Cortical Activity Associated with Rhythmic Grouping of Pitch Sequences

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ABSTRACT

Segmentational grouping in music listening refers to the organisation of individual tones into tone groups that tend to be processed and subsequently recalled as perceptual units or chunks. Grouping of tones via this process tends to occur at natural breaks in structure of a tone sequence, so that relatively larger changes in pitch, amplitude or timing are perceived as boundaries which cue the segmentational grouping process. Segmentational grouping processes have been examined using behavioural research techniques; yet neurophysiological processes underlying the grouping process have received little attention, and are poorly understood. This study aimed to identify brain regions involved in the segmentational grouping process as cued by rhythmic information. Participants performed two auditory tasks while brain electrical activity responses were monitored using Steady-State Probe Topography (SSPT).

Behavioural responses evoked in a task probing individuals' use of lengthened-duration tones to organise memory for pitch sequences indicated that longer-duration tones were used as cues to organise working memory representations of the musical patterns. Examination of dynamic SSPT responses during the encoding phase of a probe recognition task indicated that greater use of rhythmic cues to organise working memory representations was associated with activation of a network of left hemisphere frontal, temporal and parietal regions. During the lengthened tone, activation of left central and vertex regions and progressive activation of left temporal and temporoparietal regions were linked with use of the deviant status of the lengthened tone to update temporal expectations for the sequence. Excitatory responses observed in left posterior frontal and temporal regions to a tone following the lengthened tone were proposed to reflect temporal allocation of attention to this point in time, whereas sustained excitatory activation of left temporal, and temporoparietal regions reflected the role of these regions in supporting representations of the tone events in working memory. Finally, late inhibitory responses to the tone following the lengthened tone in left frontal, temporal, temporoparietal, and parietal regions were linked with the manipulation and closure of the working memory trace in association with the grouping process. Together, these findings support the activation of a network of left frontal, temporal and parietal regions underlying rhythmic grouping of pitch sequences.

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Most of all, my love and thanks to my wife Heather, whose unending love, encouragement, patience and support made the completion of this project possible. Thank you my love!

DECLARATION

This thesis contains no material which has been accepted for the award of any other degree at any University and to the best of my knowledge and belief contains no material previously published or written by another person or persons except where due reference is made.

Phil Harris
June, 2007

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ADHD	Attention Deficit Hyperactivity Disorder
BA	Brodman’s Area
CPS	Closure Positive Shift
CNV	Contingent Negative Variation
ELAN	Early Left Anterior Negativity
ERAN	Early Right Anterior Negativity
EEG	Electroencephalogram
EMG	Electromyogram
EOG	Electrooculogram
ERD	Event-Related Desynchronisation
ERP	Event-Related Potential
fMRI	Functional Magnetic Resonance Imaging
GTTM	Generative Theory of Tonal Music
GPRs	Grouping Preference Rules
GWFRs	Grouping Well-Formedness Rules
IOI	Interonset Interval
ISIs	Interstimulus Intervals
MEG	Magnetoencephalogram
M	Mean
ms	Millisecond
MMN	Mismatch Negativity
OEP	Omitted Event Potential
PET	Positron Emission Tomography
RATN	Right Anterior Temporal Negativity
s	Second
SW	Slow Wave
SD	Standard Deviation
SSPT	Steady State Probe Topography
SSVEP	Steady State Visually Evoked Potential
SOAs	Stimulus Onset Asynchronies

Chapter 1 INTRODUCTION

This study is an investigation of the cortical activity associated with rhythmic segmentational grouping of tone sequences in music listening. Segmentational grouping in music listening refers to the organisation of individual tones into tone groups that tend to be processed and subsequently recalled as perceptual units or chunks. Grouping of tones via this process tends to occur at natural breaks in structure of a tone sequence, so that relatively larger changes in pitch, amplitude or timing are perceived as boundaries which cue the segmentational grouping process. Segmentational grouping processes have been examined using behavioural research techniques; yet neurophysiological processes underlying the grouping process have received little attention, and are poorly understood.

Behavioural research indicates that listeners tend to spontaneously organise sequences of auditory events into groups of events. Segmentational organisation of both musical and non-musical sequences of individual tones into groups of tones may be based on a range of physical, spectral, temporal or spatial dimensions (e.g. Deutsch, 1980b; Handel, 1973). The tendency to impose subjective organisation on auditory sequences has been demonstrated to be sufficiently strong that listeners tend to spontaneously organise sequential auditory events into groups even in the absence of explicit cues that provide a basis for the grouping process (e.g. Abecasis, Brochard, Granot, & Drake, 2005; Bolton, 1894). In the temporal dimension, relatively greater time intervals between event onsets have been demonstrated to evoke the perception of a break in an ongoing flow of auditory events, and act as a strong cue for the organisation of auditory events into groups bounded by longer time intervals (Dowling, 1973b; Frankland & Cohen, 2004). The rhythmic grouping process has been attributed to the action of processes initially formulated by the Gestalt psychologists, and explicitly represented in cognitive music psychological theories specifying the basis of listeners' mental organisation of musical information (e.g. Lerdahl & Jackendoff, 1983). Behavioural research examining use of rhythmic grouping in music listening has repeatedly demonstrated the application of rhythmic grouping processes in the music listening experience (e.g. Deliège, 1987; Frankland & Cohen, 2004).

Examination of neurophysiological responses evoked during processing of auditory sequences via functional magnetic resonance imaging (fMRI) has provided insights into brain regions that support the structural organisation of auditory event sequences.
Processing of musical syntax has been associated with activation of bilateral frontal, temporal and parietal regions, and notably, involve Broca's and Wernicke's neural regions more commonly linked with language processing (e.g. Koelsch et al., 2002; Tillmann, Janata, & Bharucha, 2003). Inferior frontal regions including Broca's area have also been demonstrated to be significantly more activated in response to structured musical extracts than unstructured extracts (Levitin & Menon, 2005). Together, this research suggests a role for frontal, temporal and parietal regions in the processing of musical structure and the integration of temporal information.

While fMRI provides precise localisation of activated neural regions, the temporal precision with which functional activation is identified is supra-second, and relationships between functional activated brain regions and temporal aspects of task performance are poorly identified through use of this imaging methodology. By contrast, electrophysiological methods provide temporal resolution in the millisecond range, and provide opportunity to examine dynamic variations in task-related neural activation. In particular, event-related potential (ERP) methods have provided insights into the temporal dynamics of neural processes that support aspects of time-based perception. Characteristic ERP responses such as the mismatch negativity (MMN) and omitted event potential (OEP) have been associated with processing of changes in the auditory environment including processing of temporally-based information, and linked with cognitive processes underlying specific reactions to temporal information (e.g. Jongsma et al., 2005; Takegata, Roggia, & Winkler, 2005). Research specifically examining processing of rhythmically-defined boundaries in music provide further insights into processes underlying temporal organisation, and demonstrate another characteristic ERP response – the closure positive shift (CPS) – elicited by rhythmic boundaries (Knösche et al., 2005). These ERP responses demonstrate that a range of frontal, temporal, and parietal neural regions may contribute to the processing of time-based information.

Together, ERP and functional imaging insights have provided an initial basis for understanding fundamental aspects of the way that listeners process temporal aspects of auditory experience. However, linking these insights with cognitive processes involved in music perception remains relatively unexplored. One challenge in examining relationships between neurophysiological responses associated with perception of temporal information and how these processes may be linked with music cognition is that use of temporal information by listeners in musical processing is flexible. While temporal information is specified by the physical properties of a musical stimulus e.g. note durations, time intervals between onsets and tempo, the manner in which temporal information may be used by the listener is subject to a range of ‘top-down’ influences, so that differences in the use of temporal information result in a range of possible perceptual outcomes for the listener. This flexibility in the use of temporal information by listeners indicates that examination of neurophysiological responses to rhythmic grouping must account for differences in the use of temporal information by the listener by seeking to understand the perceptual outcome of the listening approach adopted.

The current research adopted this perspective, and aimed to examine neurophysiological responses associated with the use of temporal information by listeners in performing a cognitive task. Listeners were presented with tone sequences that incorporated rhythmic information that may have been used as organisational cues in the listening process. By examining the extent that rhythmic information impacted on task performance, this research aimed to associate the use of temporal information with neurophysiological responses evoked during the listening process.

The research implemented steady-state probe topography (SSPT), an electro-physiological technique that examine changes in amplitude and latency of the 13 Hz steady-state visually evoked potential associated with task performance. The SSPT technique provides adequate temporal resolution to assess changes in brain electrical activity on a sub-second scale, with the temporal continuity to examine dynamic changes in task-related neural activity, and in conjunction with a 64-electrode montage provides sufficient spatial resolution to identify activation of gross neural regions. By examining SSVEP changes associated with presentation of task elements that may be used within structural organisation processes, the research sought to identify brain regions associated with the use of temporal information in the rhythmic grouping of pitch sequences.

This thesis is presented in seven chapters. Chapter 1 introduces the subject matter and structure of this thesis. Chapter 2 reviews the behavioural research that discusses grouping of sequential information, and reviews evidence examining the extent that rhythmic segmentational grouping is used in music listening. Chapter 3 reviews research examining neurophysiological responses associated with temporal organisation of sequential auditory information, particularly those neurophysiological processes that are activated by rhythmic cues which behavioural research demonstrate as important cues in the grouping process. Chapter 4 provides a description of the SSPT methodology used to assess brain electrical activity changes associated with performance of the research tasks, and formulates the hypotheses examined by the research. Chapter 5 provides a detailed description of the methodology used to examine the research hypotheses. Chapter 6 presents the behavioural and neurophysiological results of the research. Chapter 7 discusses the results and provides the conclusions of the research.

Chapter 2 GROUPING IN AUDITORY PERCEPTION

2.1 Introduction

This study is an investigation of the cortical activity associated with rhythmic segmentational grouping of tone sequences in music listening. A review of literature that provides a basis for examining this topic is presented in two chapters. This chapter provides a review of literature discussing behavioural investigations of the grouping process and provides a basis for a subsequent chapter that discusses evidence for neurophysiological networks that may subserve the grouping process. Topics covered in this chapter include discussion of processes which group auditory information into units, discussion of music theory which encompasses the use of grouping processes in music perception, and a review of evidence for the use of grouping processes in auditory cognition in general, and specifically in music listening.

2.2 The Ongoing Auditory Record

There are no ‘auditory photographs’. Unlike the visual sense where meaningful information can be delivered solely in parallel, perception of auditory information demands sequential information processing. As discussed by Drake (1998), an essential function of our auditory perceptual system is to “situate each event in time and in relation to other events occurring within a particular time span” (p. 11). In view of the sequential nature of auditory information, processes that support the situating of events within a temporal continuum and enable the forming of time relations between those events are of particular importance in the auditory domain.

In order to situate events along a temporal continuum, there is a need for the perceptual system to maintain an ongoing record of the incoming input. Perception of speech and music, in particular, requires maintenance of an ongoing record (Peretz, 1989) so that sequential auditory events and their time relations may be processed, and situated within the context of events occurring over broader time structures (Drake, 1998). However, the maintenance of an ongoing record of sensory input is constrained by the limited capacity and duration of systems supporting perception, in particular, the short-term or 'working memory' system. In view of the key role of memory in maintenance of the ongoing record, the following section will provide a brief discussion of issues affecting an individuals' ability to maintain an on-going record of auditory information, and will discuss memory systems and the constraints imposed on information storage within the short-term (working) memory system. This section also introduces 'grouping' - an organisational process which aids in the overcoming of memory constraints in forming an ongoing record of auditory input.

2.2.1 The Short-term Working Memory System

Among the various typologies used to describe the various forms of memory, aspects of memory which vary on a time-based scale are most often used as the basis for defining three primary subdivisions. These are termed ultrashort or sensory memory, short-term (working) memory, and long-term memory, as initially defined by Atkinson and Shiffrin (1968). The ultrashort or sensory form of memory refers to a process measured in milliseconds, the duration of which is related to the decay of the sensory trace (Markowitsch, 2000). Sensory memory is subdivided into iconic (visual) memory and echoic (auditory) memory forms. Long-term memory refers to information which is stored off-line for minutes to decades (Markowitsch, 2000).

The term 'short-term working memory' was initially used to discuss the intermediate form of memory consisting of a unitary information store, although Baddeley and Hitch (1974) subsequently used the term to refer to a memory system comprising multiple components. They emphasised the functional importance of this system, as opposed to its simple storage capacity, and defined short-term working memory as a limited-capacity attentional system that provides temporary storage for information that is to be manipulated or retained for a short period of time (Baddeley, 1986, 1988, 1992a, 1992b; Baddeley & Hitch, 1974). The model of working memory proposed by Baddeley and Hitch, while undergoing more recent modification in order to account for subsequent experimental data, continues to provide a useful and widely accepted structural model for the working memory system.

Working memory employs an active process to hold and manipulate information on-line (Markowitsch, 2000). The working memory system is limited in the *depth* or *length of time* information can be held, and the *span* of information that can be held on-line. The length of time information can be held reflects the limitations of what has been termed the ‘perceptual’ or ‘psychological present’, the time interval in which perceptual information is integrated within the same span of attention (Fraisse, 1963; Michon, 1987). Although various strategies may be adopted to enhance the retention period of information held in working memory, auditory retention periods obtained in empirical research typically range from 2-10s (for a review, see Cowan, 1984), although the upper limits of this store vary by stimulus and research methodology. Fraisse (1982), for example, discusses the “practical limit” as 3s and the “extreme limit” as 5s. Strategies which may enhance the retention period of information may involve a rehearsal component, whereby information is mentally rehearsed or ‘replayed’ (Baddeley, 1986), and may also involve a recoding component, whereby information is converted into a format which is more easily retained in memory. Information recoding and its impact on the constraints of the working memory system will be discussed in greater detail in the following section.

2.2.2 Working Memory and Grouping

Constraints on the *span* of information held on-line are determined by the limited *capacity* of the working memory system. The working memory span is generally agreed to be of the order of seven chunks of information, where a chunk is a subjectively defined unit (Miller, 1956). The term ‘chunk’ was adopted by Miller (1956) in his seminal paper examining determinants of memory capacity. Miller noted that while the upper limit on the number of items that may be held in working memory was in the order of seven items, individuals were able to overcome the constraints of the limited number of items by organising information into subjectively determined groups, thereby increasing the amount of information held within a limited capacity store. Miller suggested that:

> …we must recognize the importance of grouping or organizing the input sequence into units or chunks. Since the memory span is a fixed number of chunks, we can increase the number of bits of information that it contains simply

> by building larger and larger chunks, each chunk containing more information than before (p.93).

Miller proposed that the span of immediate memory “seems to be almost independent of the number of bits per chunk” (p.92). For Miller, the essential process in overcoming the limited capacity of memory was *recoding* of the incoming information. Miller suggested that there are many ways to do this recoding, but “probably the simplest is to group the input events, apply a new name to the group, and then remember the new name rather than the original input events” (p. 93).

Since Miller’s original proposal for the use of grouping to overcome memory constraints in organising sequential information, substantial research attention has been devoted to the grouping process, and has provided support for the broad use of the grouping process as proposed by Miller in human cognition, although the span of the short-term store has been suggested to be somewhat more limited than Millers initial proposal e.g. Cowan (2001) suggests four chunks as the capacity limit of a single central store. Research in the field of music psychology echoes Miller’s original proposals. Reorganisation of sequential information into subjectively determined groups has also been proposed to underlie individuals’ ability to generate ongoing records of complex sequences of auditory information such as music that defy limitations imposed by the working memory system on the experience of the perceptual present. For example, Peretz (1989) suggested that in view of the capacity limitations imposed by the working memory system, maintenance of an ongoing record of auditory events requires ‘on-line’ organisation of the input, so that the format in which the auditory information is held enables the overcoming of working memory constraints.

As this thesis examines grouping of auditory events in a musical context, the following section will discuss the principles proposed to underlie formation of groups in perception and memory within auditory contexts in general, and specifically within musical contexts. This discussion of the processes which lead to the formation of groups in musical contexts will be placed within the context of contemporary models of music cognition.

2.3 Grouping Processes

Auditory perception typically involves the processing of sequential acoustic events, often with a rapidly changing acoustic spectrum and consisting of superimposed information derived from different sources. Our auditory system has the task of analysing this spectrum so as to reconstruct the originating sound events (Deutsch, 1999) or allocate components of the sound wave to a distinct sound source (Peretz, 1989). In order to prevent indiscriminate linking of perceived elements, this parsing of the sound wave into distinct components requires a set of mechanisms which determine the forming of linkages between some elements of the sound wave and inhibits the forming of linkages between others (Deutsch, 1999).

In musical contexts, parsing of the sound wave involves the processing of relationships between sound components such as frequency, amplitude, temporal location, and spatial location in order to either fuse components into unitary sound images, or alternatively, separate components into multiple sound images (Deutsch, 1999). This process of *auditory scene analysis* (Bregman, 1990) acts as a basis for the grouping of elements to form individual tones (*simultaneous grouping*), and underlies processes which connect events into distinct sound streams (*sequential grouping*). McAdams (1996) notes that once information is organised into events and event streams via these grouping processes, what is conventionally considered to be music perception begins. In addition to these processes, a third grouping process, *segmentational grouping*, 'chunks' event streams into musical units (McAdams, 1989). A summary of these three grouping processes may be described as:

- Simultaneous grouping – sound components grouped into individual tone complexes;
- Sequential grouping – sequences of tone complexes divided into separate sound 'streams';
- Segmentational grouping – sequences of tone complexes grouped into sequence units or 'chunks'.

The following section discusses research examining simultaneous grouping, sequential grouping, and segmentational grouping processes. This review of these grouping processes will demonstrate the prevalence of grouping processes in the perceptual organisation of auditory information.

2.4 Simultaneous Grouping

In music listening, simultaneous grouping of sound components to form individual tones occurs in response to several factors. In particular, spectral components are more likely to be perceived as a unified tone complex if the components stand in simple harmonic relationships with each other (Bregman & Doehring, 1984; De Boer, 1976; Mathews & Pierce, 1980) or if the onsets of spectral components are synchronous (Bregman & Pinker, 1978; Darwin & Ciocca, 1992; Rasch, 1978, 1988). Several other factors are proposed to enhance perceptual fusion of sound components. Deutsch (1999) notes that naturally sustained sounds tend to undergo small frequency fluctuations which maintain the frequency ratios of the spectral components. This coherent frequency modulation has been proposed as a factor underlying perceptual fusion (for a discussion, see Bregman, 1990), although the impact of this factor on the unification of sound components appears to be minimal when placed in conflict with other grouping factors such as harmonicity (Carlyon, 1991, 1992). Another factor proposed to impact on perceptual fusion - coherent amplitude modulation - is related to the tendency for the amplitude of spectral components of natural sounds to rise and fall in synchrony (Bregman, Abramson, Doehring, & Darwin, 1985). The effect of this factor on perceptual fusion, however, may also be attributed to mechanisms involved in pitch perception (Deutsch, 1999), and further strong evidence in support of this factor is yet to be obtained.

2.5 Sequential Grouping

Sequential grouping refers to a process whereby events presented in a sequence may be perceived either as a connected series or split into separate perceptual streams based on perceived differences in auditory characteristics such as pitch. Streams formed via this process are segregated perceptually from other co-occurring auditory events, resulting in an inability to direct attention to multiple streams simultaneously (Bregman & Campbell, 1971). Bregman and Campbell termed this process *stream segregation*

(1971). Early stream segregation research observed that the tendency of two repeatedly alternating tones to split into two streams depended upon the presentation rate and the frequency difference between the tones, so that separate streams were formed in response to combinations of faster presentation rates and larger frequency separations between tones (Miller & Heise, 1950). Stream segregation effects have also been demonstrated in response to differences in timbre (Singh, 1987; Van Noorden, 1975; R. M. Warren, Obusek, Farmer, & Warren, 1969; Wessel, 1979).

Research examining stream segregation has demonstrated a "breakdown of temporal processing" (Deutsch, 1999, p.317) as a result of stream formation, so that processing of temporal information between streams is difficult. Listeners are unable to judge the order of events occurring in separate streams (Bregman & Campbell, 1971; Dannenbring & Bregman, 1976), and find temporal information more difficult to process between streams than within streams (Divenyi & Hirsh, 1972; Fitzgibbon, Pollatsek, & Thomas, 1974). For example, Bregman and Campbell demonstrated that presentation of 100 ms auditory events alternating between two different pitch ranges resulted in the perception by a majority of listeners that the events were presented first in one pitch range then presented in the other (Refer to Figure 2.1a and 2.1b).

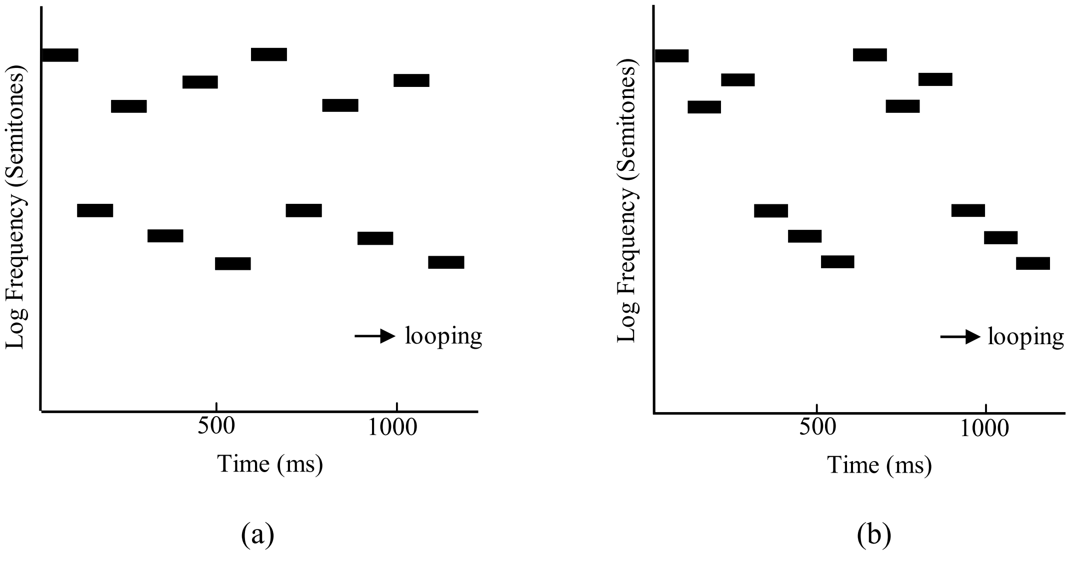

Figure 2.1 Sequential grouping examples

(a) Representation of stimuli presented in Bregman and Campbell (1971) Experiment 1. Tones alternate between a 'high' and a 'low' frequency range, (b) Representation of the organisation of stimuli that a majority of participants reported hearing.

