns N' Roses - Sweet child of mine
49. Harry Chapin - Cat's in the cradle
50. Helen Reddy - I am woman
51. Hoyt Axton - Joy to the world (jeremiah was a bullfrog)
52. Hunters and Collectors - Holy grail
53. Jason Mraz - I'm yours
54. Joe Jackson - Is she really going out with him?
55. Lighthouse family - High (forever you and me)
56. Lionel Richie - Dancing on the ceiling
57. Lynyrd Skynyrd - Sweet home Alabama
58. Madonna - Material girl
59. Madonna - Holiday
60. Madonna - Like a prayer
61. MC hammer - U can't touch this
62. Men at Work - I come from a land down under
63. Michael Jackson - Billie jean
64. Michael Jackson - Black or white
65. Michael Jackson - Thriller
66. Monty Python - Always look on the bright side of life
67. New Radicals - You get what you give
68. Nickelback - Photograph
69. Oasis - Wonderwall
70. Paul Simon - You can call me Al
71. Peter, Paul, and Mary - Puff the magic dragon
72. Phil Collins - In the air tonight
73. Pink - Get this party started
74. Powderfinger - My happiness
75. Prince - Purple rain
76. Queen - We are the champions
77. REM - Losing my religion
78. Rolling Stones - I can't get no satisfaction
79. Shania Twain - Man I feel like a woman
80. Snow Patrol - Chasing cars
81. Spice Girls - Stop right now
82. Spice Girls - Wannabe
83. Sting and the Police - Every breath you take
84. Sting and the Police - Roxanne
85. The Beatles - I wanna hold your hand
86. The Jackson 5 - Blame it on the boogie
87. The Monkees - I'm a believer
88. The Proclaimers - I'm gonna be (500 miles)
89. The Rembrants - I'll be there for you
90. The Rolling Stones - I can't get no satisfaction
91. The Rolling Stones - You can't always get what you want
92. The Verve - Bittersweet symphony
93. The Whitlams - Blow up the pokies
94. The Who - Who are you?
95. Tracy Chapman - A hundred years
96. U2 - Beautiful day
97. U2 - Elevation
98. Van Morrison - Brown eyed girl
99. Village People - YMCA

100. Wham - Wake me up before you go-go
Appendix B

Table B1

*Chi-square Results for Each Participant to Determine Whether They Responded by Guessing*

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<th>Participant</th>
<th>Chi-square Statistic</th>
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<td>1</td>
<td>$\chi^2(1, N = 37) = 26.98, p &lt; .05$</td>
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<td>2</td>
<td>$\chi^2(1, N = 37) = 7.53, p &lt; .05$</td>
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<td>$\chi^2(1, N = 37) = 66.13, p &lt; .05$</td>
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<td>$\chi^2(1, N = 37) = 32.19, p &lt; .05$</td>
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Appendix C

Table C1

*Overall Percentage Accuracy of the Participants Unlikely to be Responding by Guessing*

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