2.6 Segmentational Grouping

As discussed in sections 2.4 and 2.5, simultaneous grouping processes fuse elements to form unitary sounds and sequential grouping processes connect or separate events into sound streams. At larger temporal scales, the duration or span of auditory information involved may approach the limitations of the perceptual present or short-term working memory system, and require the action of processes that enable the ongoing maintenance of the auditory record. Fraisse (1963) proposed that, in addition to limitations of the duration and span of individuals' ability to represent information in the present, the duration of the perceived present can only last for that amount of time that information can be organised as a single unit. Similarly, Michon argues that information in the present is a discreet segment, and that "consciousness is chopped up into meaningful, or at least structurally coherent segments" (1987, p.91). The boundaries of these segments are determined by various temporal and non-temporal structural properties, typically at natural breaks in the event structure (Clarke, 1999), yet the requirement for distinct units is sufficiently critical that subjective grouping processes impose segmentation even when no physical cues are available for the determination of stimulus boundaries (Michon, 1987). These processes are reflected in the application of a third grouping process - segmentational grouping - which acts to group individual tones to form perceptual units. It is at this level of auditory analysis that perceptual organisation of information reflects the reorganisation processes discussed by Miller (1956), in that groups of notes determined by segmentational grouping processes tend to be processed and subsequently recalled as perceptual units or chunks. This grouping of notes to form perceptual units is the central issue of this thesis. As such, the following sections will provide detailed evidence of the psychological reality of these auditory perceptual units in both non-musical and musical contexts.

2.6.1 Grouping of Non-Musical Stimuli on a Small Temporal Scale

Early investigations of rhythm perception noted that listeners tended to subjectively organise sequences of tones with identical physical characteristics (equitone sequences) into groups of four notes (Bolton, 1894; Meumann, 1894). This grouping of tones occurred even when no other auditory cues (e.g. timing changes) were present that would act as a stimulus to initiate grouping. Subsequent research examining this subjective organisation of tones suggested that listeners subjectively organised isochronic sequences (equitone sequences with identical time intervals between events) into groups of two, three, or four with an accent on the first tone of each group (Abecasis et al., 2005; Brochard, Abecasis, Potter, Ragot, & Drake, 2003; Fraisse, 1956; Harrell, 1937; Vos, 1977). Generally, the number of tones grouped in equitone sequences is dependent on tempo, so that more tones are grouped at faster tempos (Bolton, 1894; Fraisse, 1956; Meumann, 1894).

Research examining equitone and isochronic sequences indicate a tendency in listeners to organise sequences spontaneously into groups of tones based on subjectively determined parameters not present in the auditory stimulus. When an auditory sequence does provide information that can be used as a basis for organisation, listeners may group auditory sequences based on a range of physical, spectral, temporal, or spatial dimensions. Examples of factors demonstrated to result in segmentational grouping of stimuli appear in Figure 2.2.

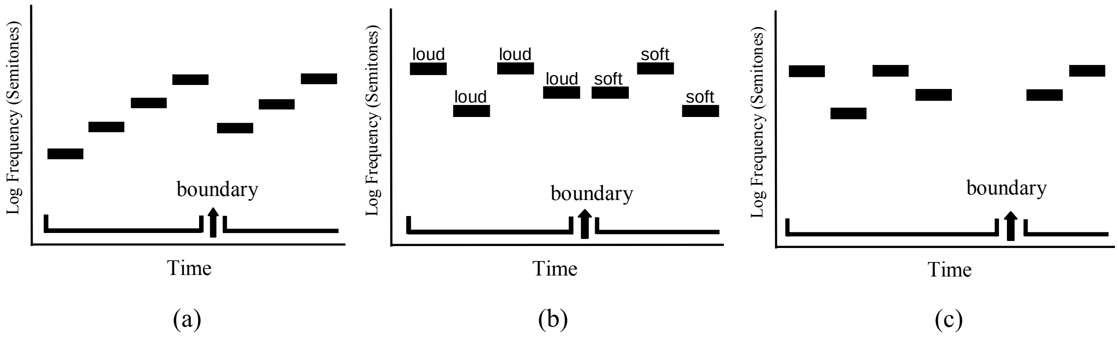

Figure 2.2 Segmentational grouping examples.

Square brackets on the time axis represent groups resulting from grouping process. (a). Grouping via continuity of pitch pattern. (b). Grouping via change in relative amplitude of events. (c). Grouping via change in time interval between event onsets.

Research examining perception of auditory sequences in non-musical contexts has indicated that grouping of events occurs in response to frequency-based characteristics of the auditory events such as continuity of pitch pattern (Divenyi & Hirsh, 1974; McNally & Handel, 1977; Nickerson & Freeman, 1974; Van Noorden, 1975; R. M. Warren & Byrnes, 1975); time-based characteristics such as relatively longer time intervals between event onsets (Garner, 1974; Garner & Gottwald, 1968; Handel, 1973;

Handel & Yoder, 1975; Povel & Okkerman, 1981; Preusser, Garner, & Gottwald, 1970; Royer & Garner, 1970; Vos, 1977), and amplitude-based characteristics of the auditory events such as intensity differences (Handel, 1974; Handel & Yoder, 1975). A common factor determining the grouping of events throughout this research is the finding that discontinuities in auditory characteristics are perceived as group boundaries.

2.6.2 Musical Groups on a Small Temporal Scale

In music perception, grouping of events has been extensively documented, and segmentational grouping processes acting in music perception have been identified at wide range of temporal scales. The smallest musical unit derived by the grouping of notes is termed a ‘motif’, and has been defined as "the briefest intelligible and self-existent melodic or rhythmic unit, consisting of two notes or more” (Scholes, 1964, p.382). At the next highest temporal scale, sections of musical sequences that may be perceived as perceptual units are referred to as phrases. The musical phrase is “a basic structural unit in music as far as it presents a syntactically complete musical idea that acts in balanced relationship with other component material within a composition” (Tan, Aiello, & Bever, 1981, p.534). Research examining grouping at the level of motifs or phrases are not clearly differentiated in the literature, and research examining grouping at these levels consists of a degree of overlap. Strict definitions of the temporal scale under examination have often not been provided by researchers, with the use of the term ‘phrase’ occasionally adopted for examination of perceptual units more appropriately defined as motifs. As a result, research proposed to examine processes occurring at the phrase level may have been considered as demonstrating processes acting at the motif level. Peretz draws a distinction between grouping of phrases and grouping on smaller temporal scales in discussing “intermediate levels where grouping mechanisms serve to produce perceptual units larger than an individual tone or phoneme but smaller than an entire phrase or sentence” (1989, p. 159). This distinction is important as processing of events at the motif and phrase level may draw on different processes, and in particular, memory processes underlying processing of motifs and phrases may differ. The total duration of brief motifs presented at higher tempos may fit within the span of the ultra short echoic memory system and draw on different processes to those underlying grouping of material at the larger temporal scale of grouping at the phrase level, which would typically draw on working memory or long-term memory resources. With this distinction in mind, the following section will review research examining grouping at the motif and phrase levels separately, and where the classification provided differs from that provided by the original author, the basis of classification into motif or phrase level in the current document will be noted.

2.6.3 Motif Level Grouping of Musical Stimuli

Research using patterned auditory stimuli discussed in Section 2.6.1 has demonstrated that physical aspects of the auditory stimulus may be used as a basis for organising events into groups. Research using more music-like patterns sought to understand the extent these processes were adopted in music listening. Research using musical stimuli indicated that temporal proximity of events acts as a strong determinant of group organisation, such that relatively longer time intervals between event onsets are perceived as boundaries between groups (Frankland & Cohen, 2004; Ryan, 1996), and events bounded by relatively longer intervals are subjectively chunked in phenomenal experience (Deliège, 1987), or in memory (Deutsch, 1980a, 1980b; Dowling, 1973b). Discussion of this research and other studies that provide support for the salience of relatively longer time intervals as grouping cues will be discussed in detail in sections 2.8 and 2.10.

Research at the motif level has also demonstrated that segmentational grouping may occur in response to a relative change in dynamics (Deliège, 1987; Ryan, 1996), articulation or timbre (Deliège, 1987), or in response to relative changes in pitch proximity (Deliège, 1987; Ryan, 1996; Wang & Sogin, 1990). Instructional set has also been demonstrated to impact on organisation of visually presented material. Gregory (1978) used a click localisation technique to demonstrate that the perceived timing of a click presented to one ear while listening to a sequence of tones presented to the other ear depended upon how the tone sequence was segmented on a musical score viewed during the presentation. Varying the segmentation on the score produced a shift in the perceived click location to the timing of the segmentation, suggesting that score segmentation determined the structure of units of perception.

Research examining the extent that grouped structures are retained in memory for musical stimuli have demonstrated that grouped memory representations at the motif level may also be constructed using pitch contour cues (Peretz & Babai, 1992), and pitch proximity cues (Wang & Sogin, 1990). A recent study conducted by Dalla Bella, Peretz, and Aronoff (2003) provides further support for the psychological reality of grouped memory representations at the level of the musical motive. Dalla Bella et al. demonstrated that access to melodies stored in long-term memory was via three to four note motives. The specific grouping cues used to delineate motives in this research were not specified, although the author has referred to the use of surface musical properties which have been already shown to play a role in segmenting music into motives (Dalla Bella, 2005).

2.6.4 Grouping in Language and Music at the Phrase Level

Grouping of individual auditory events at the phrase level has been demonstrated widely for both speech perception and music. Grouping at the phrase or clause level has been demonstrated in several ways in speech perception, with substantial evidence supporting the existence of grouping at the phrase level provided by click localisation research. This technique typically requires the listener to report when a click is presented to one ear while listening to speech or language presented to the other ear. In early click localisation research, Ladefoged and Broadbent (1960) observed that a click superimposed on a spoken sentence was heard as having occurred one or two syllables earlier. This migration of the click was interpreted as a tendency for perceptual units to be processed as discrete units. Fodor and colleagues subsequently observed that a click embedded in spoken sentences tended to be located closer to the nearest major phrase structure boundary than to its actual position, suggesting that phrases were processed as functional units in speech perception (Fodor & Bever, 1965; Garrett, Bever, & Fodor, 1966). Subsequent research demonstrated that the more independent a clause is from what follows, the stronger the effects of the segmentation (Carroll & Tanenhaus, 1978; Townsend & Bever, 1978). Other language research protocols indicate that strings of verbal sequences tend to be recalled in accordance with their temporal grouping (Bower & Springston, 1970; Bower & Winzenz, 1969; McLean & Gregg, 1969), and grouped in accordance with either meaning or grammatical structure (N. F. Johnson, 1965, 1968; Martin, 1967). Participants also take longer to decide that a two-word probe occurs in a two-clause phrase when the probe straddles clause boundaries than when it falls within a clause (Stewart & Gough, 1967), and have greater difficulty recognising a two-word probe that straddles a phrase boundary in a sentence than a probe drawn from within a phrase (Suci, Ammon, & Gamlin, 1967).

Early research examining grouping at the phrase level in music perception also implemented the click localisation technique, and demonstrated that phrase boundaries marked by specific types of acoustic features delineated the auditory events used to organise units of perception (Gregory, 1978). Sloboda and Gregory (1980) provided additional support for these data by showing that click migration occurred in conditions where boundaries between phrases were structurally marked, whereas Stoffer (1985) demonstrated click migration to phrase boundaries marked by temporal accents, harmonic cadences or melodic contour changes. Taken together, data obtained in click localisation studies provide evidence that musical phrase boundaries delineate perceptual units, so that click localisation is restricted to temporal regions bounded by these units.

Phrase level cues have repeatedly been demonstrated to determine structure of working memory representations of musical events. Grouped working memory representations have been demonstrated in response to melodic phrasing (Sloboda & Parker, 1985), and phrases marked by harmonically-determined pitch patterns (Boltz, 1991; Tan et al., 1981), although Boltz (1991) noted that the effects of harmonic phrasing on memory were only apparent when phrase endings were emphasised by temporal accentuation. Chiappe and Schmuckler (1994) demonstrated significant effects of phrasing on memory so that phrase boundaries were associated with modified recall of note information surrounding the boundary. Similar melodies with no phrasing were not associated with modified recall effects, suggesting that the phrase served as a functional unit in memory. The cues used to initiate these phrase boundaries share common features with cues initiating motif-level boundaries. Handel and Todd (1981) observed that temporal gaps in sequences cued phrases, a result partially supported by Deliège (1989), who observed that familiarity was a strong determinant of listeners' segmentations at this temporal scale. Segmentation of unfamiliar material was strongly influenced by temporal gaps on initial listening, though use of these cues to determine segmentations diminished with continued listening and future segmentations were more prevalent at larger time-scales.

2.6.5 Higher-Level Grouping

Segmentational grouping processes have been widely demonstrated to operate in perception and memory for musical sequences at the temporal scales of musical motifs and musical phrases. Similar segmentation processes have also been demonstrated to operate at even higher temporal scales of music perception, so that boundaries in larger-scale sections of music may be identified through changes in pitch register, temporal proximity or timbre (Clarke & Krumhansl, 1990; Deliège & El Ahmadi, 1990).

2.7 Processes Underlying Group Formation

The previous discussion has examined a substantial body of research demonstrating the application of grouping processes in music perception. The literature shows that grouping processes operate in one form or another across most, if not all time scales of musical perception. Grouping processes support the fusion of individual sound characteristics to form unified sound complexes, determine the organisation of sound sequences into unified or separate sound streams, and segment sound sequences into perceptual units. These perceptual units may underlie both phenomenal experience and memory for music at time-scales ranging from a few notes to large-scale sections of music.

2.7.1 Application of Top-Down Versus Bottom-Up Processing

When discussing the processes underlying the formation of grouped structures in music, music theories distinguish between aspects of music cognition that are based on universal processes (i.e. common to all individuals irrespective of age, experience, or culture), and those processes that are dependent on experience with the musical idiom. Experience with the musical idiom results in the development of knowledge structures (schema) within long-term memory that represent relations between events that have been repeatedly encountered within the cultural context (McAdams, 1996). Schema may be developed in response to pitch, duration, or timbre relationships, so that, for example, commonly encountered scales or harmonies would be encoded as abstract structures in long-term memory. These schemas form the basis of expectations which are applied when listening to music, so that a musical stimulus may activate an existing schema, and as a result, processing and expectations of the stimulus are subsequently influenced by the existing representation in long-term memory.

Processes used in the early stages of music perception, such as the simultaneous grouping processes used to organise sound components into sound complexes, and sequential grouping processes used to delineate sound streams have been proposed to result from processes which are universal and innate so that the influence of age, experience or culture is minimal. (Bregman, 1990). However, while this proposal is broadly accepted, this may not be true for all individuals or for all tasks.

Processes which occur at subsequent stages of music perception are more sensitive to the influence of existing knowledge structures. Following the organisation of sound into events and streams, subsequent organisation of musical information may be influenced by existing schemas which subserve top-down processing, in addition to factors which are determined directly from cues available in the musical surface and subserve bottom-up processing. Segmentational grouping is one such organising process which may be sensitive to the influence of both bottom-up and top-down processing. Relative use of bottom-up versus top-down processing in segmentational grouping is determined by the extent that the sequence of incoming stimuli matches with aspects of musical experience stored in long-term memory and evokes relevant schema. Event sequences consisting of unfamiliar event relationships are less likely to match those schemas stored as a function of cultural experience, and so are more likely to be processed using bottom-up surface-based approaches. As such, familiarity of the musical stimuli is a key factor in the relative use of processing strategies. When listening to a new piece of music from a familiar musical culture, bottom-up processes such as grouping via temporal proximity may be used to determine perceptual organisation. In addition, familiar stylistic aspects of the piece may evoke learned schemata which in turn will guide subsequent processing and expectations of the musical structure.

The hierarchical level at which segmentation via bottom-up processes is applied is also dependent on the familiarity of the musical stimuli. Drake (1998) observed that when learning to play a novel piece of music, musicians initially segmented the sequence into groups of four notes. At the third week of practice, segmentations were into groups of four or eight notes, and at week five, segmentations were into groups of four and 16 notes. Drake concluded that the more familiar the musicians were with the music, the more they were able to apprehend higher hierarchical segmentation organisations. As discussed in Section 2.6.4, Deliège (1989), also, noted that segmentation of unfamiliar material was strongly influenced by temporal gaps on initial listening, though use of these cues to determine segmentations diminished with continued listening and future segmentations were more prevalent at larger time-scales.

2.7.2 Common Factors Underlying Grouping Processes

Literature regarding segmentational grouping indicates that a range of distinct characteristics of auditory experience may serve as stimuli for the grouping of separate sound events. As summarised by Krumhansl, “Two successively presented tones will, with other conditions being equal, tend to group together to the extent that they are sounded close in time. Spatial location, frequency proximity, timbral similarity, and the formation of simple contours (patterns of increasing or decreasing pitch) also contribute to the probability that successively sounded tones are perceived as part of the same unit; moreover, in some cases these variables may override temporal proximity, producing two or more interleaved streams” (1990, p.153).

While this list of factors observed in grouping research indicates a diverse range of auditory characteristics underlying the grouping process, two key concepts – proximity and similarity - provide a basis for the initiation of a segmentational group via bottom-up processes (Krumhansl, 1990). These two factors provide a basis for grouping in response to specific event characteristics with their impact on the grouping process linked by a common impetus for the initiation of a group – the detection of a contrast in auditory surface characteristics. As agreed by most theoretical approaches discussing bottom-up processes that subserve grouping, a change in any sound parameter leads to the perception of a break in the sequence, resulting in the creation of groups which are separated by the changes (e.g. Dalla Bella et al., 2003; Deutsch, 1999; Drake, 1998; Krumhansl, 1990; A Penel & Drake, 1998; Peretz, 1989). The processes by which the detection of change in auditory characteristics results in group formation have been proposed to operate in accordance with principles described by the Gestalt school of psychology (Koffka, 1922; Wertheimer, 1923/1938). In view of the proposed significant role of Gestalt-based processes in segmentational grouping, the following section briefly describes the principles outlined by the Gestalt psychologists which have been proposed to underlie the grouping process, followed by a review of research which examines the validity of Gestalt-based processes in auditory organisation.

2.7.3 Gestalt-Based Grouping

There is wide agreement that organisation of individual musical events into groups via bottom-up processes occurs in accordance with simple principles originally described by the Gestalt school of psychology (Koffka, 1922; Köhler, 1929; Wertheimer, 1923/1938). Particularly influential are the ideas of Wertheimer (1923/1938), who proposed a series of perceptual principles that specify the features of sensation that are used as cues by the perceptual system to determine the arrangements and divisions of perceptual wholes. An overriding law of Prägnanz or 'goodness' was proposed to determine that the most salient arrangements (of those that are possible from a combination of individual elements) are those that form the most unified wholes and maximise simplicity. Application of all individual Gestalt principles are governed by this governing principle of Prägnanz. The principles of organisation which act under the organisational maxim of Prägnanz draw predominantly on phenomenological descriptions of visual experience, yet several of the principles - The Factor of Proximity, and the Factor of Similarity are proposed to apply equally to auditory experience as to visual experience.

The Proximity Principle is of specific relevance to the subject matter of this thesis, and proposes "that form of grouping is most natural which involves the smallest interval" (1923/1938, p.73). As for most of the principles nominated by Wertheimer (1923/1938), visual examples representing the spatial relationships of individual elements with each other are used as a basis for discussing the Proximity Principle. Wertheimer's original example is represented below as Figure 2.3. In each of Wertheimer's examples, the most natural grouping of the elements is proposed to be that which involves the smallest interval. Notably, the reference to interval is not specified uniquely with regard to the spatial dimension of the visual modality, as Wertheimer proposes that the principle is intended to apply equally to temporal aspects of auditory organisation:

"That the principle holds for auditory organization can readily be seen by substituting tap-tap, pause, tap-tap, pause, etc. for (i)[1], and so on for the others." (1923/1938, p.73).

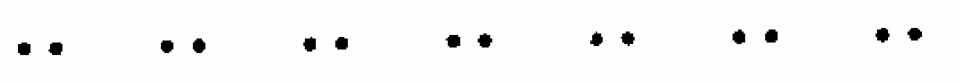

Figure 2.3 Wertheimer's (1923/1938) original Proximity Principle example. Initial example used in Wertheimer (1923/1938) to demonstrate a stimulus configuration sensitive to the effects of the Proximity Principle .

A second organising principle discussed by Wertheimer (1923/1938), the Factor of Similarity accounted for the tendency of like parts to be perceived as banding together. Wertheimer notes that, as for the Factor of Proximity, the Factor of Similarity applies also to auditory experience.

2.8 Validating Proximity-Based Grouping in the Temporal Domain

The Gestalt psychologists relied predominantly on an introspective approach as a basis for determining the principles of perceptual organisation. However, empirical support for the operation of the Proximity Principle has been obtained using both visual and auditory stimuli via research approaches examining a range of perspectives on perceptual organisation. The following section discusses the various research approaches that have supported the proposal that decreases in relative proximity provides a strong cue for perceptual organisation.

2.8.1 Pattern Learning

Following Miller's (1956) introduction of the concept of recoding, psychologists studying pattern learning responses suggested that the amount of information to be retained in a sequence can be manipulated by recoding, or chunking subsets of more than one item into a single memory code. This early pattern learning research

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[1] (i) denotes reference to Figure 1 in original publication. Original figure reproduced as Figure 2.3 here.

demonstrated that sequence memorising was sensitive to the effect of event proximities. The following studies represent the key findings that support the action of the Gestalt Proximity Principle in the organisation of event sequences.

Garner and associates (Garner & Gottwald, 1968; Preusser et al., 1970) examined responses to isopitch, isointensity repeating auditory patterns featuring equitemporal intervals that were either filled with an event or were not. Garner noted that individuals tended to perceive that a pattern began with the longest run of stimulus filled intervals – the run principle, and ended following a longer gap of unfilled intervals – the gap principle. Of key importance to the current discussion was the finding that the strength of the prediction made by the gap principle was proportional to the length of the longest gap, thus the relative change in temporal proximity was a predictor of perceptual organisation for the events up to and including the increase in time between events. Subsequent research examining the run-gap principles demonstrated an interaction between rate of presentation and dominance of one principle over another. At inter-stimulus intervals (ISIs) of 250 to 500 ms the gap principle tended to be emphasised, and at ISIs greater than 500 ms the run principle was dominant (Preusser, 1972).

Royer and Garner (1970) examined subjective organisation and grouping of repeating auditory sequences made up of two differently pitched noises. Patterns presented to participants were started at different points in the pattern for each trial and then continuously repeated. Participants reported hearing preferred start and end points in response to repeating pitch aspects in the patterns. However, if this structure was made to conflict with temporal pauses inserted into the patterns, organisation based on pause location dominated over the pitch-based organisation.

Handel (1973), also examined responses to repeating auditory patterns made up of two differently pitched tones. The eight- and nine-note patterns were segmented by pauses, and it was found that compatible segmentation (e.g., an eight-element pattern segmented by two resulting in stable temporal units when the patterns were repeated) resulted in excellent identification performance in a recognition test, but incompatible segmentation (e.g., an eight-element pattern segmented by three) led to poor performance.

Restle (1972) examined individuals' abilities to learn patterns of six flashing lights, and inserted pauses into sequences at timings that either matched or conflicted with the subdivisions of the sequence patterns. Learning performance was significantly better for those sequences where the pause matched the subdivisions than those that conflicted. Restle concluded that: "the effect of phrasing (elicited by a pause) is mainly one of marking and indicating natural boundaries between sub-patterns. Phrasing is effective in making the structure of a pattern easier to apprehend" (p. 390).

Garner (1974) continued the use of repeating tone series and provided further support for the existence of the run-gap principles, described in this work as "holistic organizing principles". Notably, results obtained in response to run-gap incompatibilities led to the suggestion that the run principle was a rather weak pattern predictor.

Handel and Yoder (1975) examined the effects of intensity and duration accentuations on rhythmic organisation in both the auditory and visual domains. When an auditory pattern was presented with no accentuation, subjects organised the pattern in accordance with the run–gap principle. When the pattern was presented with duration accentuation, however, subjects used the duration accentuation as the basis for rhythmic organisation. Notably, intensity accentuation did not dominate over the organisational cues provided by the run-gap principles.

Vos (1977) used repeating tone series to determine factors impacting on the perceived structure of the pattern. The results of two experiments strongly supported the action of the Gestalt Law of Proximity by demonstrating that the first tone of a perceptual group was perceived to be the tone that was immediately preceded by a long interval.

Taken together, findings of pattern learning research featuring manipulation of event proximities strongly support the role of the Gestalt Proximity Principle in perceptual organisation of sequential events. A consistent finding across a range of methodological approaches and sensory modalities is that when individuals process sequential sensory events, a relative increase in temporal distance between events is strongly associated with the perception of a break in the sequence, and organisation of the events reflect this perception. One key principle evolving from this research, the gap principle, strongly reflects the Gestalt Proximity Principle. Notably, another key principle derived from pattern learning research, the run principle, does not equate as readily with the Gestalt Principles. As noted by Garner (1974), when the run and gap principles were placed in competition, the run principle was concluded to be a weak predictor of pattern organisation.

Findings obtained in pattern learning research are either explicitly discussed in terms of the Gestalt principles with strong support offered for the action of the Gestalt Proximity Principle (eg. Vos), or if not explicitly discussed in terms of the Gestalt principles, support is offered for processes that act in accordance with the Gestalt Proximity Principle (eg. Garner's Gap Principle). As noted by Vos (1977), while Garner and associates refrain from explicitly discussing the Gestalt Principles, these authors adopt the use of terms such as *holistic organizing principles, goodness of pattern*, and *figure-ground effects* which suggest an influence of Gestalt theory on the discussion of the observed effects.

2.8.2 Language Research

Pattern learning research findings provide strong support for the action of the Gestalt Proximity Principle in perceptual organisation of auditory sequential events. A common feature of experimental designs employed in pattern learning research was the presentation of non-verbal stimuli. Additional support for the wider applicability of the Proximity Principle in auditory processing is provided by studies examining the potential role of the process in language processing. As discussed in Section 2.6.4, research employing strings of verbal materials have shown that strings of verbal sequences tend to be recalled in accordance with their temporal grouping (Bower & Winzenz, 1969; McLean & Gregg, 1969), and notably, use of temporal cues as a grouping determinant of strings of verbal materials has been demonstrated to supersede grouping cued by verbal meaning (Bower & Springston, 1970).

Taken together, results obtained through language studies and pattern learning research indicate that the Proximity Principle acts in both verbal and non-verbal auditory organisation processes. In view of the observed prevalence of this principle in the organisation of auditory information, Gestalt-based processes have also been proposed to play a significant role in the organisation of musical information, and have been incorporated in a range of music cognition theories. The following section provides a context for discussion of grouping processes in music perception by providing an overview of a key contemporary model of music perception – the Generative Theory of Tonal Music (Lerdahl & Jackendoff, 1983), which incorporates Gestalt principles within formal principles of music cognition. Specific examples of the action of Gestalt-based processes in music processing in accordance with this theory are provided, followed by discussion of the role of proximity-based grouping in music cognition.

2.9 The Generative Theory of Tonal Music

As discussed in Section 2.7.1, two distinct types of processes are proposed to underlie the organisational process resulting in the formation of auditory groups in a musical context. Bottom-up processes use cues in the auditory surface (pitch, duration, intensity, etc) to determine organisation, whereas top-down processes rely on previous experience with the musical idiom to determine organisation. The relative application of top-down versus bottom-up processes is influenced strongly by the extent that the music is familiar or that the sequence of musical events matches with aspects of musical experience stored in long-term memory.

Most music theoretical approaches that consider factors impacting on the generation of grouped perceptual structures at motif and phrase time-scales emphasise the role of bottom-up processes in accordance with the Gestalt principles, particularly those which encompass processes of proximity and similarity as a driving force in determination of group formation (Dalla Bella et al., 2003; Deutsch, 1999; Drake, 1998; Krumhansl, 1990; A Penel & Drake, 1998; Peretz, 1989). Music theories have been developed which attempt to formalise the influence of the grouping principles in music perception (Boltz & Jones, 1986; Deutsch & Feroe, 1981; Lerdahl & Jackendoff, 1983; Tenney & Polansky, 1980). The most thorough and explicit of these theories is the "Generative Theory of Tonal Music" proposed by Lerdahl and Jackendoff (1983).

In their highly influential theory regarding the mental structuring of music, Lerdahl & Jackendoff (1983) propose a theory which aims to characterise a listeners' connection between the musical surface of a piece and the structure the listener attributes to the piece in their final understanding of the piece. The theory adopts an approach analogous to that proposed by the school of generative-transformational grammar (Chomsky, 1957), which attempts to characterise what an individual knows when speaking a familiar language, enabling them to generate an unlimited number of sentences using a formalised system of principles for rules, known as a grammar. Similarly, Lerdahl and Jackendoff's Generative Theory of Tonal Music (hereafter *GTTM*) formalises the connection between the presented musical surface and the body of knowledge a listener brings to a hearing in a system of rules which assigns analyses to pieces.

Lerdahl and Jackendoff restrict GTTM to formalising the role of those components of musical intuition that are hierarchical in nature. Four components are proposed to enter into the mental structure of a piece. The first component, *grouping structure,* parses the event stream into a grouping hierarchy composed of motives, phrases and sections. This component reflects the action of segmentational grouping processes discussed in section 2.6. In parallel, a *metrical structure* is developed that reflects the alternation of strong and weak beats that occur regularly at multiple hierarchical levels. These two components are combined to provide a hierarchical segmentation of the piece into time-spans. A third component, *time-span reduction*, assigns structural importance to pitches dependant upon their position in the grouping and metrical structure. Via this process, structurally important pitches are represented at higher levels of the hierarchy, whereas less structurally important pitches are not represented and so are 'reduced'. The fourth component, *prolongational reduction*, assigns a hierarchy to the pitches that reflect their role in harmonic tension and relaxation, continuity and progression. While the theory does not formalise the role of non-hierarchical components of music (timbre, dynamics, motivic-thematic processes), the authors state that these dimensions play an important role in the theory and the influence of these factors in establishing the hierarchical structure of a piece is taken into account. The following sections discuss the Grouping Structure component of *GTTM*.

2.9.1 GTTM - Grouping Structure Composition

The grouping structure component of GTTM is firmly grounded in the principles proposed by the Gestalt psychologists discussed in Section 2.7.3. In introducing the concept of grouping structure, Lerdahl and Jackendoff note the ubiquity of grouping processes in human cognition: “If confronted with a series of elements or a sequence of events, a person spontaneously segments or "chunks" the elements or events into groups of some kind” (1983, p.13). Applied to the musical context, Lerdahl and Jackendoff suggest that a listener naturally organises a musical sequence into units such as motives, phrases and sections.

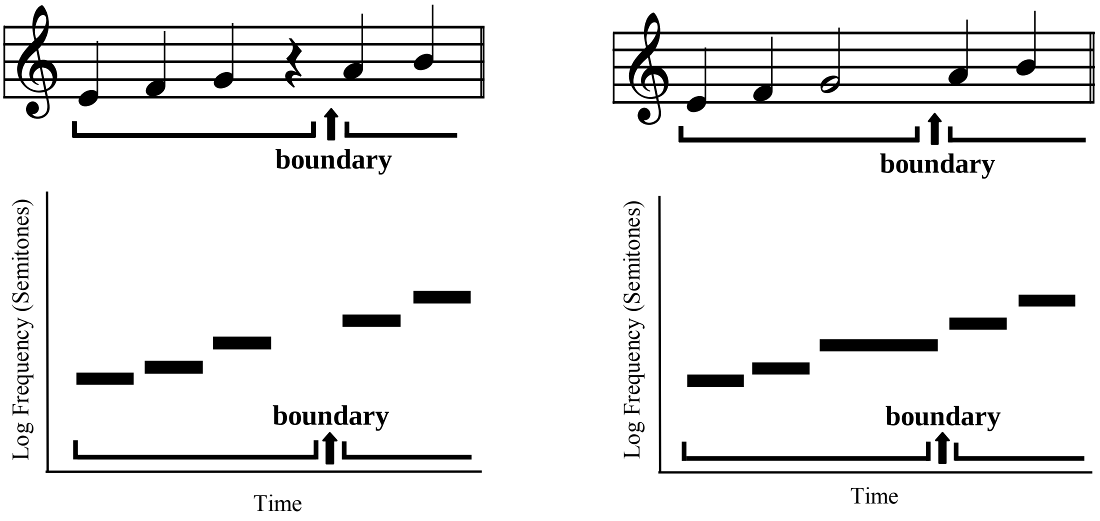
GTTM specifies a series of rules by which the organisation of a piece into a grouping structure is determined. Lerdahl and Jackendoff note that as music is not tied down to specific meanings and functions, “almost any piece of music is potentially vastly ambiguous” (1983, p.9), and as a result a generative music theory must not only assign structural descriptions to a piece, but differentiate amongst more or less preferred interpretations. Accordingly, two sets of rules determine the establishment of grouping structures in GTTM. *Grouping well-formedness rules* (GWFRs) establish the range of possible ‘well-formed’ structural interpretations of a sequence, whereas *grouping preference rules* (GPRs) establish which of the possible structures correspond to a listener’s actual hearing of a piece. In combination, the rules seek to determine the interpretation of a piece most likely to be heard by a listener who is experienced in the musical idiom. An experienced listener in this sense is an individual who is familiar with the musical idiom and able to organise the musical sequence into a comprehendible structure. As such, an experienced listener in the sense of the theory need have no formal musical training.

2.9.2 Grouping Preference Rules

The grouping structure component of *GTTM* draws heavily on the Gestalt tradition and is formulated with direct reference to the work of Wertheimer (1923/1938), Köhler (1929) and Koffka (1922) discussed in Section 2.7.3. In accordance with the Gestalt approach, grouping preference rules draw on the Gestalt ideas that visual and auditory groups are perceived in terms of the proximity and similarity of sequence elements. The Gestalt principles form the basis of the grouping preference rules that define possible boundaries of note groups based on the patterns of attack, articulation, dynamics, and registration occurring in the musical surface. More global considerations underlie other rules that determine which of the boundaries are retained at higher levels of the hierarchy (Frankland & Cohen, 2004). The first of the GPRs merely specifies the avoidance of very small group sizes, particularly groups with only one event. Rules two and three implement the Gestalt notions of proximity and similarity as grouping influences to specify grouping structures.

2.9.3 Proximity-Based Grouping

Lerdahl and Jackendoff introduce grouping preference rule two as an elaborated and explicit form of the principle of proximity discussed with reference to the Gestalt psychologists. Notably, GPR 2 applies the principle of proximity specifically to the temporal dimension, so that GPR 2 detects breaks in the musical flow, which are heard as boundaries between groups. Visual representations of the application of GPR 2 adapted from Lerdahl and Jackendoff appear in Figure 2.4.



(a) (b)

Figure 2.4 Generative Theory of Tonal Music proximity grouping preference rule examples

Upper and lower figures represent musical stave and frequency/time representations of a tone sequence promoting GPR2 (Proximity) group boundary formation at the indicated timing. (a) Example of GPR2a (Slur/Rest) Rule. A relatively greater time interval between the end of a tone and the beginning of another promotes formation of a group boundary. (b) Example of GPR2b (Attack-Point) Rule. A relatively greater time interval between tone onsets promotes formation of a group boundary[2].

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[2] Adapted from Lerdahl and Jackendoff, 1983

Lerdahl and Jackendoff (1983) defined GPR 2 as follows:

GPR 2 (Proximity) Consider a sequence of four notes $n_1n_2n_3n_4$. All else being equal, the transition n_2-n_3 may be heard as a group boundary if:

a. (Slur/Rest) the interval of time from the end of n_2 to the beginning of n_3 is greater than that from the end of n_1 to the beginning of n_2 and that from the end of n_3 to the beginning of n_4.

b. (Attack-Point) the interval of time between attack points of n_2 and n_3 is greater than that between attack point n_1 and n_2 and that between attack points of n_3 and n_4.

GPR2 applies the Gestalt proximity principle ("That form of grouping is most natural which forms the smallest interval") specifically to the temporal organisation of groups. This translation of the principal specifically to the auditory domain places GPR2 strongly in accordance with Wertheimer's' original proposal that the proximity principle holds equally well for auditory organisation of patterns, such as those structured as tap-tap, pause, tap-tap, pause (1923/1938, p.73).

2.9.4 Similarity-Based Grouping

The third of the local details rules, GPR 3, is based on the principle of similarity as discussed by Wertheimer (1923/1938) and is formulated in order to cater for changes in the musical flow, which are heard as boundaries between groups. Essentially, GPR 3 specifies that similarity of physical qualities between events promotes incorporation of events within a group.

2.9.5 Application of the GPRs

GPRs which use local detail cues available in the musical surface apply the Gestalt principles of proximity and similarity as an impetus for the delineation of group boundaries. Together, the grouping structure defined by these local detail rules depends on the detection of change in the musical surface (Frankland & Cohen, 2004). Lerdahl and Jackendoff propose that the distinctiveness of the transition between a given pair of notes is the key factor impacting on the likelihood that a transition will result in a grouping boundary. This distinctiveness is determined by the extent that the relative change contrasts with events on either side of the potential boundary. Changes relative to events on only one side of the potential boundary are proposed to elicit only weak ‘grouping intuitions’, whereas changes relative to events on either side of the potential boundary elicit strong grouping intuitions. Relatively larger changes may result in sufficiently strong grouping intuitions for the boundary to be incorporated within higher-level grouping structures. Additionally, grouping factors may reinforce or conflict with each other to produce weaker or stronger boundary intuitions. These considerations are formalised in larger-level rules (GPRs 4-7) which specify the establishment of higher-level grouping boundaries in response to relatively larger changes, interaction between grouping factors and the influence of more global principles.

2.9.6 GTTM Grouping Structure Summary

GTTM provides a theory by which the final state of a listener’s understanding of a piece of music may be gained. The importance of the grouping process as a key component of *GTTM* is unquestionable. Lerdahl and Jackendoff emphasise the primary role of grouping when they suggest that:

> When a listener has construed a grouping structure for a piece, he has gone a long way toward "making sense" of the piece: he knows what the units are, and which units belong together and which do not. This knowledge in turn becomes an important input for his constructing other, more complicated kinds of musical structure. Thus grouping can be viewed as the most basic component of musical understanding (1983, p.13).

This proposal of grouping as the most basic component of musical understanding provides strong justification for deep examination of the processes underlying this fundamental aspect of music perception. As discussed in Section 2.9.5, in GTTM, the essential factor driving the grouping process is the perception of change in the musical flow, a factor which is accounted for by the application of the Gestalt principles of proximity and similarity in the formulation of GPRs 2 and 3. Further examination of research which has sought to examine the validity of these grouping preference rules based on the Gestalt principles will shed light on the extent that the Gestalt principles of proximity and similarity are active in the processing of musical sequences.

2.10 Validating Gestalt-Based Rules of GTTM

GTTM is the most thorough and explicit of the music theories that have been developed which attempt to formalise the influence of the grouping principles in music perception (Peretz, 1989). As a consequence, the grouping preference rules specified in *GTTM* have been the subject of most of the empirical investigations seeking to determine the role of Gestalt processes in forming group structure (Clarke & Krumhansl, 1990; Deliège, 1987; Frankland & Cohen, 2004; Ryan, 1996). Most recently, Frankland and Cohen (2004, Exp 1.) compared the explicit parsing of melodies with predictions derived from *GTTM* GPRs 2 and 3. Participants were asked to segment three simple monophonic melodies into small but meaningful units by pressing a key at the end of one unit and the beginning of the next. In repeated trial conditions, participants parsed the same melodies three to six times. For each respondent, a boundary profile was created from the key-press segmentation task. Within-subject reliability analysis indicated that the boundary locations nominated by participants were consistent across repetitions of the task, indicating that learning effects or other top-down processing was not a major factor in the parsing profiles, Between-subject reliability ranged from correlation values of $r = 0.709$ ($SD = 0.188$) to $r = 0.670$ ($SD = 0.216$). These analyses were supported by cluster analyses which indicated that boundary profiles of 90% of participants were encompassed by a single cluster. Comparison of boundary profiles to the quantification of the rules indicated that the Attack-point rule (GPR 2b) (relatively longer time intervals between notes onsets are perceived as a boundary), was the most successful of the rules at predicting boundaries. Correlations between boundaries predicted by this rule and the quantified boundaries were highly significant for all melodies and ranged from $r = 0.913$, $p < .001$ to $r = 0.732$, $p < .001$. Additional multiple regression analyses indicated that the Attack-point rule was the only significant predictor of boundary placement when a step-wise approach was adopted.

Frankland and Cohen summarised these analyses by concluding that the Attack-point rule (essentially, longer notes cue group endings) was important for parsing melodies, and other GPRs tested “were of questionable utility, even though there was considerable opportunity for their use” (2004, p.525).

A second experiment using material from a classical repertoire replicated the initial design. As in Experiment 1, the Attack-point rule was consistently the most important rule. Overall, predictions based on the Attack-point rule correlated with $r = 0.71$ of participants’ boundary locations (accounting for 50% of the variance) in all melodies except one whose boundaries were also correlated with the Rest rule. In summary, Frankland and Cohen concluded that the Attack-point rule was found to have strong, consistent, empirical verification. A combination of all rules in a multiple regression indicated that only this rule was useful for predicting the boundaries in the melodies.

Frankland and Cohen (2004) provide a detailed analysis of data pertaining to individuals’ use of four of GTTMs’ key grouping preferences rules. Results indicated that participants used features of the musical surface consistently to segment melodies into units, and that choices of cues to segment the melodies was consistent across participants, irrespective of musical training. Of the potential grouping cues available to participants, only the appearance of relatively longer notes acted as a strong and reliable cue for the initiation of boundaries. Other cues were used less frequently (the appearance of rests as a cue), or rarely (larger pitch changes, relative shifts in note duration). In view of the direct relationship between the Attack-point rule and the Gestalt proximity principle, this data strongly supports the action of this principle in auditory organisation, whereas grouping based on the Gestalt principle of similarity is not supported by the data.

2.10.1 Other Research Examining the Local Detail Rules of GTTM

Several other studies have explicitly tested the grouping preference rules of Lerdahl and Jackendoff, and by implication the influence of the Gestalt grouping principles, by asking participants to identify boundary locations in musical segments (Clarke & Krumhansl, 1990; Deliège, 1987; Peretz, 1989, Experiment 1; Ryan, 1996).

Deliège (1987) conducted an empirical examination of Lerdahl and Jackendoff's (1983) GPRs by examining listeners segmentations of standard musical repertoire extracts as well as specially constructed test sequences. Overall, greater than 90% of both musicians' and non-musicians' segmentations were significantly in accordance with boundary locations predicted by the GPRs. In sequences where a single boundary location accorded with a GPR, Attack-point (GPR 2b) was the rule most often selected by both musicians and non-musicians, and was also the cue promoting the easiest boundary decision. Use of other rules was more variable between musicians and nonmusicians, with segmentations cued by changes in dynamics, and timbre the only other rules used frequently irrespective of musical training. In a second experiment where preference rules were placed in conflict in neighbouring locations, segmentations were still highly in accordance with GPRS, although different rules were favoured by musicians and non-musicians, with timbre the only rule frequently used by both musicians and non-musicians. Deliège concluded that the "grouping preference rules constitute theoretical principles backing up strongly the grouping intuitions of a subject while hearing music" (p.356). Overall, proximity of attack-point, and change in timbre were the most preferentially applied cues for boundary locations. Musicians' boundary locations were more in accordance with the location predicted by the GPRs, although musical training did not fundamentally modify the grouping mechanisms.

Ryan (1996) replicated and expanded the research conducted by Deliège (1987) in two experiments that were designed to test the perceptual validity and relative strengths of Lerdahl and Jackendoff's (1983) GPRs when presented in isolation and in competition with each other. Participants were asked to segment 13-note musical sequences into sections by pressing a key on a keyboard when hearing a note that started a group. In both experiments, listeners segmented melodies in general accordance with the GPRs. When boundaries predicted by GPRs were presented in isolation, Register, Dynamics, Slur/Rest, and Attack-point boundaries were segmented most in accordance with GPR predictions. When rules were placed in competition with each other in Experiment 2, boundaries cued by changes in register, dynamics, and attack-point were most in accordance with GPR predictions. No significant differences were observed between boundary locations as a result of musical training. Notably, boundaries not in accordance with the Attack-point rule were often due to the perception that segmentation occurred immediately before a longer-duration note, rather than after.

Ryan concluded that Lerdahl and Jackendoff's (1983) GPRs accurately describe and predict grouping behaviour, although some uncertainty was noted with regard to the positioning of a boundary as a result of a boundary cue such as a longer note.

Peretz (1989, Experiment 1) investigated musicians and non-musicians segmentations of folk tunes by asking participants to segment the tunes "into their parts". Tunes used in the experiment were selected to include at least one theoretical boundary specified uniquely by conditions equivalent to the GPRs for a pitch skip (GPR 3a - Register), temporal pause (GPR 2b – Attack-point), or by both a temporal pause and parallelism (GPR 6 – Parallelism). Overall, segmentations made by participants corresponded closely with the theoretical boundaries. Segmentation of the sequences was strongly in accordance with the theoretical boundaries specified by temporal pauses for both musicians (100%) and non-musicians (83%) and this effect was enhanced for the non-musicians when a pause coincided with parallelism (93.8%). Pitch skip was less salient as a grouping cue, with 64% of musicians' segmentations and 54% of non-musicians' segmentations in accordance with predicted boundaries. Overall, these data provide further support for the application of the Gestalt Proximity Principle as a basis for determining boundaries of note groups in musical sequences.

Clarke and Krumhansl (1990, Experiments 1 and 4) presented musically trained listeners with Stockhausen and Mozart piano pieces. On the second listening, participants indicated perceived boundaries of segments by pressing a foot-pedal after hearing a boundary. Clarke and Krumhansl indicated that boundaries detected by participants "relate quite directly to Lerdahl and Jackendoff's (1983) grouping preference rules" (p.228). The four general categories of segmentation cues identified were: silences and long pauses (GPR 2a/2b); contrasts in dynamics register, texture or rhythm (GPR 3 a-d); changes in pitch content, melodic contour, and shifts between vertical or horizontal organisation (no direct GPR equivalent), and restatement or repetition of previously heard material (GPR 6). As participants were informed that segments of interest were "relatively larger-scale segments" (p.225), segments identified by the procedure were at a higher level of grouping structure (group durations of 30–50 s) than those examined by Frankland and Cohen (2004), Deliège (1987), Peretz (1989, Experiment 1), and Ryan (1996), indicating that the grouping preference rules support grouping structure at both lower and higher hierarchical levels.

2.10.2 Summary Of Research Examining The Local Detail Rules Of GTTM

Studies which have empirically assessed listeners' use of the GPRs by examining listeners' identifications of boundary locations provide consistent support for the application of the GPRs in smaller musical segments (Deliège, 1987; Frankland & Cohen, 2004; Peretz, 1989, Experiment 1; Ryan, 1996), and this is further supported by data demonstrating segmentations of larger-scale segments in accordance with the GPRs (Clarke & Krumhansl, 1990). Musical training does not generally result in significant differences in segmentations, although training appears to impact on the frequency that segmentations are applied in accordance with the rules, so that musicians tend to segment somewhat more in accordance with the rules than non-musicians. This effect is not strong, however, and reached significance in only one study (Peretz, 1989, Experiment 1).

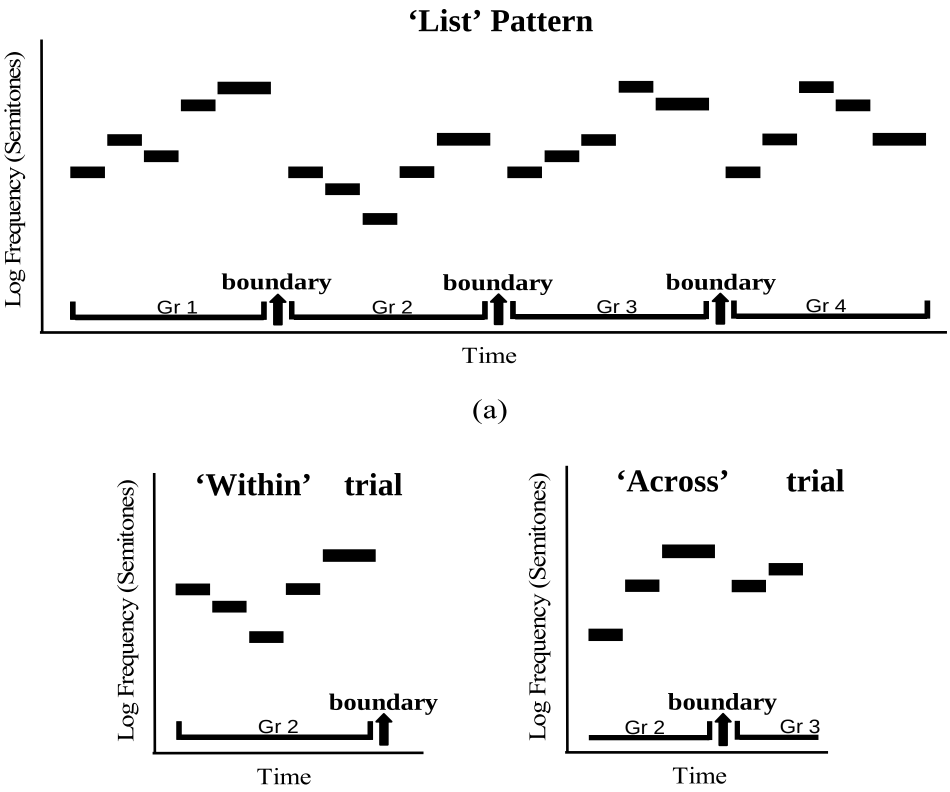
Some rules are used as cues for segmenting significantly more than others. In accordance with the Gestalt Proximity Principle, relatively longer notes (GPR 2b – Attack-point) feature as a strong cue used to determine listeners' boundaries, and are most consistently applied in research examining listeners' segmentations of musical material. When boundaries were presented in isolation, longer notes were identified as the sole boundary cue, or a predominant cue by Clarke and Krumhansl (1990, Experiments 1 and 4), Deliège (1987), Frankland and Cohen (2004), Peretz (1989, Experiment 1), and Ryan (1996). Relatively longer notes were also identified as a cue promoting an easier decision on placement of boundary location (Deliège, 1987). Use of other segmentation cues was more variable. Clarke and Krumhansl found support for application of all local detail rules in determining high-level segmentations (1990, Experiments 1 and 4), and this data was supported at smaller time-scales for Register, Dynamics, and Slur/Rest rules by Ryan (1996), whereas Frankland and Cohen (2004) found only weak support for Rest rules and none at all for other rules not based on proximity changes. Cues based on changes in register received variable support depending on musical training and degree of conflict with other rules by Deliège (1987), but only weak support from Peretz (1989, Experiment 1). Similarly, change in timbre featured strongly as a cue in data obtained by Deliège (1987), but not in other research.

Together, research examining phenomenal segmentations supports the psychological validity of the GPRs as a basis for establishing segmentations, although the consistency with which rules were applied varied from one to another. Only boundaries cued by relatively longer note durations were consistently identified by listeners, whereas boundaries cued by other rules were less consistently identified, and the relative salience of these rules varied across protocols. One possible explanation for this is that as different choices of music to be segmented were used in the reviewed protocols, differences in relative salience of segmentations may reflect music content differences across protocols, rather than differences in the relative utility of segmentations rules overall. Music choices may be preferentially segmented by one rule over another due to factors unaccounted for in experimental designs, resulting in the observed relative differences in salience of rules across protocols. Despite this variation in musical choices across protocols, segmentations based on relatively longer note durations were consistently identified by listeners, suggesting that this factor in particular is a salient cue for perceptually segmenting the musical flow in a range of musical types.

2.11 Proximity-Based Grouping in Memory

Peretz (1989) argues that data obtained in tasks requiring listeners to perform segmentations while listening to them can be argued to support the function of clustering determinants at a perceptual level. However, Peretz notes that segmentations observed through these tasks reflect *explicit* segmentations which may bear no relationship to the mechanisms that function *implicitly* when listening to music. Furthermore, Peretz notes that tasks providing phenomenal segmentations provide no evidence regarding the extent that the grouped structure maintains its integrity in memory. However, a number of studies have examined the impact of grouped structure on memory representations, particularly with regard to the use of relatively longer-duration notes as a grouping cue.

Dowling (1973b) presented listeners with 20-note sequences grouped into five-note groups by relatively longer note durations. A representation of the rhythmic grouping of patterns presented by Dowling appears as Figure 2.5(a). After listening to a 20-note pattern, listeners were presented with a five-note extract of the pattern and asked to judge if the test pattern had occurred in the original pattern or not. Half of the test patterns matched the rhythmic grouping of the original pattern and ended on a longer-duration note as in Figure 2.5(b), whereas half cut across group boundaries as indicated in Figure 2.5(c).



(a)

(b) (c)

Figure 2.5 Example of experimental design used in Dowling (1973)

(a) 'List' pattern consisting of four five-note phrases grouped by longer notes. (b) 'Within' test pattern consisting of an entire five-note phrase. (c) 'Across' test pattern consisting of three notes of one phrase and two notes of the next.

Dowling argued that if longer notes are used to determine perceptual boundaries, recognition of probes matching the grouped structure of the original pattern would be superior to recognition of probes which straddle the end of one group and the beginning of the next. The results indicated that probes matching a rhythmic group were recognised with significantly greater accuracy than probes straddling across groups, leading Dowling to summarise that the "results provide a clear indication that rhythmic grouping functions in memory for tonal sequences in much the same way as in memory for verbal materials" (1973b, pp. 38-39)[3].

Deutsch (1980a) examined recall of rule-based hierarchically-structured pitch sequences, and manipulated positioning of pauses within the sequence so as to either match or conflict with the pitch structure. Recall performance levels were high when the pauses matched the pitch structure, but low when they conflicted with pitch structure. Grouping of patterns based on the temporal structure of the patterns was so strong that listeners were unable to take advantage of pitch structure when this conflicted with temporal structure. Also notable was the finding that a measure of association between recall performance for adjacent notes, the transition shift probability, indicated that the recall performance for the first note of each chunk and the previous note was less strongly related than for any other pair of notes, indicating that temporal groups tended to be coded as chunks and retained or forgotten independently. Deutsch concluded that temporal structure had a "profound effect" on perceived structure and that memory performance demonstrated grouping in accordance with temporal proximity rather than sequence structure. Similarly, Boltz and Jones (1986) examined recall of 12-note rule-based melodic patterns by musically trained listeners and found that pattern reproduction was significantly better when pauses were in phase with pitch structure of sequences than when it conflicted with the pitch structure. Boltz and Jones noted important interactions in memory for melodies between temporal structure defined by pauses and melodic structure, lower order phrase structure, higher order rule structure and contour.

Peretz (1989, Experiment 2) used a probe recognition technique to examine the extent that segments defined by relatively longer note-durations were encoded as chunks in memory. The same folk tunes as used in Peretz (1989) Experiment 1 were presented to listeners, followed by a 3-note probe stimulus. Probe stimuli were extracted from four locations in the original fragment, two of which were extracted from within a group, and two extracted straddling over a group boundary. As demonstrated by Dowling (1973), Peretz argues that probes extracted from within a group would be recognised more

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[3] Rhythmic grouping in memory for verbal materials was discussed in Section 2.6.4.

easily than probes straddling across groups. Notably, the majority of the folk tunes presented in this research were made up of group sizes of greater than three notes, and as result, few of the within-group probes presented actually accorded with a whole group. This factor may have strongly impacted on results obtained, which indicated that within-group probes were not recognised more accurately than across-group probes, and non-significant trends in the opposite direction were observed. Peretz noted that the design failed to present probes consisting of entire groups of notes, and questioned the adequacy of this design to tap into grouped representations.

The research reviewed in this section indicates that, with the exception of data obtained by Peretz (1989, Experiment 2), sequences that are temporally structured by relatively longer notes or pauses are encoded in memory in accordance with the structure defined by the temporal information. This temporally-determined structure in memory is sufficiently salient that it may dominate memory codes defined by pitch-based structuring (Deutsch, 1980a). Data presented by Peretz (1989, Experiment 2) demonstrating recognition unaffected by temporal structure does not provide a strong argument against this proposition, as this research employed an experimental design which fails to account for data presented by Deutsch (1980a) demonstrating that temporally-defined groups tend to be retained or lost as units. These data also address the concerns of Peretz (1989) that data obtained through explicit segmentations of musical sequences may only reflect processes underlying explicit segmentations. Together with findings obtained in response to research examining phenomenological segmentations, these data provide strong support for the proposal that proximity-based temporal changes, particularly relatively longer note durations, provide a strong impetus for the formation of grouped structure in both perception, and memory for musical sequences.

2.11.1 Grouping Effects on Music Performance

In addition to research demonstrating the psychological validity of grouping processes in music perception through explicit segmentation tasks and implicit memory-based tasks, the existence of groups as a mental representation is further supported by research examining the impact of proximity-based grouping cues on musical performance.

Musical performance studies demonstrate that performances typically vary from a musical score along several dimensions. *Expressive timing* variations are often considered the most important dimension (A. Penel & Drake, 1999) and result in elements being performed slower or faster than indicated on the score. Grouping based on proximity-based score variations has been demonstrated to play a central role in eliciting these timing variations in music performance, resulting in *phrase-final* or *group-final lengthening* - the slowing down towards the end of a group. The mechanism through which grouping impacts on timing has been attributed to several different origins. Penel and Drake (2004) investigated a range of potential explanations and proposed that group-final lengthening is due to a combination of three factors:

- Perceptual constraints result from the impact of grouping on perceived timing so that some IOIs are perceived as being shorter or longer than they really are (Drake, 1993; A Penel & Drake, 1998; A. Penel & Drake, 1999; Repp, 1992, 1998a, 1998b, 1999b). Timing variations in performance are proposed to compensate for these biases.
- Motor constraints on performance timing result from the use of rhythmic groups as planning units for motor control (A. Penel & Drake, 1999; Repp, 1999a).
- Musical communication of grouped structure results in performers using timing variations to communicate the hierarchical grouping structure of a piece (Clarke, 1985; Palmer, 1989, 1996; A Penel & Drake, 1998; Sloboda, 1985; Todd, 1992).

Taken together, these three factors provide a basis for data obtained in a range of experimental investigations of phrase-final lengthening. Furthermore, each of these three factors provide specific support for the psychological reality of grouped sequences of musical events underlying distinct aspects of musical behaviour.

2.11.2 Groups Define Boundaries of Perceptual Present

Research examining structural organisation of music has strongly supported the psychological validity of a segmentational grouping process that structures perception, memory and performance of musical sequences. The process acts to organise musical sequences in response to physical cues presented at the musical surface, and in the absence of explicit cues may also impose organisation in response to subjectively determined factors. Findings of this research also accord with those processes proposed to support and delineate the experience of the perceptual or psychological present and its relationship with memory. That is, segmentation processes use structural boundaries as cues for division of the "stream of consciousness" into internally representable and integrated units. Clarke (1987) discussed application of the segmentation process with regard to the organisation of perceptual experience:

> Perception does not flow in an entirely homogeneous fashion: it segments experience into a succession of units, whose relative autonomy is a function of the coherence of the perceptual information and the perceptual strategy of the observer. Each of these durational segments is a perceptual present, and has the property that until it is a complete and bounded segment, the information within it continues to be active and available (p. 229).

Information in the present remains available until it can be processed at a higher and more abstract level. Structural boundaries, such as syntactic events or pauses, act to cue this shift from instantaneous availability to the generation of a representation at higher levels (Michon, 1987). This shift occurs as a result of the segmentational grouping processes described in this review. Prior to the generation of this higher-level representation in response to a boundary cue, information remains available at the level of the surface structure until recoding results in the irretrievable loss of this surface information. Michon proposes that as boundary cueing results in the delineation of structurally "healthy" patterns represented at higher levels, this provides an explanation of research obtained in both music and language contexts demonstrating that memory does not readily straddle two successive structural units (Dowling, 1973a; Peretz, 1989; Peretz & Babai, 1992; Stewart & Gough, 1967; Suci et al., 1967; Tan et al., 1981).

Michon proposes that abstract representations generated as a result of the grouping process not only reflect organisation cued by stimulus characteristics, but also integrative processes which incorporate the context and the implicit knowledge about the events. As such, this grouping and recoding process has been proposed to integrate structural representations derived via bottom-up processes cued by stimulus characteristics with top-down processes representing implicit knowledge about the events (Michon, 1987). This implicit knowledge may incorporate schemas developed through experience in the musical idiom. In this manner, the grouping process would act to determine a temporally integrated whole that encompasses information derived from both sensation and experience.

Pauses attain particular significance as a structural cue when discussed with reference to segmentation of the perceptual present. Gap detection and rhythmic reproduction studies indicate that while individuals are able to accurately perceive and reproduce time intervals *within* rhythmically derived structures, they are impaired at perceiving or reproducing time intervals *between* rhythmic groups (e.g. Bolton, 1894; Fraisse, 1956; Thorpe, 1985; Thorpe & Trehub, 1989; Woodrow, 1909). Fraisse (1963), Fraisse and Lavit (1986), and Michon (1987) discuss this phenomenon in terms of processes suggested by the Gestalt psychologists. Gaps (and equally pauses) between rhythmic groups serve to reinforce the distinction between successive perceptual units, reflecting Gestalt-like processes which act to distinguish between aspects of a sensation which provide maximal information and achieve a dominant perceptual quality, and aspects which are relatively devoid of information that take on the status of background. In essence, these authors propose that processing of groups and gaps occurs in terms of Gestalt figure-ground relationships.

In addition to providing a segmentation cue in accordance with principles outlined by the Gestalt psychologists, the pause has also been described as an “information bucket” (Michon, 1987), in which information that has not been integrated into a pattern of events immediately upon presentation is localised in order to achieve perceptual closure. This proposal is supported by click localisation research (Fodor & Bever, 1965; Garrett et al., 1966) (discussed in Section 2.6.4). Furthermore, several authors have proposed that the pause provides additional processing time within which higher-order abstraction processing may be completed (e.g. Bower & Springston, 1970; Martin, 1972).

Together, these proposals indicate that relatively longer temporal intervals are important cues for the establishment of structural representations of auditory information, and in addition, represent a key timing within which information delivered sequentially may be integrated in the generation of higher, more abstract representations.

Chapter 3 NEUROPHYSIOLOGY OF TEMPORAL CHANGE PROCESSING

3.1 Introduction

Literature discussed in Chapter 2 demonstrates that environmental ‘change’ acts as a cue for organisation of sequential information. In particular, perceived breaks in the flow of a previously established continuum are used as cues for the structuring of sequential information. In the auditory modality, this perception of change may occur in temporal and frequency-based dimensions, so that an event characteristic which substantially differs from a pattern established by previous presented events will be perceived as a cue for the delineation of group boundaries. This chapter will discuss electrophysiological and functional brain imaging research which provides spatial and temporal information regarding sequence structuring via lengthened temporal intervals. Substantial insights into the understanding of how the brain processes temporal information have been provided by brain imaging technologies which have sought to assess both the timing of brain processes supporting temporal processing, and the location of brain regions which support this process. By jointly examining these two aspects of temporal processing, greater understandings of the cognitive processes underlying temporal perception have been gained.

Understanding of the timing aspects of processes supporting temporal processing have been largely gained through electrophysiological techniques which examine event-related potentials (ERPs) - averaged recordings of brain electrical activity responses to specific events. This section will examine ERP research in temporal processing, and will focus on two specific ERPs which occur in response to the detection of change in the auditory environment:

- the mismatch negativity response – a response proposed to reflect the automatic detection of event characteristics which differ from those previously presented in sequence, and
- the omitted event potential - a response which reflects detection of change from an established pattern specifically in the temporal dimension.

Following this discussion, this chapter will examine other brain imaging research which has examined processes that may be used in the structuring of the temporal aspect of auditory sequences, and may support aspects of temporal processes involved in music perception

3.2 The Mismatch Response

Näätänen discusses cognitive processes underlying the detection of events which differ from those previously presented in an auditory sequence as stemming from a pattern matching process. By this approach, a template or trace of event characteristics is established by repeated presentations of event characteristics. Each subsequent stimulus is compared to this template, and differences between the event and a template elicit a mismatch process (Näätänen & Winkler, 1999). An early ERP response reflecting this detection of change from an established trace of stimulation is the mismatch negativity response (MMN). The MMN response is reflected by enhancement of a negative-going ERP waveform with a maxima in frontocentral regions occurring approximately 100-200 ms after the onset of a stimulus that differs from the most recent history of previous stimulation. MMN responses have been demonstrated in response to detection of changes in physical characteristics of auditory stimuli including pitch, frequency, intensity, timbre and duration (for a review see Näätänen, 1990), and is proposed to originate from bilateral generator sources in the auditory cortex (Alho et al., 1998; Opitz, Mecklinger, Friederici, & von Cramon, 1999; Opitz, Rinne, Mecklinger, von Cramon, & Schröger, 2002; Scherg, Vajsar, & Picton, 1989; Tervaniemi et al., 2000), and from right frontal sources (Giard, Perrin, Pernier, & Bouchet, 1990; Opitz et al., 2002). MMN paradigms have been proposed to be particularly useful for examination of processes underlying music cognition (Tervaniemi & Huotilainen, 2003).

3.2.1.1 Attention and top-down processing

Processes underlying the auditory MMN response have been proposed to be independent of attention, and reflect pre-attentive aspects of auditory processing (Escera, Alho, Schröger, & Winkler, 2000; Näätänen & Winkler, 1999; Ritter, Sussman, Deacon, Cowan, & Vaughan, 1999). As a number of studies have demonstrated that the

MMN response is not affected by task-related top-down effects (Alain & Woods, 1997; Näätänen, Paavilainen, Tiitinen, Jiang, & Alho, 1993; Ritter et al., 1999) it has been proposed that stimulus-driven bottom-up processes form the basis of sound organisation, and that sounds are extensively analysed and regularities are detected regardless of the focus of attention (Escera et al., 2000; Näätänen & Winkler, 1999; Ritter et al., 1999). However, attention effects have been demonstrated to influence the MMN response under certain conditions (Alain & Woods, 1997; Dittmann-Balcar, Thienel, & Schall, 1999; Näätänen, Paavilainen et al., 1993; Paavilainen, Tiitinen, Alho, & Näätänen, 1993; Woldorff, Hackley, & Hillyard, 1991) leading to the proposal that while stimulus-driven sensory mechanisms form the basis of sound organisation, goal-driven attentive processes may modify the neural representation of sound (Sussman, Winkler, Huotilainen, Ritter, & Näätänen, 2002; Sussman, Winkler, & Wang, 2003).

3.2.1.2 Passive attention switch

The process generating the MMN response is generally accepted as playing a key role in passive attention to sound change (Escera et al., 2000; Näätänen, 1990; Näätänen & Winkler, 1999). Upon detection of infrequent change in the acoustic input, this process initiates a call for attention (Öhman, 1979) to potentially important environmental stimuli. As such, the process is proposed to act as a passive attention switch that supports the entry of new information into an attentional system with limited capacity (Escera et al., 2000; Näätänen & Winkler, 1999). Further support for the proposal of the MMN-generating process within passive attention switching is that the MMN is often followed by an ERP correlate of attention switching - the P3a response (Knight, 1996; Lyytinen, Blomberg, & Näätänen, 1992; K. C. Squires, N. K. Squires, & S. A. Hillyard, 1975).

3.2.1.3 MMN for time-based change

In the temporal dimension, MMN responses have been demonstrated in response to a range of time-based relationships between auditory events. Following regular presentation of auditory events, changes in timing between event onsets elicits an MMN when the inter-onset interval (IOI) is decreased (Ford & Hillyard, 1981; Hari, Joutsiniemi, Hamalainen, & Vilkman, 1989; Näätänen, Jiang, Lavikainen, Reinikainen,

& Paavilainen, 1993; Nordby, Roth, & Pfefferbaum, 1988) or increased relative to the standard timing between onsets (Alain, Woods, & Ogawa, 1994; Gomes, Ritter, & Vaughan, 1995; Näätänen & Alho, 1995; Russeler, Altenmuller, Nager, Kohlmetz, & Münte, 2001; Tervaniemi, Maury, & Näätänen, 1994; Yabe, Tervaniemi, Reinikainen, & Näätänen, 1997; Yabe et al., 1998; Yabe et al., 2001).

MMN responses are elicited in conditions that lead to the perception of a time-based group boundary i.e. in response to an increase in IOI relative to the standard timing between onsets (Atienza et al., 2003; Takegata et al., 2005). However, a specific limitation of this correspondence between conditions eliciting an MMN response, and those eliciting time-based perceptual boundaries, is indicated in research examining MMN responses to omitted note onsets. This research indicates that an MMN may be elicited in response to an omitted onset following a regular presentation of events only within approximately 240 ms of the previous event (Tervaniemi et al., 1994; Winkler, Czigler, Jaramillo, Paavilainen, & Näätänen, 1998; Yabe et al., 1997; Yabe et al., 1998; Yabe et al., 2001) which corresponds with the temporal window of integration – the period of time in which auditory events are integrated into a unitary event (Yabe et al., 1998). As behavioural evidence demonstrates that segmentational grouping occurs in response to lengthened temporal intervals at IOIs well beyond this temporal range (e.g. Dowling, 1973b; Peretz, 1989), this data indicates that while MMN responses may be elicited in certain conditions shown to evoke perception of time-based group boundaries, the MMN response does not accompany all time-based grouping conditions, so may only be a limited correlate of other processes underlying the perception of time-based grouping processes.

3.2.1.4 MMN reflects action of flexible auditory model

The generation of MMNs in response to changes in event temporal relationships indicates that the system underlying generation of the MMN is not only sensitive to deviations in physical characteristics from those of an established trace, but is also sensitive to changes in temporal relationships between events. Therefore, this system must be capable of encoding regularities in temporal relationships between events and using this information in an extrapolatory fashion, so that time-based expectations for future events are formed (Näätänen & Winkler, 1999). In accordance with this proposal, the MMN response reflects properties of a flexible auditory model that generates and revises expectations for future events based on the current stimulus environment. Flexible adaptation of the auditory model reflected by MMN responses is demonstrated by differences in MMN responses to deviant stimuli presented within and across perceptual groups. Atienza et al. (2003) presented tone sequences that were organised into perceptual groups of six tones delineated by an increased time interval after each sixth tone. Deviant tones within these groups have been demonstrated to elicit an MMN response for stimulus onset asynchronies (SOAs) of up 640 ms, whereas deviant tones presented as the first tone after an increased SOA (i.e. presented across a perceptual group) elicited an MMN only when the SOA was less than around 240 ms, i.e. within the range of the temporal window of integration (Atienza et al., 2003). This result was interpreted with regard to the generation and resolution of expectancies underlying the MMN response. Deviant notes occurring within a group reflect the violation of expectations generated by previous notes, whereas the occurrence of a group boundary changes the environmental context of the existing neural trace, reducing the relevance of this trace to the most recent conditions (i.e. a new group of tones), and as a result, expectations of future events based on this trace are no longer relevant, and no MMN occurs. This decay in relevance of the trace underlying the MMN is further demonstrated by additional studies demonstrating a reduction of the relevance of the MMN-generating trace following a perceptual grouping cue (Takegata et al., 2005; Winkler, Schröger, & Cowan, 2001). In particular, Takegata, Roggia, & Winkler (2005) demonstrated a graded effect of perceptual grouping on the MMN-generating trace as a function of the strength of the cue eliciting the perceptual boundary.

As such, examination of variations in MMN responses in response to perceptual grouping provides strong support for the proposal that the MMN-generating trace reflects a flexible model of the auditory environment, and crucially, demonstrates the substantial influence of perceptual boundaries on auditory models upon which temporal expectations are based. In particular, temporally-based perceptual boundaries initiate a revision of the temporal model in a process which attenuates the relevance of less recently presented events as a basis for generating expectations for future events, in order to provide an auditory model based on the most recently presented temporal information.

The following section will discuss another ERP response – the omitted event potential (OEP) – a response which reflects detection of change from an established pattern specifically in the temporal dimension, and demonstrates responses to omitted notes which more closely align with conditions evoking the perception of a time-based group boundary.

3.3 The Omitted Event Potential

3.3.1 Conditions Producing the Omitted Event Potential

Early research examining brain electrophysiological responses demonstrated characteristic event-related potential (ERP) responses to omission of stimuli from repetitive temporal sequences in both the auditory, visual and somatosensory domains (Barlow, 1969; Klinke, Fruhstorfer, & Finkenzeller, 1968; Ruchkin & Sutton, 1973; Ruchkin, Sutton, & Tueting, 1975; Sutton, Tueting, Zubin, & John, 1967). In one of the earliest descriptions of the response, Sokolov (1963) reported that the omission of a stimulus from a regular series of stimulus presentations elicited a complex of electrophysiological responses at the point in time when the omitted stimulus was scheduled to occur. Following on from this research, Sutton et al. (1967) demonstrated an omission response in the 100- to 500 ms interval when an auditory click was expected by subjects but not presented. More recent investigations of the auditory omission response have detailed the multiple components of the response. Typically, omitted stimuli may elicit an ERP response consisting of an early negativity localised in frontal or temporal regions with a latency of approximately 150- to 200 ms, followed by a positive ERP response localised in frontal, temporal or parietal regions with a latency of approximately 350- to 700 ms (Baudena, Halgren, Heit, & Clarke, 1995; Besson & Faita, 1995; Besson, Faita, Czternasty, & Kutas, 1997; Joutsiniemi & Hari, 1989; Nittono, Biro, Hayashi, Sakata, & Hori, 2000; Paller, McCArthy, & Wood, 1992; Tarkka & Stokic, 1998). Other ERP components observed to follow the biphasic response include the ‘slow wave’ (SW) response which appears as a sustained frontal negativity (Baudena et al., 1995). This complex of ERP responses to omitted stimuli has been variously termed ‘emitted potentials’ (Ruchkin & Sutton, 1973, 1978; Ruchkin, Sutton, Munson, Silver, & Macar, 1981; Ruchkin et al., 1975); ‘omission responses’ (Raij, McEvoy, & Hari, 1997), and ‘omission evoked potentials’ (Jongsma et al., 2005;

Jongsma, Quiroga, & van Rijn, 2004). For consistency, the response will be referred to throughout this thesis as the omitted event potential (OEP).

3.3.1.1 Expectation

The OEP is most commonly conceived of as an electrophysiological representation of temporal expectation for a sensory event (Besson et al., 1997; Jongsma et al., 2005; Jongsma et al., 2004; Raij et al., 1997; Simson, Vaughan, & Ritter, 1976; Weinberg, Walter, Cooper, & Aldridge, 1974; Weinberg, Walter, & Crow, 1970). Omitted event potentials are most often observed in protocols where expectation for event presentation at a particular point in time is developed via regular stimulus presentations and then violated via non-presentation. As such, models of processes underlying OEP generation assume that expectation for an event not only consists of the event characteristics, but also develops along a temporal dimension so that the expectation for an event may be directed to a particular point in time. This view is particularly well supported by research demonstrating performance benefits associated with directing of attention to task-relevant points in time (Lange, Kramer, & Roder, 2006; Lange & Roder, 2006; Lange, Rosler, & Roder, 2003; Miniussi, Wilding, Coull, & Nobre, 1999), and specifically encompassed in the domain of music cognition in Dynamic Attending Theory (Drake, Jones, & Baruch, 2000; Jones & Boltz, 1989) and the concept of future-oriented attending (Jones & Boltz, 1989; Jones, Boltz, & Kidd, 1982; Jones, Kidd, & Wetzel, 1981) which propose that musical expectancies are time-based. Jones emphasises the role of temporal structure in guiding musical expectations so that future-oriented listing allows the listener to anticipate when a note will be presented. As discussed by Jones (1981, p.38), ‘An event that occurs too early or too late violates one's expectancy just as much as does the timely appearance of the wrong event'.

3.3.1.2 OEPs in a music context

In view of the likely key role of expectancy in music listening, a range of authors have examined OEPs using stimuli designed to tap into processes that may be evoked in musical listening. Besson and colleagues (Besson & Faita, 1995; Besson, Faita, & Requin, 1994; Besson & Macar, 1987; Weyerts et al., 1999) have examined responses to violations of listeners’ musical expectations by delaying presentation of the final note in familiar and unfamiliar musical sequences, and observed characteristic OEPs at the timing of when the final note was expected. Besson et al. have noted that the OEP observed following a delayed note presentation “clearly demonstrated that the rhythmic violation was inconsistent with the musical expectancy” (1997, p.12). Other music-based protocols have consistently demonstrated OEPs in response to delayed or omitted notes (Janata, 2001; Jongsma et al., 2005; Jongsma et al., 2004; Nittono et al., 2000). Furthermore, OEP responses observed 300-700 ms after expected note presentation are larger in amplitude for familiar than unfamiliar melodies, further emphasising the role of expectation in the generation of OEPs (Besson & Faita, 1995; Besson et al., 1994).

In contrast to the afore-mentioned authors, Janata (2001) has questioned the central role of expectation in generating the OEP. In a series of experiments, Janata presented participants with an eight-note musical sequence featuring equitemporal note presentations. On subsequent presentations of the sequence, only the first three or five notes of the original sequence were presented. In some experimental conditions, participants were given accurate information regarding the number of notes that would be omitted from the forthcoming sequence and were instructed to imagine the omitted notes and respond at the timing of the final note presentation. In other conditions, participants were given inaccurate information so that either more or less notes were presented than expected. Other conditions requested passive listening to the sequences. As hypothesised, OEPs were elicited in conditions where notes were unexpectedly omitted. However, OEPs were also observed when participants imagined the missing notes following accurate information regarding the number of notes that would be presented. Janata interpreted these findings as evidence that an OEP can be generated independently of the expectation that an event will actually occur, provided that listener attends to a sequence and forms a mental image of the missing auditory event. While this research suggests that event expectation is not required for the generation of an OEP, Janata draws attention to research suggesting similarities between imagery and expectation, and notes that it is possible that auditory imagery “may not be so different from the formation of auditory expectancy” (p.189). As such, while this finding provides impetus for further examination of the role of musical imagery in the generation of OEPs, the role of expectation in the generation of OEPs remains central in most conceptions of the OEP.

3.3.1.3 Attention

The OEP is sensitive to a number of task factors. The amplitude of OEPs has been shown to be sensitive to:

- omission probability - less frequent stimulus omission are associated with larger OEPs (Ruchkin et al., 1975);
- inter-onset interval (IOI) – generally, shorter ISIs are associated with larger amplitude OEPs than those elicited by longer time intervals (Busse & Woldorff, 2003; Raij et al., 1997);
- stimulus familiarity – more familiar sequence material has been associated with larger OEPs (Besson & Faita, 1995; Besson et al., 1997; Besson et al., 1994).

The OEP is also particularly sensitive to the degree and type of attention paid to the stimulus (Janata, 2001; Jongsma et al., 2005; Jongsma et al., 2004; Joutsiniemi & Hari, 1989; Karamürsel & Bullock, 2000; Picton, Woods, & Proulx, 1978a; Raij et al., 1997; Sutton et al., 1967). When subjects are instructed to ignore stimulus sequences, OEPs have been shown to be significantly weaker than when directing attention to the stimuli (Bullock, Karamürsel, Achimowicz, McClune, & Basar-Eroglu, 1994; Joutsiniemi & Hari, 1989; Raij et al., 1997). OEPs may also be modulated by attention effects intra-modally. For example, Sutton et al. (1967) demonstrated that OEPs were not elicited when subjects paid attention to the intensity of auditory stimuli, rather than their timing. Attention effects on OEP amplitude may also be dependent on stimulus presentation rate, so that at presentation rates greater than 6 Hz, attention to the stimuli may not be a necessary condition of eliciting an OEP (Bullock et al., 1994).

3.3.2 Localisation of OEP Generators

Omitted note potential localisation has been discussed in numerous scalp ERP studies. Tone omissions typically elicit a negative ERP potential with a latency of approximately 150- to 200 ms over frontal/vertex regions (Besson & Faita, 1995; Jongsma et al., 2005; Nittono et al., 2000; Raij et al., 1997), followed by a late positive potential with a latency of approximately 350- to 1000 ms reported over a range of frontal, vertex, and parietal regions (Besson & Faita, 1995; Ruchkin et al., 1981; Simson, Vaughan, &

Ritter, 1977; Simson et al., 1976; Sutton, Braren, Zubin, & John, 1965; Sutton et al., 1967). Localisation of OEP generators has been less often reported using magnetoencephalographic (MEG) and intercranial recording electrodes, both of which provide greater site specificity than scalp electroencephalogram (EEG) recordings. Using intercranial electrodes, Baudena et al.(1995) reported on data recorded in frontal lobe locations and described a strong N2a /P3a /SW response elicited by infrequent stimulus omissions. The locations in the frontal lobe where the N2a/P3a /SW responses were most clearly evoked were the inferior frontal gyrus pars triangularis and the anterior cingulate gyrus. Additional findings from this research were reported by Halgren et al. (1995) who noted an additional late parietal OEP response.

Posterior frontal lobe origins of the early component of the OEP response are further supported by results of several MEG studies demonstrating attention-sensitive components of the response in the posterolateral frontal cortex (Joutsiniemi & Hari, 1989; Raij et al., 1997). Mid-temporal areas also play a critical role in the response. Raij et al. (1997) reported MEG results finding that stimulus omissions produced largest deflections over the same cerebral regions as tones, and the magnetic field patterns evoked by omissions closely resembled those evoked by tones. Using a model based on N100m tone onset magnetic field patterns, Raij et al. (1997) found that while posterolateral frontal activation was commonly elicited by tone omissions, a combination of three sources – bilateral mid-temporal cortex, and right superior temporal sulcus – ‘adequately’ explained the magnetic field pattern model. Similarly, Weyerts et al. (1999) acquired ERP, MEG and fMRI responses to unexpected delays in note presentations in musical sequences and observed that while ERP responses to omitted notes indicated a frontocentral location for both small negative and large positive OEPs, MEG data and fMRI recordings identified similar sources of brain activity in bilateral primary and secondary auditory cortex.

3.3.3 Reconciling OEP Source Localisation Differences

To summarise findings concerning localisation of the OEP response, it appears that while ERP research suggests frontal regions underlie early components of the OEP response, MEG and fMRI methods suggest that sources underlying these early responses are localised to auditory cortex in the temporal lobes. Later OEP responses have been observed in frontal central and parietal regions. Contributions from both anterior and posterior cingulate gyri have also been observed. An early attempt to reconcile omission response findings suggested that both visual and auditory omissions evoke early modality-specific activity in the secondary sensory cortices, and later activity in the inferior parietal and frontal association areas (Simson et al., 1977).

Differences in observed generator locations may be partially due to differences in techniques used to examine the OEP response. For example, ERP and MEG techniques are differentially sensitive to tangentially vs. radially-oriented currents. Raij et al. (1997) suggested that the temporal/frontal sources found to underlie the MEG OEP potential are not necessarily directly related to sources found in ERP studies because of the differences in current orientation sensitivity between the techniques. These authors proposed that the ERP responses may receive major contributions from radially oriented currents which are silent in MEG recordings. Use of combined ERP, MEG and fMRI techniques in examining OEP responses by Weyerts et al. (1999) partially supports the current-based explanation of topographical differences observed in various studies, as frontocentral ERP responses were found to reflect bilateral primary and secondary auditory cortices source activity observed in MEG and fMRI data. However, other research using source analysis techniques has proposed frontal but not temporal lobe sources for OEPs (Tarkka & Stokic, 1998). As such, further clarification of frontal/temporal OEP generators is required.

While differences in the importance of frontal sources of the OEP response may be partially explained by current orientation, task demands may play a central role in determining whether late OEP responses are observed in frontal or parietal regions. Notably, activation tasks used for OEP research typically adopt designs where participants either respond to infrequent and unexpected stimulus omissions, or respond to other aspects of the stimulus sequence. These procedural differences may underlie patterns of observed OEP responses. Table 3.1 outlines OEP research where task instructions and localisation of the late positive component of the OEP are specifically discussed.

Table 3.1. **Summary of OEP research protocols.**

Authors	Task instructions	Late Positive OEP Localisation
(Busse & Woldorff, 2003)	Respond to deviant pitch (not omitted tone)	Frontal
(Baudena et al., 1995)	Respond to omitted tone	Frontal (note - only frontal sites assessed)
(Besson et al., 1994)	Recognise melody	Frontal, Vertex, Parietal maxima
(Besson & Macar, 1987)	Recognise melody	vertex, parietal, R.temporoparietal
(Karamürsel & Bullock, 2000)	Predict time of next click or count omissions	Vertex, Frontal
(Ruchkin et al., 1975)	Predict single or double click	Vertex (note - only vertex assessed)
(Nittono et al., 2000)	Rate congruity of endings	Vertex, parietal
(Joutsiniemi & Hari, 1989)	Count omissions	Frontal (note - only lateral frontal and lateral parietal sites assessed)
(Raij et al., 1997)	Count omissions	Mid-temporal
(Tarkka & Stokic, 1998)	Count omissions	Not assessed
(Jongsma et al., 2005)	Count 5 omitted beats	Parietal
(Jongsma et al., 2004)	Count omissions	Parietal
(Janata, 2001)	Mental imagery of omitted notes	Parietal
(Jocoy et al., 1998)	Respond to omitted tone	Parietal
(Besson & Faita, 1995)	Detect omitted note	Parietal maxima
(Simson et al., 1976)	Respond to omitted tone	Parietal

Notably, frontal localisation of the late positive OEP is less frequently observed than parietal localisation. While some overlap of anterior/posterior localisation with regard to task instructions is evident in research presented in Table 3.1, frontal/vertex localisation is most commonly associated with task instructions requiring attention to more holistic aspects of the sequence, whereas parietal localisation of the late positive OEP is most commonly associated with instructions requiring specific attention and response to the omitted tones. Also, OEP responses in frontal regions are often reported by research that has acquired responses from frontal or temporoparietal regions only. Thus, activity observed in these regions may be less strongly associated with OEPs in response to attended omissions than activity observed in vertex or parietal regions.

Observed differences in anterior-posterior localisation of the OEP late positive component in accordance with task instructions suggest that OEP late positive response localisation reflects the role of the omitted tone in different cognitive demands required of a task. Where task instructions require attention to more holistic aspects of the stimulus, the context within which omitted tones may be heard is equivalent to the rare deviant stimulus in an oddball task, whereby the omitted tone is presented as an unexpected deviant *non-target* requiring no response. Localisation observed in response to this context is predominantly in frontal regions. Alternatively, task instructions requiring attention to the omitted tone with no immediate response contextualise the omitted tone as an unexpected deviant *target* requiring no response. Other task instructions that require a response to detection of omitted tones contextualise the omitted tone as a rare deviant *target* which may or may not be expected and requires subsequent action. Localisation observed in response to this context is predominantly in parietal regions. As such, omitted stimuli appearing within these contexts may elicit different cognitive processes associated with these different contexts, and may be associated with the observed differences in anterior-posterior localisation. The following section will discuss cognitive processes proposed to subserve activation of anterior and posterior regions in rare stimulus conditions which parallel conditions impacting on OEP localisation.

3.3.4 Relationship of OEP to P3a/P3b Responses

The OEP has been demonstrated to be sufficiently sensitive to the same task factors as another late positive potential - the evoked P300 response - that is has been proposed that the OEP and P300 potential reflect the same processes (Besson et al., 1997; Jongsma et al., 2005; Ruchkin & Sutton, 1973; Sutton et al., 1967). The P300 component, labelled such in reference to its polarity and approximate latency following stimulus presentation, was initially described in 1965 (Sutton et al., 1965). Initial reports (eg. Klinke et al., 1968; Sutton et al., 1965; Sutton et al., 1967) emphasised the endogenous nature of the potential, i.e. a component of the human evoked potential which did not strictly reflect the physical parameters of the eliciting stimuli. Instead, the component appeared to reflect active cognitive processing of stimulus information on the part of the subject.

Squires, Squires, and Hillyard (1975) provided evidence that the P300 was not a unitary phenomenon, but was composed of at least two separate phenomenon. Squires et al. (1975) found an auditory P300 deflection related to attended stimuli (both targets and non-targets), and noted another, earlier onset P300 deflection specifically related to low-probability stimuli (both attended and ignored). Potentials elicited by attended stimuli had a parietal scalp distribution and were termed P3b, whereas low probability stimuli had a more anterior distribution – centroparietal in the rare target condition and centrofrontal in the ignore condition. These findings were subsequently replicated by Snyder and Hillyard (1976). Further clarification of distinctions between separate P300 phenomenon were displayed by a series of studies by Courchesne and colleagues (eg., Courchesne, 1978; Courchesne, Courchesne, & Hillyard, 1978; Courchesne, Hillyard, & Galambos, 1975). In these studies, a variety of unannounced complex novel stimuli were embedded within series of standards and targets. In each of these studies, a frontal or centrofrontal P300 component was observed in response to the novel stimulus (the "novels P3") while a parietal P300 was associated with the rare targets. The strong relationship of the P3a potential to stimulus novelty has led to the common usage of the term the ‘novelty P3 response’ in reference to the P3a (eg. Daffner et al., 2000; Tsuchiya, Yamaguchi, & Kobayashi, 2000). It is generally accepted that the principal factors responsible for P3a elicitation are stimulus novelty in low-attention, task-irrelevant conditions which result in the automatic dedication of additional attention-related resources to the event (Escera et al., 2000; Halgren, Marinkovic, & Chauvel, 1998; Kiehl et al., 2005).

3.3.4.1 P3a overview

The P3a response is commonly preceded by the N2a (MMN) response, and the MMN-P3a response is considered to be involuntary, automatic and regarded as an ERP sign of attention switching (K. C. Squires et al., 1975). This proposal is supported by findings showing increased reaction times to target stimuli immediately following irrelevant novel sounds that elicit a P3a response (Berti, Roeber, & Schröger, 2004; Grillon, Courchesne, Ameli, Geyer, & Braff, 1990; Woods, 1992). As such, increased reaction times following the P3a suggest an attention switch to the novel sounds has occurred and attentional reorientation to the relevant target stimuli is required prior to response. The MMN-P3a has also been associated with the orienting response to novel stimuli (Alho et al., 1998; Baudena et al., 1995; Daffner et al., 2000; Daffner et al., 1998; Halgren et al., 1995; Ritter, Vaughan Jr., & Costa, 1968) and has been proposed to represent the cortical component of the OR (K. C. Squires et al., 1975). However, the ERP complex and the autonomic OR have been dissociated on the basis of differences in reactions to repetition or changes in stimuli task relevance (Näätänen & Gaillard, 1983; Roth, Dorato, & Kopell, 1984), and are consequently considered to be different parts of an overall orienting complex evoked by stimuli which require further evaluation (Donchin et al., 1984; Roth, 1983).

3.3.4.2 P3b overview

While the P3a occurs in conditions requiring no attention to the P300-eliciting stimulus, the P3b response "is exquisitely sensitive to the attentional demands of the task" (McCarthy, Luby, Gore, & Goldman-Rakic, 1997 p.1630) with higher task attention reflected by a P3b amplitude increase and latency decrease (for review see R. Johnson, Jr., 1988). The response is generally elicited in response to low-probability target stimuli in high attention task conditions , although it may also be elicited in response to low-probability non-target stimuli during high attention task conditions (eg. R. Johnson, Jr., 1984; Rappaport, Clifford, & Winterfield, 1990; N. K. Squires et al., 1975). Task factors in addition to attention which have been demonstrated to modulate either amplitude or latency of the P3b response are:

- expectancy – P3b amplitude correlates inversely with a subject's expectancy of the stimulus (Donchin & Coles, 1988; R. Johnson, Jr., 1986; K. C. Squires, Wickens, Squires, & Donchin, 1976);
- discrimination difficulty - more discriminable targets elicit shorter P3b latency and greater P3b amplitude (Comerchero & Polich, 1999; Donchin, 1979; N. K. Squires, Donchin, Squires, & Grossberg, 1977);

- category membership - P3b latency varies with the time required to identify the category to which an individual stimulus belongs (Donchin & Coles, 1988; Janata, 1995; Kutas, McCarthy, & Donchin, 1977).

Additionally, a number of studies have noted the degree to which the amplitude of P3b responses reflects the delivery of information by the stimulus. The amplitude of P300 invoked by task relevant stimuli is not solely a function of the information carried by the stimuli; that information must actually be used by a subject (R. Johnson, Jr. & Donchin, 1978; Stuss & Picton, 1978). Stuss and Picton (1978), for example, discovered that in a task in which feedback on task performance initially provided valuable information to subjects, P300 invoked by the feedback progressively decreased in amplitude as subjects mastered the task. Johnston (1984) has proposed a model in which P300 amplitude is determined by "the additive effect of subjective probability and task-information".

The contemporary view of the P3b response is that the response reflects the establishment of a connection between posterior association cortex, temporal and temporoparietal regions critical for initiation of memory mechanisms (Calhoun, Adali, Pearlson, & Kiehl, 2006; Knight, 1994; Polich, 2003). The P3b is proposed to follow stimulus evaluation when an updating of the mental model of the current stimulus environment is required. Elicitation of the P3b is based on the contents of a transient memory buffer and its appearance may reflect the updating of working memory (Donchin & Coles, 1988).

In musical contexts, the association between P3b responses and the updating of working memory has been examined by comparing ERP responses of normal individuals with subjects possessing absolute pitch ability. Absolute pitch, or 'perfect pitch' is most simply defined as long-term memory for pitch (Hantz, Crummer, Wayman, Walton, & Frisina, 1992). Individuals demonstrating this ability may name pitches without the use of a reference pitch, or produce a given pitch on request. According to the viewpoint of the P3 potential as a signature of the updating of working memory, if pitch task demands require comparison of pitches presented in sequence, subjects without AP ability should demonstrate P3 responses during pitch comparison phases of the task due to the updating of working memory representations, whereas AP subjects with a reference to long-term pitch representations would not need to update working memory, and subsequently not demonstrate a P3 response. Results have generally supported this contention. Typically, normal subjects successfully performing pitch discrimination tasks demonstrate P3b responses during pitch comparisons, whereas AP subjects demonstrate smaller P3b responses (Klein, Coles, & Donchin, 1984; Wayman, Frisina, Walton, Hantz, & Crummer, 1992); absent P3b responses (Hantz et al., 1992); or different topography to normal subjects (Hantz, Kreilick, Marvin, & Chapman, 1997). Further confirmation of the attenuated P3b amplitude in AP subjects being due to specific pitch-memory ability was provided by Klein et al. (1984). While AP subjects in that study demonstrated smaller P3b responses than normals in response to the auditory oddball task, responses of AP subjects to a visual oddball task elicited similar amplitude P3b responses to normal subjects, demonstrating the dependence of the attenuated P3b auditory potential on specific pitch memory ability rather than a memory-independent process. In conclusion, P3 studies implementing AP subjects have provided further evidence for proposals for the P3b as a reflection of processes involving the updating of working memory.

3.3.4.3 Link between OEP and P3 responses.

Notably, factors shown to modulate P3b amplitude and latency share strong parallels with those factors demonstrated to influence amplitude of the late positive OEP response. The amplitude of both evoked P3b and OEP have been demonstrated to be inversely correlated with stimulus probability (Jenks, 2002; Ruchkin et al., 1975); sensitive to the degree and type of attention paid to the stimulus (Picton et al., 1978a; Raij et al., 1997; Sutton et al., 1967); and the amount of information delivered by the stimulus (Klinke et al., 1968; Ruchkin & Sutton, 1973; Sutton et al., 1967).

Topography of both P300 and OEP responses are also influenced by similar task conditions. Rare or unexpected non-target auditory events elicit P3a responses in frontal/vertex areas whereas event omissions under similar task conditions also elicit OEP responses in these regions. Similarly, high attention conditions demanding attention to rare auditory targets (either actual or omitted) have most often been associated with positive parietal responses for both P3b and OEP responses. In view of these factors, early research examining the OEP response considered P300 and OEP responses as manifestations of the same phenomenon, supported by research demonstrating that absence of a stimulus resulted in a P300 only when that absence delivered information to the subject. The absence of the same stimulus when that absence delivered no information did not elicit an omission response (Klinke et al., 1968; Ruchkin & Sutton, 1973; Sutton et al., 1967). As such, omission responses were demonstrated to be equally sensitive as the P300 response to the extent that event information is used by the subject, and was taken as further evidence of the unitary nature of P300 and OEP responses. In musical contexts, late positive OEP components demonstrate similar morphology to positive potentials observed in response to incongruous notes in musical phrases (Besson and Macar, 1987; Paller et al 1992; Verlager, 1990) which have previously been discussed in terms of late positive component or P300 responses. As such, late positive OEP responses may reflect aspects of processes in common with those underlying violation of expectation in a range of musical and non-musical contexts.

Despite the similarities between P300 and OEP responses, some doubt has been cast on the unitary nature of the responses due to differences in amplitude and latency features of the two potentials. OEP responses demonstrate lower amplitude and longer duration response than evoked P300 potentials (Jocoy et al., 1998; Ruchkin & Sutton, 1979), suggesting the possibility of differences in underlying processes. Alternatively, temporal uncertainty is greater in the OEP response than in the P300, as OEP timing reflects the individual's sense of time judgment, whereas evoked P300 responses are typically elicited in response to the timing of an external event (Jocoy et al., 1998). In support of this proposal, rhythmic experts demonstrate less OEP latency jitter compared with non-musicians (Jongsma et al., 2004). As such, lower amplitude OEP responses may reflect greater jitter in timing of individual OEP responses (Ruchkin & Sutton, 1979; Ruchkin et al., 1981), whereas increased latency of the OEP may reflect the temporal uncertainty of the conditions underlying the OEP response (Jocoy et al., 1998). In view of these factors, the consensus is that P3 and OEP responses are indeed manifestations of the same response (Besson et al., 1997; Jongsma et al., 2005; Ruchkin & Sutton, 1973; Sutton et al., 1967). For example, Jongsma et al. (2005) termed an omission-evoked ERP response the OEP P300, and Besson et al. (1997) concluded that the evoked P300 and the late positive OEP are “one and the same physiological process, reflecting the same cognitive operations” (p.5).

3.3.5 Cognitive Processes Underlying the OEP Response

The OEP response and MMN responses to temporal change play a significant role in enhancing our understanding of how auditory sequences are processed by the brain. The responses demonstrate that a regular temporal sequence elicits the development of internal expectations of the timing of future stimuli, thus demonstrating the brains’ ability to model the temporal input pattern. When stimulus timing expectations based on the internal model are not met, a response which is tightly time-locked to the expected stimulus occurrence is produced signalling the deviation from the predicted event. The OEP response has been proposed to reflect the action of the same cognitive processes as those underlying P300 responses, in particular, the P3b response. That is, the violation of the temporal expectation initiates a process which involves the updating of the temporal model established by the context prior to the deviant event. Hughes et al. (2001) discussed the processes required to detect temporal change from an established pattern in a sequence of temporally discrete events. Hughes noted that detection of change in discrete events requires generation of a neural representation of the event that can span the temporal interval between the events and also store information used to generate probabilities of occurrence of future events, which form the basis of expectations. The evaluation of a current event in the context of the recent past would then employ mechanisms that are sensitive to differences between stored representations and the current event. The process by which the stored representation or model of the recent auditory past is updated with the current context has been proposed to involve the establishment of cortical connections between those brain regions which support monitoring and processing of the current environment – temporal and parietal regions, with those that support the working memory representations of the recent environment – temporal, hippocampal and dorsolateral prefrontal cortex regions.

Neuroimaging studies have repeatedly demonstrated a key role for the dorsolateral prefrontal cortex in maintenance of verbal and non-verbal working memory traces (e.g. Barch et al., 1997; Braver et al., 1997; reviewed in Hillary, Genova, Chiaravalloti, Rypma, & DeLuca, 2006; Rypma & D'Esposito, 1999). In musical contexts, neuroimaging methodologies have demonstrated the involvement of temporal and frontal cortices in working memory traces for melodic information. For example, Zatorre et al. (1994) examined cerebral blood flow (CBF) changes in response to different aspects of a melodic pitch memory task and demonstrated right superior temporal cortex participation in perceptual analysis of melodies; additional right prefrontal cortex contributions in pitch comparison, and an interaction between right temporal and frontal cortices for the active retention of pitch. These findings are well supported by neuropsychological literature examining musical function within temporal regions (eg. Liegeois-Chauvel, Peretz, Babai, Laguitton, & Chauvel, 1998; Samson & Zatorre, 1992; Zatorre, 1985), and frontal regions (Samson & Zatorre, 1988; Zatorre & Samson, 1991); documentation of extensive reciprocal projections between dorsolateral prefrontal cortex and primary and secondary auditory cortex (Alexander, Newman, & Symmes, 1976; Pandya & Yeterian, 1990); and further evidence of functional interactions between temporal and frontal cortices in working memory for pitch (Azou et al., 1995), chords (Mazziotta, Phelps, Carson, & Kuhl, 1982), and visual working memory (Sarnthein, Petsche, Rappelsberger, Shaw, & Von Stein, 1998). As such, substantial evidence supports the involvement of a frontal-temporal network in the maintenance and updating of musical working memory.

Neuroimaging research findings also demonstrate an important role for the dorsolateral prefrontal cortex in the temporal organisation of cognition (Knight & Grabowecky, 1996; Petrides, 1991; Pribham & Tubbs, 1967). Original proposals of a role for this area in the organization of event series followed evidence of deficits in temporal chunking following dorsolateral prefrontal cortex lesions (Pribham & Tubbs, 1967). It has been proposed that one role of the dorsolateral prefrontal cortex involves the inhibition of primary auditory cortex. This is supported by findings that damage to this area in humans results in disinhibition of early onset primary cortical evoked potentials (Chao & Knight, 1996) and deficits in detection of novel events (Knight, Scabini, & Woods, 1989). Knight and Grabowecky discussed the prefrontal patient’s inability to maintain a temporal stream, and suggested that the combination of the novelty detection process, coupled with the gating of sensory input, is intimately connected with the coding of the beginning and end of events (1996). Thus, it may be hypothesised that the dorsolateral prefrontal cortex plays a role in the temporal organisation of auditory event series.

The following section will discuss research which examines how processes which detect changes in the auditory environment may be used within the higher process of language and music perception.

3.4 The Closure Positive Shift Potential

Research demonstrating OEP and MMN responses to temporal change in the auditory environment reflect processing of events that vary from an established temporal standard. These changed events elicit characteristic responses in view of their potential importance in delivering new information. Lengthened auditory events may also elicit characteristic ERP responses in language processing when the lengthening of the event acts as a prosodic cue, that is, if the lengthening of the event serves as a cue to determine segmentation or saliency. Lengthened-duration syllables and pauses between words may act as cues to phrase boundaries, and may also reinforce or disambiguate syntactically-determined phrase structure (Beach, 1991; Steinhauer & Friederici, 2001). ERP research examining prosodic markers during syntactic processing has demonstrated that phrase boundaries in spoken language processing may be marked by a positive ERP shift with a centroparietal distribution and duration of several hundred milliseconds (Steinhauer, Alter, & Friederici, 1999). This response has been termed the closure positive shift (CPS), and was initially proposed to reflect the closing of the prior phrase (Steinhauer et al., 1999). Subsequent language research has demonstrated the CPS in response to duration-based prosodic cues (Steinhauer & Friederici, 2001), and notably, CPS responses were observed in response to pauses within ‘sentence melodies’ – speech filtered to remove all lexical cues (Steinhauer & Friederici, 2001, experiment 3). The CPS does not occur in response to all prosodic boundaries during speech perception, however. In one experiment, the CPS was not influenced by the presence or absence of a pause at the prosodic boundary (Steinhauer et al., 1999, experiment 3), and in view of research demonstrating CSP responses as a result of closure processes at non-prosodic boundaries (Hruska & Alter, 2004), the CPS has been proposed to represent closure processes that can occur as a result of the perception of phrase boundaries, rather than a response to the perception of the phrase boundary itself (Knösche et al., 2005).

Knösche, Neuhaus, Haueisen et al. (2005) examined the extent that duration-based phrase cues elicit CPS responses in music listening by trained musicians. ERP responses to musical sequences featuring pause-cued phrases were compared to ERP responses to the same sequences without pauses. A significant broadly distributed CPS response was elicited in sequences where pauses cued phrase structure compared to unphrased versions of the same sequences. EEG analysis demonstrated the CPS response at central and centroparietal electrodes peaking at approximately 550 ms after the offset of the phrase boundary. The observed EEG activations were associated with activation of posterior cingulate cortex, retrosplenial cortex, and the posterior part of the left hippocampus – the amplitude and topography noted to be similar to CPS responses observed in language research. Simultaneously-acquired MEG responses were associated with generators in right posterior hippocampus, the anterior cingulate, and the subcallosal region. Based on the similarities in paradigm, amplitude and topology, the authors concluded that the positive EEG responses associated with the phrase boundaries could be interpreted as the music equivalent of the language CPS – the 'music CPS'. In view of the timing of the CPS response and previous language research demonstrating a role for the CPS in closure, the authors conclude that CPS effects observed in this research do not directly reflect the detection of the phrase boundary, and rather reflect the activation of memory and attention-related processes involved in integrative processing of the phrase boundary. Prior to this timing, additional effect of the phrase boundary were observed in enhanced P200 responses to phrased versus unphrased sequence versions. The authors note that while enhanced P200 response may have reflected recovery of neuronal populations after the pause (a commonly observed N1-P2 effect), they suggest that this enhanced response may also reflect the action of higher order feature extraction necessary for the recognition of boundary between two phrases.

Taken together, language and music research paradigms examining the CPS response demonstrate that while the CPS may occur in response to stimulus conditions that initiate the perception of phrase boundaries, the CPS response may also occur in other contexts which do not represent boundaries of phrases. In common across all CPS paradigms, however, is the finding that the CPS is elicited in auditory sequences where specific cues trigger a process that acts to achieve information processing closure. This closure process required the integration of recently presented information in order to enable ongoing sequential processing. Within this context, demonstration of the CPS response in response to musical phrase boundaries has been interpreted in terms of a process that follows the detection of a boundary and results in the activation of memory and attention processes necessary for the transition of one phrase to the next (Knösche et al., 2005). As such, the CPS is an example of a process which may form one component of the wider system which detects group boundaries and implements this information within a higher information processing context.

3.5 Summarising ERP Responses

Literature presented in this chapter has discussed two ERP responses: the MMN and OEP, that serve to trigger the activation of higher processing in response to the detection of change in auditory temporal structure, and another ERP response: the CPS, which occurs in response to processing closure and may occur in response to perception of phrase boundaries.

This literature indicates that activation of higher processes may occur in response to temporal conditions that cue segmentational grouping processes discussed in Chapter 2. Relatively longer temporal intervals may elicit characteristic electrophysiological responses (MMN, OEP, or CPS depending on the stimulus conditions), and in parallel may drive segmentational grouping processes. As such, the relationship between the MMN, OEP and CPS responses and segmentational grouping warrants consideration. Research discussed in this chapter indicates that the range of temporal conditions demonstrated to elicit these ERP responses is broader than those eliciting segmentational grouping responses, and in view of this, MMN, OEP and CPS responses may occur in the absence of segmentational grouping. Not withstanding this observation, co-occurrence of electrophysiological markers of temporal change and segmentational grouping responses would suggest that these responses participate in a system that responds to the detection of change in the auditory environment.

Whereas lengthened auditory events may evoke ERP responses associated with temporal variation, *sustained* auditory events have been demonstrated to evoke characteristic slow ERP responses associated with processing of the sustained portion of the event. A negative-going ERP, the ‘sustained potential’, with a latency of approximately 150 ms following onset of the tone has been demonstrated in association with tone bursts of 600 ms or greater duration (Hari, Sams, & Järvilehto, 1979; Järvilehto, Hari, & Sams, 1978; Picton et al., 1978a; Picton, Woods, & Proulx, 1978b). Sustained potential demonstrate an ongoing negativity throughout the duration of a sustained stimulus of up to 10 seconds (Picton et al., 1978b), with maxima at central electrodes. The amplitude of sustained potentials is influenced by the effects of attention and expectancy, so that attention to the duration of the tone produces an enhanced negativity of the response at frontal and central electrodes (Picton et al., 1978a), whereas greater expectancy for a sustained tone has been associated with a reduced sustained potential for the first tone in a series, and an enhanced sustained potential for subsequent tone in a series (Hari et al., 1979).

Another ERP response that may be associated with sustained auditory events is the contingent negative variation (CNV), a slowly developing ERP response reflecting an anticipatory response to an expected stimulus (Walter, Cooper, Aldridge, McCallum, & Winter, 1964). The CNV is maximal at central electrodes and has been associated with sustained auditory events when incorporated within stimulus trains, and in this scenario has been proposed to represent subjective uncertainty about the timing of stimulus offset of a sustained auditory event (Järvilehto et al., 1978). Crucially, acquisition of CNV or sustained potentials requires EEG amplifier filter settings that allow acquisition of responses varying on a slow time-scale and is best conducted using DC-coupled EEG amplification, whereas standard EEG or ERP methods require use of low cut filter settings that limit DC drift, and as a result, these filter settings limit assessment of slow ERP responses (Regan, 1989).

3.6 Localisation of Structural Integration

Research discussed in Chapter 2 demonstrated that segmentational grouping processes provide a mechanism for the structuring of perception, memory and performance of musical sequences. Literature presented in this chapter has considered candidate processes that may support the segmentational grouping process from a temporal perspective. That is, processes have been discussed that may be elicited in temporal conditions understood to cue segmentational grouping processes. This section will now discuss neuroimaging research that seeks to understand the role of various brain structures in supporting the structuring of auditory information in musical and non-musical contexts. Research discussed in this section will approach this issue from the perspective of research examining music listening as an integrated task and provide additional context for discussing the cognitive processes and brain regions supporting segmentational grouping in musical contexts.

3.6.1 Structure

Musical structure manifests itself in the way that musical elements are grouped over time (Bent & Drabkin, 1987), and while segmentational grouping supports aspects of this musical structure, the concept of structure as a whole pertains to systems encompassing a range of musical components (Pomerantz & Lockhead, 1991). In view of this, investigations of musical structure have incorporated a range of musical attributes as a basis for structural investigations. In particular, ERP examinations of music structure have focused on identifying brain regions activated by violations of musical syntax established by harmonic contexts. Typically in this research, chord sequences are presented in order to generate harmonic expectations that are either fulfilled or violated by a subsequent chord. As processing harmony depends on implicitly acquired structural knowledge of the music (Besson, 1998), use of this implicit knowledge is equated with musical syntax in the same way that language processing draws on an implicitly acquired knowledge of grammatical structuring (Lerdahl & Jackendoff, 1983; Patel, Gibson, Ratner, Besson, & Holcomb, 1998; Sloboda, 1986; 2003).

Violations of musical syntax elicited via this approach elicit a number of characteristic ERP responses. A late positive ERP component occurring approximately 600 ms after a harmonic incongruity, the P600, has been linked with integration of structural information (Patel, Gibson et al., 1998). This response has been observed for both chord and melodic violations of expectation, and demonstrates a parietal maxima (Besson & Faita, 1995; Besson et al., 1994; Koelsch, Gunter, Friederici, & Schroeger, 2000; Patel, Gibson et al., 1998; Regnault, Bigand, & Besson, 2001). Notably, research comparing ERP activation elicited by syntactic violations in language and music has demonstrated statistically indistinguishable P600 responses in both conditions, suggesting potential commonalities between neural structures supporting syntactic processing of language and music (Patel, Gibson et al., 1998).

Earlier, negative ERP responses have also been observed in response to harmonic violations. These earlier responses occur around 150- to 350-ms after an unexpected harmonic event, predominantly over anterior temporal or frontal regions and are typically lateralised to the right hemisphere. These responses, termed the right anterior temporal negativity (RATN) (Patel, Gibson et al., 1998) and early right anterior negativity (ERAN) (Koelsch et al., 2000) have been taken to reflect the application of music syntactic rules. Using MEG, the magnetic equivalent of the ERAN, the mERAN, has been shown to result from bilateral frontal lobe generators in Broca's area and its right hemisphere homologue (Maess, Koelsch, Gunter, & Friederici, 2001). Processing of syntactic incongruities in language processing has been noted to elicit a characteristic early negative ERP response over left inferior frontal regions around Broca's area (Friederici, 1995; Friederici, Meyer, & van Cramon, 2000) and this early left anterior negativity (ELAN), occurs at a similar timing to the musical ERAN response observed in the right hemisphere homologue to Broca's area. In view of the critical role in syntactic processing of language played by Broca's area, findings of Broca's activation in music syntactic processing provides impetus for suggestions of a broader role for Broca's area in syntactic processing beyond merely processing of syntax in language.

Koelsch (2002) noted activation of Broca's area in fMRI responses to both harmonic and timbral changes – suggesting that syntax processing was too narrow a definition of the processing subserved by Broca's area. Further support for a broadening of the definition of the role played by the bilateral inferior frontal regions in language and music is provided by data suggesting that these regions are not only sensitive to harmonic violations reflecting syntactical processing, but also to other types of violations such as violations of sensory consonance (Regnault et al., 2001; Tillmann et al., 2003). Koelsch (2002) discusses activation of Broca's and also Wernicke's area in oddball musical contexts as processing of a deviant event within a rule-based musical context, and this interpretation is supported by data suggesting that early inferior frontal activation reflects integration of deviant acoustical events within a temporal structure whereas later frontal and posterior responses reflect rule-based structural processing (Regnault et al., 2001; Tillmann et al., 2003).

Patel and colleagues (Patel, 2003; Patel, Iversen, & Hagoort, 2004) provide an explicit hypothesis regarding the role of frontal regions in structural integration. Patel hypothesised that the functional role played by frontal brain regions linked with language processing is to support the processing of syntactical operations in multiple domains. The 'shared syntactic integration resource hypothesis' proposes that both language and music require structural integration as a key part of syntactic processing. According to this hypothesis, syntactic processing depends on coordination of brain regions that provide syntactic representations – 'representation regions', with 'processing regions' that provide the resources for the integration of syntactic information. Patel proposes that frontal regions provide the required resources to support the structural integration of syntactic representations residing in temporal or parietal regions. By this approach, Broca's aphasics (i.e. individuals demonstrating syntactic comprehension deficits following damage to Broca's area) would be expected to demonstrate deficits in harmonic syntactic processing in addition to language syntactic comprehension deficits. In support of this hypothesis, Patel et al. (2006) demonstrated deficits in processing of musical syntactic information in Broca's aphasics compared to performance of matched controls. Importantly, performance in the music task was a significant predictor of performance in a syntactic linguistic task, but not a semantic linguistic task, indicating that left hemisphere language circuits provide resources that contribute towards musical syntactical processing as well as those contributing to language processing.

In order to investigate brain regions supporting processing of temporal structure without activating additional processing resulting to violation of structure, Levitin and Menon (Levitin & Menon, 2003, 2005) adopted a task that presented listeners with scrambled and non-scrambled musical segments. Scrambled music was constructed by randomly reordering 250- to 350-ms fragments of musical segments in order to disrupt musical attributes that manifest over time such as musical contour, movement through tonal and key spaces, and any rhythmic groupings lasting longer than 350 ms. As such, musical examples used in both standard and scrambled conditions retained the same pitch distribution, loudness profile, and timbre/spectral distribution. Scrambled version of the music, however, lacked temporal structure provided by those musical aspects that operate over time-scales greater than 350 ms. Standard versions of the music elicited significant bilateral fMRI activation in the pars orbitalis regions of inferior frontal cortex (BA 47) and adjoining anterior insula cortex (right greater than left) compared to scrambled musical versions. In view of data obtained in this study and previous result implicating inferior frontal and insula regions in integration of musical (Koelsch et al., 2002; Maess et al., 2001; Tillmann et al., 2003) and non-musical information (Friederici et al., 2000; Meyer, Friederici, & von Cramon, 2000), Levitin and Menon propose that the pars orbitalis region of inferior frontal cortex comprises a structure tracker, and in combination with the anterior insula constitutes a "modality-independent brain area that organizes structural units in the perceptual stream to create larger, meaningful representation. That is, they may be part of a neural network for perceptual organization, obeying the rules of how objects in the distal world "go together" when they are manifested as patterns unfolding in a structured way over time" (2005, p.572).

Notably, hemispheric distinctions observed between rhythm and metre processing suggest a relative left hemisphere dominance for temporal organisation of time intervals (Di Pietro et al., 2004; Fries & Swihart, 1990; Mavlov, 1980; Wilson et al., 2002). Substantial evidence from lesion research supports a key role for the left hemisphere in this process (Di Pietro et al., 2004; Efron, 1963; Mavlov, 1980; Prior et al., 1990; Robin et al., 1990; Swisher & Hirsh, 1972; Vignolo, 2003), and early findings of a relationship between the impaired ability to indicate the number of tones in a series and receptive language aphasia (Horenstein, LeZak, & Pitts, 1966) led to the proposal that the left hemisphere is involved in the perceptual integration of events in time (Efron, 1963; Swisher & Hirsh, 1972). In view of these findings, left hemisphere regions involved in temporal organisation may play a role in the structural integration of sequential musical information.

3.6.2 Structural Integration Summary

ERP, MEG and fMRI research examining the processing of musical structure point to consistent involvement of frontal lobe regions, particularly the inferior frontal lobe and neighbouring insular cortex, and parietal regions in supporting the processing of sequential auditory information in order to organise structural aspects into meaningful wholes. Additional involvement by more posterior regions including Wernicke's area is also indicated by this research. A contemporary view of the role of these regions, previously understood to participate in processing of structural aspects of only language, now encompasses structural processing of a range of auditory tasks including aspects of musical processing. This structural processing includes processes supporting processing of syntax in both language and music, but also applies to a broader range of processes that involve the integration of incoming information with expectations developed in response to recently presented information. This integration process acts to update the ongoing model of the auditory environment in order to maintain a contextually relevant model of current experience, and optimise the basis by which expectations of future events are determined. Among other implications of this process, this updating process involves organisation of structural units into larger meaningful wholes.

As reviewed in this chapter, a range of characteristic electrophysiological responses have been observed in association with cognitive processes supporting the updating of the model of the auditory environment, and these responses indicate participation of temporal, parietal and frontal regions in this updating process in response to events initiating perception of structural endings, and following events indicating structural beginnings.

Structural aspects of musical experience that appear to be processed by these frontal, temporal and parietal regions includes suprasegmental organisational processes, including those governed by rule-based knowledge, and also those driven in a bottom-up fashion by cues determined directly from the auditory surface which provide prosodic information (such as rhythmically determined phrase boundary cues). As such, investigation of relationships between the organisational processes underlying segmentational grouping of auditory sequences discussed in Chapter 2, and processes conducted by the brain regions outlined in this chapter, may further clarify regional neural contributions towards the rhythmic grouping process.

The following chapter provides a review of Steady-State Probe Topography, an electrophysiological technique which provides a suitable approach for the examination of regional brain contributions towards rhythmic grouping processes.

Chapter 4 STEADY-STATE PROBE TOPOGRAPHY

4.1 Introduction

Various brain imaging techniques are available to investigate cortical activity, each with their own inherent benefits and drawbacks. Studies which seek to investigate changes in cortical activity in response to musical factors have specific requirements which negate the use of many imaging techniques. These requirements include a need to capture cortical activity changes in small temporal intervals, without producing training effects due to multiple stimulus repetitions. Functional magnetic resonance imaging (fMRI), while able to accurately localise activity, suffers the limitation of a supra-second temporal resolution (McCarthy et al., 1997). The temporal resolution of event-related potential (ERP) techniques, on the other hand, is in the range of milliseconds, yet hundreds of stimulus repetitions may be necessary to obtain adequate signal-to-noise ratios (Regan, 1989). A relatively recent imaging technique - the steady-state probe topography technique (SSPT) utilises the steady-state visually evoked potential (SSVEP) and possesses the temporal resolution necessary to examine changes in cortical activity occurring on a sub-second scale without the number of repeated measures necessary as when employing ordinary evoked potential techniques (Silberstein, 1995b). The SSPT utilises a probe-ERP paradigm in conjunction with stimulus conditions that elicit a steady-state ERP response. Each of these aspects of the SSPT methodology will be discussed in the following section.

4.2 Probe-ERP Paradigm

The probe paradigm, initially implemented in an ERP design by Galin and Ellis (1975), examines changes in ERP responses to task-irrelevant ‘probe’ stimuli presented in association with performance of a cognitive task. Variations in ERP responses to the task-irrelevant stimulus are assumed to reflect variations in neuronal activation associated with performance of the concurrent task (Papanicolaou & Johnstone, 1984), and are interpreted within a context of a ‘limited resource’ model. By this approach, brain regions are assumed to possess a limited processing capacity, so that allocation of processing resources to a given task may result in the reduction of processing resources devoted to another simultaneous task. In this manner, cognitive task-related performance is assumed to result in the attenuation of an ERP signal in response to a simultaneously presented task-irrelevant probe (Papanicolaou et al., 1987). Support for this proposal is indicated by increases in regional cerebral blood flow accompanied by a reduction in probe-ERP amplitude (Papanicolaou et al., 1987; Papanicolaou & Johnstone, 1984).

Early probe-ERP research demonstrated cognitive task-related probe-ERP asymmetries in conjunction with visual probe stimuli (Galin & Ellis, 1975) and auditory probe stimuli (Shucard, Shucard, & Thomas, 1977). Subsequent research has examined probe-ERP responses to performance of a wide range of cognitive and emotional tasks including research examining visual attention differences amongst children with and without attention-deficit hyperactivity disorder (Jonkman et al., 2000), differences in reading task performance amongst dyslexic and non-dyslexic children (Johnstone et al., 1984), language processing (Papanicolaou, 1980), mental rotation (Papanicolaou et al., 1987), face recognition (Everhart, Shucard, Quatrin, & Shucard, 2004), and viewing of affective images (Cuthbert, Schupp, Bradley, McManis, & Lang, 1998). A comprehensive review of the theoretical considerations and experimental applications of the probe-ERP method is provided in Papanicolaou and Johnstone (1984). Steady-state probe topography utilises the probe-ERP approach in conjunction with a visual stimulus presented at rate sufficient to generate a steady-state ERP response. The following section discusses implementation of steady-state responses within a probe-ERP paradigm.

4.3 Steady-State Probe Topography (SSPT)

A rapid change in a sensory stimulus elicits a transient evoked potential (EP). If this stimulus is repeated rapidly enough to prevent the evoked potential returning to baseline the elicited response is termed a steady-state evoked potential (Regan, 1989). Regan (1989) noted that the steady-state evoked potential elicited by a repeated stimulus can be described as the sum of sinusoidal components at the stimulus frequency and its harmonics, and as a result, any specific harmonic of the steady-state evoked potential can be determined when the amplitude and phase difference between the stimulus and response are known. This occurs via a process termed *coherent demodulation* (Regan, 1989) which determines the Fourier coefficients of the EEG signal at the stimulus frequency via a process equivalent to narrow band-pass filtering at the stimulus frequency. The resulting analysis determines the magnitude of the steady-state evoked potential response at the stimulus frequency, and the latency of the steady-state evoked potential response with respect to the stimulus waveform. As task-irrelevant stimulus presentation and EEG acquisition via this paradigm are ongoing during task performance, the analysis process may determine steady-state evoked potential amplitude and latency values for each cycle of the sinusoidal stimulus resulting in the production of amplitude and latency *time series* with sufficiently fine-grained temporal resolution to determine responses occurring on a sub-second time scale (Linden, Picton, Hamel, & Campbell, 1987). Steady-state evoked potentials have been generated in response to auditory stimuli (Galambos, 1982; Galambos & Makeig, 1985, 1988; Karamürsel & Bullock, 2000; Linden et al., 1987; Makeig & Galambos, 1989; Pantev et al., 1993; Patel & Balaban, 2000; Rohrbaugh, Varner, Paige, Eckardt, & Ellingson, 1990), somatosensory stimuli (Galambos, 1982; Giabbiconi, Dancer, Zopf, Gruber, & Muller, 2004; Muller, Neuper, & Pfurtscheller, 2001), and visual stimuli (Belmonte, 1996; Herrmann, 2001; Klemm, Gibbons, Allen, & Harrison, 1982; Mast & Victor, 1991; Regan, 1966, 1977). Additionally, use of visual steady-state stimuli to generate the steady-state visually evoked potential (SSVEP) response has been extensively examined by Silberstein and colleagues (eg. Kemp, Silberstein, Armstrong, & Nathan, 2004; Silberstein, Cadusch, Nield, Pipingas, & Simpson, 1996; Silberstein, Ciorciari, & Pipingas, 1995; Silberstein, Nunez, Pipingas, Harris, & Danieli, 2001; Silberstein et al., 1990). Silberstein's technique, Steady-state Probe Topography (SSPT) employs electrode montages that acquire EEG responses over 64 or more sites, and as a result, topographic representations of task-related SSVEP amplitude and phase responses may be constructed, and plotted over multiple time-series points in order to provide a dynamic representation of task-related changes in cerebral activation.

4.3.1 SSVEP Temporal Resolution and Signal-to-Noise Ratio

Fourier coefficients may be calculated for each cycle of the steady-state stimulus, enabling an upper limit of the temporal resolution of the steady-state response at the period of the sinusoidal stimulus. For example, the SSVEP resulting from a 13 Hz stimulus may be calculated using as little as 77 ms (1/13s) of data. However, there is a directly inverse relationship between the bandwidth of the SSVEP response and the time period used to determine the Fourier coefficients (Regan, 1989), and as a result, achieving effective signal-to-noise ratio of the SSVEP response requires integration periods including multiple stimulus cycles. Initial investigations of steady-state responses achieved extremely high signal-to-noise ratios by using integration periods of several minutes (Regan, 1977). However, as integration over this time scale averages out any dynamic changes in responses during this period, subsequent research seeking to examine dynamic changes in response to cognitive processes have adopted averaging periods in the second, and sub-second time-scales. Silberstein et al. (1990) used an integration period of 10 s, whereas Silberstein, Burkitt and Wood (1993) demonstrated that as SSVEP signal power is concentrated at the stimulus frequency (Pipingas & Silberstein, 1996), an integration period of a few seconds provided a sufficiently high signal-to-noise ratio that EMG, EOG and eye-blink artifact, and 50 Hz mains interference had little effect on the SSVEP responses. Subsequent research has examined SSVEP responses using averaging periods of as little as five to ten stimulus cycles of a 13 Hz stimulus (0.39 - 0.78 s) (Harris, Silberstein, Nield, & Pipingas, 2001; Kemp, Gray, Eide, Silberstein, & Nathan, 2002; Kemp et al., 2004; Silberstein et al., 1998; Silberstein, Line, Pipingas, Copolov, & Harris, 2000). Notably, these studies used a cosine averaging window that weights data located nearer to the centre data point more heavily than more lateral data points, and as a result, the effective temporal resolution of these studies may be considered to be considerably higher than the stated temporal resolution.

4.3.2 SSVEP Topography

The amplitude of the steady-state response is strongly determined by the stimulus frequency. Peaks in SSVEP amplitude responses have been observed at stimulus frequencies of 10, 20, 40 and 80 Hz (Herrmann, 2001; Regan, 1989). Responses obtained in response to the lower frequency bands have been proposed to originate over more widespread areas of the brain than visual cortex alone (Speckreijse, Estevez, & Reits, 1977) suggesting that these lower frequencies may provide more suitable stimulation rates for the investigation of responses originating in areas other than visual cortex. Silberstein (1995b) notes that the topography of the low frequency SSVEP is generally characterised by an amplitude maximum in the occipito/parietal region, although this occipito/parietal amplitude maximum may be accompanied by a smaller amplitude maximum in the frontal region. Regional variations in the 13 Hz SSVEP extending well beyond visual cortex in occipito/parietal regions have been repeatedly observed. In particular, 13 Hz SSVEP changes associated with cognitive processes have been identified in frontal, prefrontal, temporal, central and parietal regions (Kemp et al., 2002; Kemp et al., 2004; Silberstein et al., 1995; Silberstein et al., 1998; Silberstein et al., 2001; Silberstein, Song, Nunez, & Park, 2004).

4.3.3 SSVEP Investigations and Interpretation

Early research examining 13 HZ SSVEP responses identified task-related reductions in SSVEP amplitude in occipito-parietal and right prefrontal regions during different segments of a visual vigilance task (Silberstein et al., 1990). These amplitude reductions were proposed to reflect involvement of the occipito-parietal region in heightened visual attention and right prefrontal involvement in the mediation of attentional processes.

A subsequent study examined SSVEP responses associated with the Wisconsin Card Sorting task (Silberstein et al., 1995). The Wisconsin Card Sorting task is a neuropsychological test of prefrontal lobe function in which participants determine which of a number of possible strategies correctly sorts cards into four piles. After the respondent correctly applies this strategy for six to 10 card sorts, the sorting strategy is changed and the respondent must then determine the new strategy. Demands are placed on prefrontal lobe function by the need to relinquish an old strategy and determine a new one (Milner, 1963). Using an SSVEP integration period of 0.77 s, SSVEP responses at different phases of task performance were observed, and notably, the timing of determining a new sort criterion was associated with a transient SSVEP amplitude reduction and a SSVEP phase lag at right prefrontal and right temporal electrodes. Silberstein et al. interpreted the observed amplitude and phase lag reductions as transient increases in regional activity at the timing when neural resources were specifically required for the generation of new sort criterion. These SSVEP effects were proposed to be similar to the phenomenon of event-related desynchronisation (ERD) whereby transient reductions in alpha amplitude are associated with regional increases in cortical activity (Pfurtscheller, Aranibar, & Maresch, 1979; Pfurtscheller & Klimesch, 1990).

Task-related variations in SSVEP responses have also been observed in several studies examining performance of the AX-CPT task. In this task, participants are presented with a series of letters at 2 second intervals and must respond to the presentation of the letter ‘X’ only when preceded by the letter ‘A’. Silberstein, Cadusch et al. (1996) observed transient reductions in SSVEP amplitude and phase lag at parietal sites during the A-X interval - interpreted as reflecting heightened visual attention during this anticipatory period, and over central and frontal areas following a correct response – interpreted as being associated with response selection and execution. Faster response times to targets were associated with greater reduction in frontal phase lag, suggesting that SSVEP latency reductions index the strength of regional cortical coupling reflected by information processing speed. Clinical research employing the AX task has examined SSVEP differences between young males diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) and a control group (Silberstein et al., 1998). While the control group demonstrated a similar prefrontal SSVEP latency reduction following a correct response as demonstrated in Silberstein, Cadusch et al. (1996), the ADHD group demonstrated no latency reduction at this timing, suggesting that prefrontal networks in the ADHD group were not activated at this phase of the task for the clinical group. Similarly, schizophrenic participants have failed to demonstrate prefrontal SSVEP latency reductions shown by normal participants in response to the AX task, demonstrating an absence of prefrontal excitatory processes at the timing when additional neural resources are required to perform the AX task (Silberstein et al., 2000).

Research examining SSVEP responses in a range of cognitive tasks has demonstrated an association between amplitude reductions and increased task demands, suggesting a link between regional activation and SSVEP amplitude reductions. However, Silberstein (1997) demonstrated that demands placed on working memory were associated with an SSVEP *increase* at frontal and parietal sites. Interpreting this data, Silberstein (1998) proposed that information that is to be held actively is reticulated through reciprocally related cortical regions forming re-entrant loops. Holding information ‘on line’ would be associated with increased loop gain of the cortico-cortico re-entrant loops, and would be manifested as an increase in the amplitude of the SSVEP at the regional frequency range. Consistent with this proposal, significant alpha band power increases in prefrontal regions have been associated with retention of visuospatial information in working memory (Klimesch, Doppelmayr, Pachinger, & Ripper, 1997), and this alpha band power increase in prefrontal regions may be further enhanced in association with *manipulation* of visuospatial information (Sauseng et al., 2005). Silberstein et al. (2001) demonstrated variations in SSVEP amplitude as a function of demands placed by a visual object working memory task. While an 'intake' phase of the task elicited SSVEP amplitude reductions over occipito-parietal regions, the task phase requiring holding of the object in working memory elicited SSVEP amplitude *increases* similar to those elicited in the previous working memory research (Silberstein, 1997). This amplitude increase was accompanied by an SSVEP latency decrease over frontal regions. In summarising this data, Silberstein (2001) emphasised the role of cognitive modes in determining SSVEP amplitude responses. Cognitive modes dominated by perceptual process would be associated with SSVEP amplitude reductions, whereas cognitive modes that require the holding of information in working memory would be associated with reticulation of information around re-entrant loops reflected by SSVEP amplitude increases.

SSVEP latency changes have been proposed to index changes in transmission times in cortico-cortico and thalamo-cortical loops resulting from excitation or inhibition of post-synaptic cells (Silberstein, 1995b; Silberstein et al., 2001). By this view, decreases in synaptic delay in re-entrant loops are reflected by a reduction in transmission times of the re-entrant loop (loop-time) and produce a reduction in the phase difference between the visual sinusoidal stimulus and the SSVEP, observed as a reduction in phase lag of the SSVEP response. In accordance with this proposal, SSVEP latency decreases in the prefrontal areas have been interpreted as reductions in transmission times between prefrontal neural networks (Silberstein, Cadusch et al., 1996; Silberstein et al., 2001), whereas removal of facilitation, or cortical inhibition in prefrontal areas has been linked with latency increases (Silberstein et al., 1997).

SSVEP latency changes have also been proposed to be sensitive to working memory task-related changes. Silberstein (2001) proposes that cognitive tasks requiring information to be held actively on-line will be associated with increased transmission efficiency of the participating re-entrant loops, and this would be reflected by a reduction in phase lag of the SSVEP response. In accordance with this proposal, holding information on-line in working memory has been related to SSVEP latency decreases (Silberstein et al., 2001; Silberstein et al., 1997). However, SSVEP latency *increases* have been associated with working memory tasks when the task involves the manipulation of information, as opposed to simply holding it on-line (Silberstein, Song, Nunez, & Park, 2003; Silberstein et al., 1997). In a mental rotation task, Silberstein et al. (2003) observed that progressive increases in degree of manipulation required to successfully perform the task were associated with progressive latency increases during the manipulation phase of the task. These latency increases were interpreted as indicating increased activation of inhibitory synaptic processes required to support manipulation of the information.

4.3.4 Summary of Other SSPT Research

In addition to the SSVEP research reviewed in the previous discussion, the SSPT methodology has been applied to the examination of a broad range of research questions. Insights have been gained regarding the relationships of SSVEP amplitude and phase/latency fluctuations to spatial working memory intelligence correlates (Van Rooy, Stough, Pipingas, Hocking, & Silberstein, 2001); prefrontal function in ADHD (Farrow et al., 1996; Silberstein et al., 1998) and schizophrenia (Silberstein et al., 2000); cognitive processing speed (Silberstein et al., 2004); mental rotation (Silberstein, Danieli, & Nunez, 2003; Silberstein et al., 1997); continuous task performance in normal groups and the aforementioned clinical groups (Balog, Silberstein, & Pipingas, 1994; Farrow et al., 1996; Silberstein et al., 1998; Silberstein et al., 2000); olfactory stimulation (Patterson et al., 1998); and emotional processing including anticipatory anxiety (Gray, Kemp, Silberstein, & Nathan, 2003), and emotional valence processing (Kemp et al., 2002; Kemp et al., 2004).

4.3.5 Use of SSPT in the Auditory Domain

The SSVEP has most commonly been used to examine cognitive processing related to the visual modality, but has also been demonstrated to reflect task-related cognitive processing in the auditory modality (Balog et al., 1994; Silberstein, Balog, & Pipingas, 1996). Steady-state latency decreases have been linked in the auditory domain with sensitisation of neural systems (Rohrbaugh, Varner, Paige, Eckardt, & Ellingson, 1989). Silberstein, Balog et al. (1996) demonstrated rhythmic prefrontal changes in SSVEP magnitude synchronised with components of an auditory continuous performance task. Notably, Makeig and Galambos (Makeig & Galambos, 1989) demonstrated variations in 40 Hz auditory steady-state responses following omission of clicks from a regular series. Omitted clicks evoked an initial reduction in steady-state latency and amplitude responses, which was followed by steady-state amplitude and latency increases. The series of omitted stimulus steady-state amplitude perturbations persisted over 300 ms, suggested to reflect long-lasting modulator processes that operate over several hundred milliseconds (Makeig & Galambos, 1989).

Two factors may account for the utility of the SSVEP in demonstrating aspects of auditory cognition. Firstly, visual projections in the cortex are extensive. The spatially diffuse visual stimulus preferentially stimulates the magnocellular visual system which projects to an extensive range of cortical areas including striate cortex, visual association cortex, primary somatosensory cortex, temporal cortex, and prefrontal cortex (Silberstein, 1995b). Multimodal prefrontal areas are a common projection of various sensory modalities including the auditory modality where pathways extend from both primary and secondary auditory cortex (Pandya & Yeterian, 1990). Multimodal areas are involved in the integration of input from disparate sensory modalities. Within these areas, the SSVEP may provide a measure of local activity (Silberstein, 1995b). A second factor is that sensory stimulation in the visual modality has been observed to result in activation of neuronal assemblies not specifically related to the visual modality. In particular, the sinusoidal SSVEP stimulus may generate cortical travelling waves extending from specific visual projections which drive neuronal assemblies not directly related to visual processing (Nunez, 1995). This results in the observation of driven activity in 'non-visual' areas enabling the SSVEP to provide a measure of local activity.

4.3.6 Summary of Advantages

As SSVEP signal power is concentrated at the stimulus frequency (Pipingas & Silberstein, 1996), SSPT possesses high signal-to-noise ratio and is relatively unaffected by EMG, EOG and eye-blink artifact, and 50 Hz mains interference (Silberstein et al., 1993). This high signal-to-noise ratio at the stimulation frequency provides the SSPT method with substantial advantages over standard ERP techniques that typically require substantially greater numbers of event presentations to adequately address issues associated with the broad distribution of signal power of these common artifacts. As a result, SSPT does not require the extended task durations necessary to capture the required number of averages as may occur in ERP protocols.

While artifact rejection provides SSPT with substantial benefits, the capability of the SSPT methodology to capture temporal aspects of cognitive task performance provides a unique window into the temporal dynamics of cognitive processes. By combining a temporal resolution able to resolve dynamic variations in cognitive processes with temporal continuity, the SSPT approach provides a methodology with capability to examine both tonic (Silberstein et al., 1990) and phasic aspects of task performance. As such, a range of SSPT studies have demonstrated dynamic fluctuations in activation of cortical networks involved in performance of cognitive tasks (Farrow et al., 1996; Pipingas & Silberstein, 1996) and in particular, have revealed cyclic fluctuations of amplitude and phase responses synchronised with temporal aspects of task performance (Farrow et al., 1996; Silberstein, Balog et al., 1996; Silberstein, Cadusch et al., 1996; Silberstein et al., 1995; Silberstein et al., 1990). It is this feature of the SSPT technique that provides it with the capability to examine time-varying aspects of cognitive processes underlying task performance.

Findings obtained using SSPT indicate that that the SSPT technique possesses both the temporal resolution and the temporal continuity necessary to examine time-varying cognitive processes underlying the performance of experimental tasks, and specifically, possesses temporal qualities suitable for examination of cognitive processing underlying perception of music-related auditory tasks. SSPT employs relatively high density electrode arrays consisting of 64 or more electrodes, providing the technique with the necessary spatial resolution for investigating task-related activity of gross brain regions, and has a demonstrated ability to reveal participation of brain regions underlying auditory task-related processing. As such, SSPT is a suitable technique for the exploration of cognitive processing underlying auditory temporal grouping under exploration in the current study and provides a novel approach to the examination of grouping mechanisms in musical processing.

4.4 Aim of Study and Hypotheses

The main aim of this study is to examine dynamic variations in brain electrical activity associated with auditory temporal grouping in musical tasks. Previous behavioural research indicates the psychological reality of auditory temporal grouping processes in musical contexts, and previous psychophysiological research has revealed a range of brain regions that may be involved in the temporal grouping process, yet little work has been conducted that seeks to explore the involvement of brain regions in temporal grouping within musical contexts. The present study aims to address this issue. Four experimental hypotheses proposed for this study are detailed below:

Behavioural research employing recognition paradigms have demonstrated the influence of grouping mechanisms on recognition performance. In particular, recognition tasks have demonstrated that longer-duration notes may act as structural cues in working memory representations of tone sequences. In view of research demonstrating the use of lengthened tones in sequences as a cue for the delineation of grouped structure, the first hypothesis proposes that recognition of extracts from tone sequences will be significantly better for those extracts presented in accordance with rhythmically grouped structure compared to extracts that conflict with rhythmically grouped structure. Better recognition proposed by this hypothesis will be demonstrated in behavioural scores that reflect recognition performance.

The second hypothesis is proposed in view of research demonstrating greater use of left hemisphere neural regions associated with temporal organisation of auditory stimuli. This hypothesis proposes that participants who demonstrate use of lengthened tones as a cue to rhythmically group the tone sequences will demonstrate tendency towards use of left hemisphere frontal and temporal neural regions in encoding tone sequences, whereas participants who do not rhythmically group the tone sequences will demonstrate a tendency towards use of right hemisphere frontal and temporal neural regions in encoding sequence material.

The third hypothesis is formulated in view of research demonstrating characteristic electrophysiological responses that are sensitive to deviations from temporal models developed in rhythmic sequences, and that reflect the extent that information provided by the deviation is used by the listener. This hypothesis proposes that presentation of relatively longer tones in a tone sequence will evoke dynamic responses in brain regions that are sensitive to deviations of temporal structure in frontal, temporal and parietal regions, and that activity in these regions will be greater for participants who demonstrate use of lengthened tones as a cue to rhythmically group the tone sequences.

The fourth research hypothesis is proposed in view of research demonstrating that perception of rhythmic phrase boundaries has been associated with a characteristic electrophysiological response following the phrase boundary cue. As SSVEP latency increases have been associated with working memory tasks when the task involves the manipulation of information, as opposed to simply holding it on-line (Silberstein, Song et al., 2003; Silberstein et al., 1997), this hypothesis propose that the presentation of tones immediately after relatively longer-duration tones in a to-be-remembered pitch sequence will evoke an SSVEP response in strong-grouping participants associated with the closure of grouping-related processing in temporal and parietal regions. Specifically, this response will reflect contribution of neural regions supporting CPS-related closure processes following detection of group boundaries evident in late central or parietal responses.

A partial replication of the experimental design adopted by Dowling (1973) was adopted as a suitable task to provide respondents with duration-based grouping cues. In this task, encoding of auditory tones sequences was promoted without explicit attention being directed towards the grouping cues. In this manner, the task was considered an appropriate vehicle for an electrophysiological investigation of the impact of duration-based cues on grouping behaviour. By linking participants' behavioural responses in the probe recognition task with electrophysiological responses, the experimental protocol was able to address hypothesised relationships between tone duration cues and grouping behaviour; whereas use of a 64-electrode recording montage provided a basis to determine topographic distribution of EEG responses, and the SST methodology provided sufficient temporal resolution to examine dynamic aspects of the grouping process. Together, these aspects of the experimental design provided a suitable protocol with which to examine the experimental hypotheses within a single experimental design. The next chapter describes the experimental methodology undertaken to investigate these hypotheses.

Chapter 5 METHODS

5.1 Introduction

This chapter details the experimental methodology used to investigate the research questions proposed in chapter 4. Section 5.2 describes relevant details of the participants who took part in the research. Section 5.3 provides a detailed description of the two cognitive tasks that were used to investigate the research questions. Section 5.4 details other experimental materials used in conjunction with the cognitive tasks. Section 5.5 describes the equipment used to acquire SSVEP responses examined in the research. Section 5.6 outlines the procedure undertaken with each participant, and finally, Section 5.7 details signal analysis procedures undertaken in producing the SSVEP responses.

5.2 Participants

To attain a homogenous sample, the study examined responses of female listeners only. Fifty female participants volunteered to participate in the study. Participants' ages ranged from 18 to 42 years (mean = 22.6 years, SD = 5.4 years). Participants were students in undergraduate psychology and psychophysiology courses within the university. All participants were right-handed as assessed by the Edinburgh Handedness Inventory, and had no known neurological or hearing disorders. Some participants had undertaken formal musical instrument training, with number of years exposure to professional musical instrument tuition ranging from 0 to 12 years (mean = 2.4 years, SD = 3.4 years). No participants were in the process of musical training or involved in musical performance activities at the time of participation in the research. All participants provided informed consent to involvement in the study, and were asked to withdraw if they had any history of epilepsy. The study was approved by the Swinburne Human Research Ethics Committee.

5.3 Cognitive Tasks

5.3.1 Probe Recognition Task

As discussed in Section 2.11, Dowling (1973b) presented listeners with extracts of tone sequences grouped by longer-duration tones. Results of this probe recognition task indicated that probes matching a rhythmic group were recognised with significantly greater accuracy than probes straddling across groups, suggesting that duration cues were used in the structuring of working memory representations. A modified version of the 'probe recognition task' (Dowling, 1973b; Peretz, 1989; Wang & Sogin, 1990) was used in the current research to determine the extent that participants structured working memory representations of musical patterns based on duration changes, and the relationships between this structuring process and electrophysiological responses evoked during this process. The modified probe task required participants to listen to, and memorise a 10-tone pattern of pitches, and then recognise whether an extract of the pattern played two seconds later – the probe, contained any pitch changes from the original pattern. Probe patterns were extracted from the pattern in two conditions – within group probes ended on a longer tone (within-group patterns), whereas across-group patterns consisted of a longer tone bounded by standard length tones.

5.3.1.1 Pitch factors

As listening to familiar music patterns evokes stored mental representations for the music and may involve application of higher hierarchical representations than use of surface features to structure sequences, novel tone sequences were constructed specifically for the study. One overriding concern in producing the experimental stimulus was to provide a stimulus that was as ecologically valid as possible, without introducing factors that would confound the experimental findings. In view of this aim, tone sequences used in the study used tones semi-randomly selected from the C Major scale, within a range of 1 ½ octaves above middle C (C4). Tones used in patterns were selected from:

C4 (262 Hz), D4 (294 Hz), E4 (330 Hz), F4 (350 Hz), G4 (392 Hz), A4 (440 Hz), B4 (494 Hz), C5 (524 Hz), D5 (587 Hz), E5 (659 Hz), F5 (698 Hz), and G5 (784 Hz).

In order to further promote ecological validity of the stimulus, the timbre of the tones used was a piano tone generated on a Roland XP30 synthesizer. As the focus of the research was on the temporal dimension of respondents' reactions to the stimulus, engagement of higher order timbral representations in response to the timbral quality of the stimulus was not considered a potential confounding factor. All stimuli were presented at 70 dB sound pressure level.

A further consideration in producing the pitch series of the experimental patterns was to provide patterns that were as ecologically valid as possible without providing cues which would dominate the structuring of working memory representations of the tone sequences in preference to rhythmic cues. Three main pitch-related considerations were observed: As tonal hierarchies, pitch contours, and large pitch intervals provide major cues for cognitive representations of pitch sequences (Deutsch, 1982a, 1982c), the sequences were designed to avoid providing a strong sense of tonality while still using culturally familiar pitch intervals; clear pitch contours were to be avoided, as was the use of large pitch intervals. In order to achieve these aims, the following process was adopted for the development of pitch-based aspects of the experimental sequences:

A ten-tone sequence of pitches was randomly selected from amongst the 12 pitches available using a random number generator which selected the pitch of each tone in turn. Once selected, pitches sequences were tested for adherence to a set of pitch rules:

- The **interval rule** specified that no pitch interval may span an interval greater than 4 tones e.g. The sequence C G[4] is in violation of the interval rule as it spans an interval of 5 tones (C D E F G). This rule prevents forming of attentional streams due to large interval jumps (Bregman, 1990; Bregman & Campbell, 1971).

- **Contour rule 1** specified that the direction of pitch movement from note to note may not be in the same direction for more than 2 intervals e.g. The sequence C D F G is in violation of contour rule 1 as the pitch moves upward 3 times consecutively. By contrast, the sequence C D F E adheres to contour rule 1. This rule prevents

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[4] This and following examples use tones from within the same octave e.g. C4 G4.

processing of the sequence by pitch contour rather than note duration (Deutsch & Feroe, 1981; Peretz & Babai, 1992).

- **Contour rule 2** specified that a two-tone pitch interval of the same direction may not be used twice consecutively. e.g. Neither of these sequences were used:- C E G; or G E C. This rule aids in the prevention of hierarchical structuring of pitch information used in tonal perception (Deutsch, 1982b).

- **Contour rule 3** specified that if the direction of pitch movement is the same for 2 intervals, a long note may not be placed at the second interval. e.g. In the sequence C D F E, a longer duration tone may not occur on the F, whereas it may for any of the other tones. This rule prevents contour change points being placed in competition with long duration tones for use as a perceptual cue (Boltz & Jones, 1986).

Tonality cues were also avoided by ensuring that the last tone of the pattern was a different pitch to the first tone of each of the two tone groups making up a pattern as discussed in the following section. Any trial not adhering to the rule set was discarded and a new pitch set generated. These rules were implemented in order to limit pitch-related factors acting as strong cues for the structural organisation of the tone sequences.

5.3.1.2 Temporal factors

The time interval from the onset of a tone to the next onset – the tone inter-onset interval (IOI) in the 10-tone patterns were constant (600 ms) apart from a doubling of IOI (1200 ms) once or twice in the pattern. Standard IOIs consisted of a tone presentation for 550 ms followed by 50 ms of silence. Longer IOIs consisted of a tone presentation for 1150 ms followed by 50 ms of silence. Both standard and longer tones incorporated 50 ms rise and fall times. Standard and longer tone conditions will be referred to as short and long tones respectively. To minimise serial position effects associated with the positioning of rhythmic groups within patterns, long tones were presented in either the first or second half of the patterns in 27 trials and in both pattern halves in 33 trials. This design enabled examination of grouping effects throughout the pattern.

Dowling (1973b) demonstrated an impact of rhythmic grouping on probe recognition task responses for five-tone groups ending on a long tone. In view of this research, five-tone groups ending in long tones were used as the primary stimulus to investigate the impact of rhythmic grouping on electrophysiological responses. Henceforth, the length of sequences ending in long tones will be referred to including the long tone, e.g. five-tone groups incorporate four standard length tones followed by a long tone.

Listeners may establish a sense of meter quickly (Longuet-Higgins & Lee, 1982). As the impact of rhythmic grouping on recognition performance resulting from perception of five-tone groups may overlay effects of metric factors or subjective accenting established by the long tone occurring on an odd beat (Brochard et al., 2003; Palmer & Krumhansl, 1990), an equal number of four-tone and five-tone patterns were presented in pattern first halves. Additionally, the experimental design incorporated two rhythm rules designed to lessen the availability of regularly spaced lengthened tones that may have potentially cued metric time frames (Lerdahl & Jackendoff, 1983). These rules ensured that:

- the duration of the first and second groups in each pattern differed in order to prevent the establishment of hierarchic structure
- placement of the long note in the second group did not strongly reinforce any metric cue established by the first group.

In order to prevent build up of expectations for occurrence of long tones, 10 patterns incorporated three-tone groups in the first half of a pattern, and 8 patterns incorporated four-tone groups in the second half of the pattern. Additionally, 15 patterns used a pause as a grouping cue during the first half of the pattern, and 16 patterns presented only standard duration tones in the second half of the pattern. These sections of patterns were presented in order to prevent a build-up of expectation for the occurrence of longer-duration tones and were not included in subsequent electrophysiological or behavioural analysis. Overall, long tones were presented at an overall probability of p=0.15. A summary of presentation of long tones and pauses in probe recognition task patterns is represented in Figure 5.1.

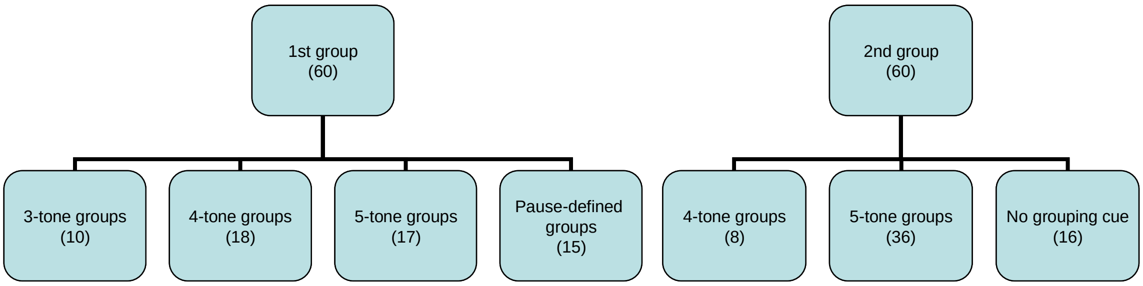

Figure 5.1 Tone groupings in probe recognition task patterns

Thirty patterns developed in conformance with the temporal and pitch rule sets formed a base set of Probe Recognition Task patterns used in the research. In order to minimise differences between sequence extracts probing within- and across-group conditions, a further 30 patterns were developed which presented pitch sequences occurring in within-group pitch sequences in across-group contexts. This was achieved by shifting the within-group pitch sequence in each of the original 30 patterns relative to the temporal structure of the pattern. This manipulation had the effect of shifting within-group pitch sequences into across-group positions, and enabled the presentation of identical probe extracts in within-group and across-group conditions. Additional tones were included at the start of each pattern in accordance with the pitch rule set in order to maintain constant pitch conditions across within-group and across-group patterns. Where shifting of tones in the pattern resulted in conflict with the pitch and temporal rules, one or more pitches were adjusted to be in conformance with the rules. Figure 5.2 provides an example of an initial pattern presented in a within-group condition and the across-group version drawing on the same pitch sequence.

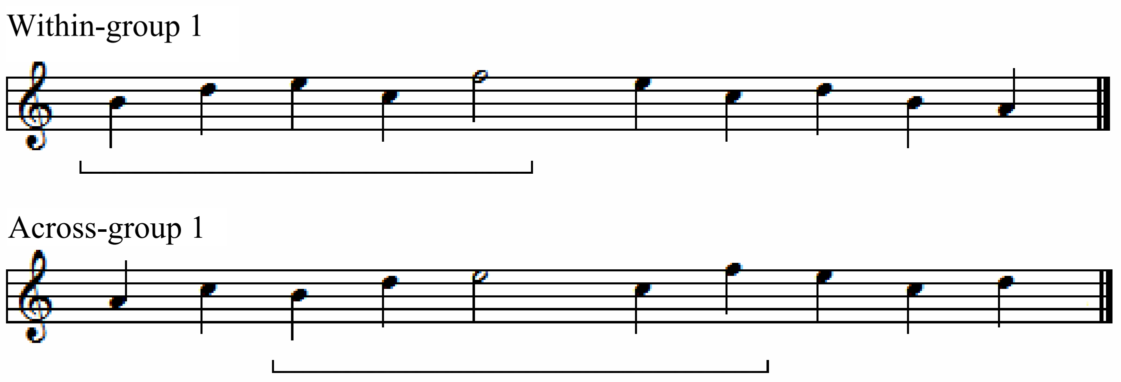

Figure 5.2 Example of probe recognition task within-group and across-group patterns

5.3.1.3 Probe patterns

A three, four, or five tone sequence was extracted from each of the Probe Recognition Task patterns for presentation as a probe pattern. Of the total of sixty probe patterns, twenty-four probe patterns presented a pattern extract ending on a long note, and twenty-four presented an identical pitch sequence in an across-group condition incorporating a long tone bounded by standard tones. The remaining 12 trials acted as foils.

In order to reduce participants' attention to long tones in probe patterns, eight foil trials probed pattern extracts that did not include a long note, and four trials probed three-tone groups in order to minimise build-up of expectation for longer tone-groups. The twelve foil trials were not included in behavioural analysis. This resulted in a set of 48 valid trials incorporating 24 valid within-group trials and 24 valid across-group trials, probing 24 first half sequences (12 within-group, 12 across-group) and 24 second half sequences (12 within-group, 12 across-group).

Half of each of the 24 valid within-group and 24 valid across-group probe patterns were modified so that the pitch of the 2nd or 4th tone was altered by an interval of a 3rd to a 5th from the original pattern to create a set of incorrect probes. Figure 5.3 provides an example of the four extract positions used in Probe Recognition Task trials. A summary of trials used for behavioural scores appears as Figure 5.4, and the procedure for a single probe recognition trial is represented in Figure 5.5.

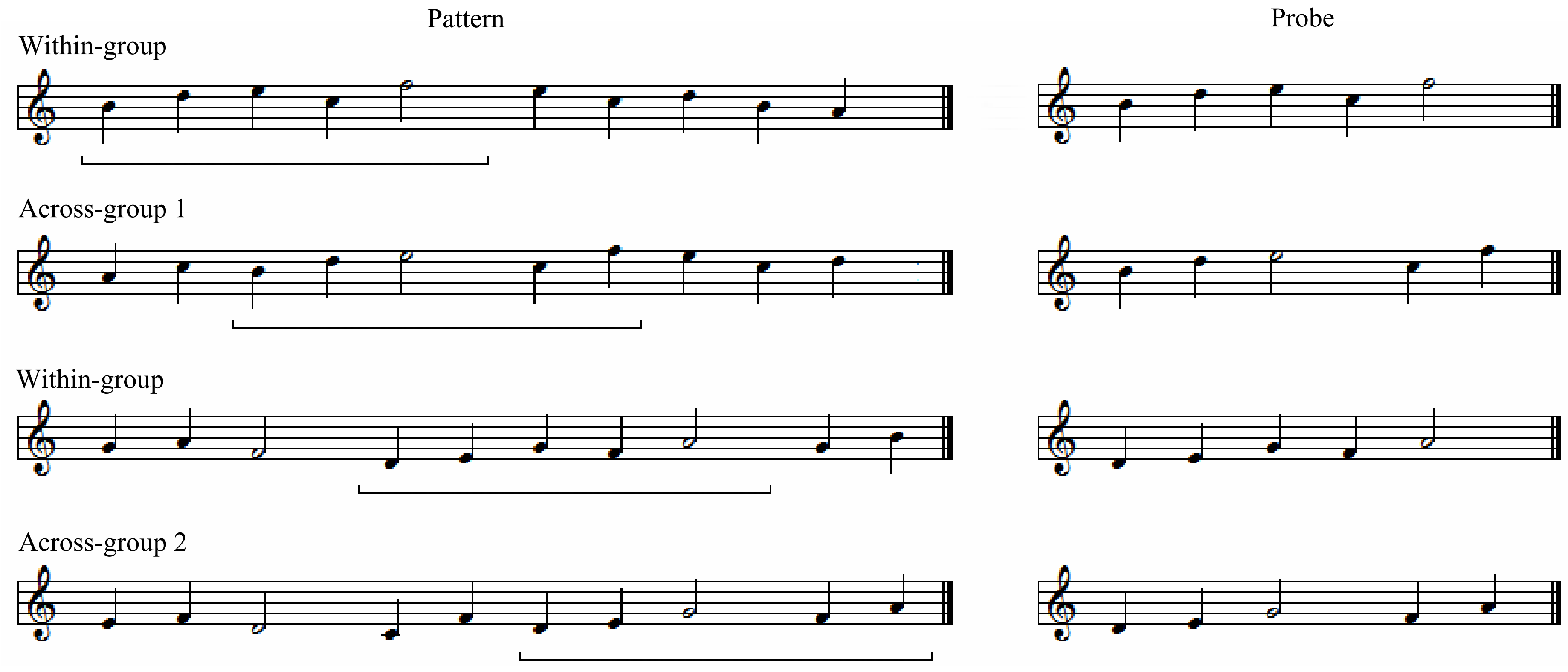

Figure 5.3 **Probe positions used in probe recognition task trials**

Examples of pattern extracts used to probe within-group and across-group pattern recognition. Brackets under each pattern identify the extract used to probe within-group recognition in the first half of the pattern (within-group 1); across-group recognition in the first half of the pattern (across-group 1); within-group recognition in the second half of the pattern (within-group 2), and across-group recognition in the second half of the pattern (across-group 2).

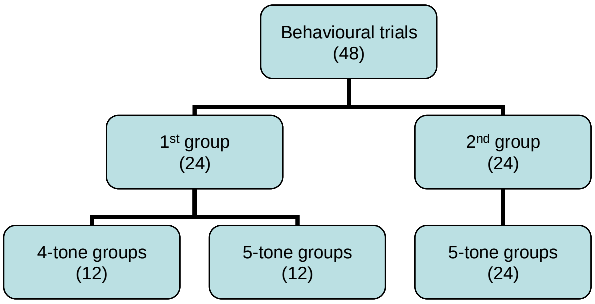

Figure 5.4 Recognition task trials used in behavioural analysis

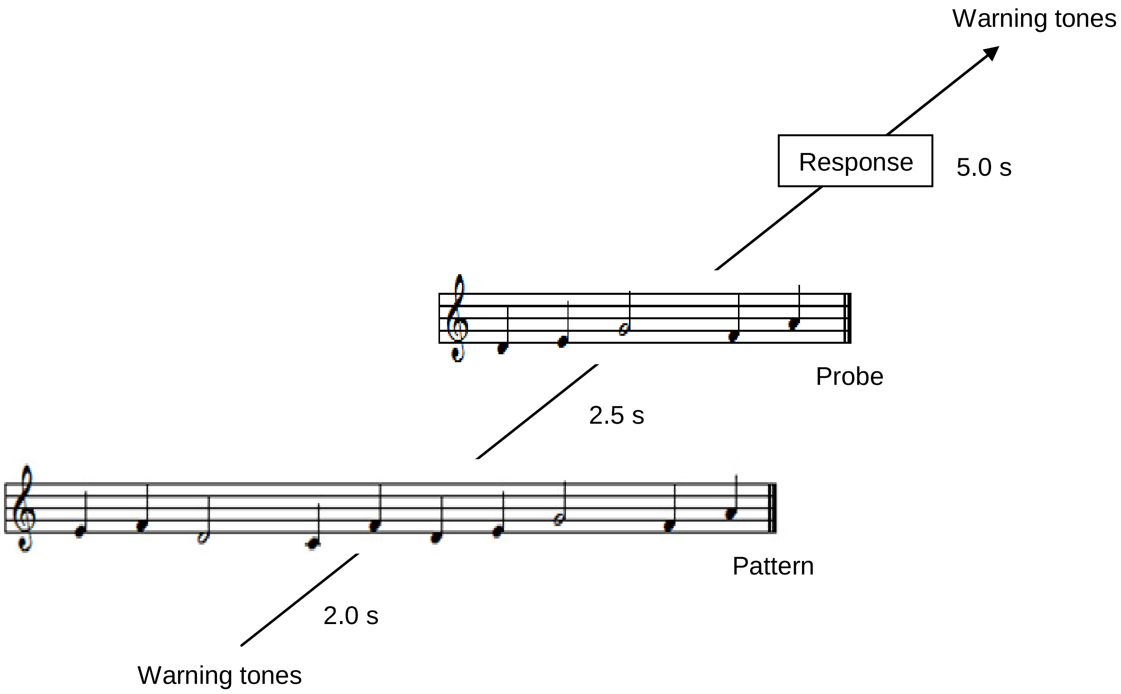

Figure 5.5 Probe recognition task experimental design

In total, 60 trials of the probe task were constructed and divided randomly into four groups of 15 trials for counterbalanced presentation in four blocks that were rotated across respondents. Within each probe recognition task trial, warning tones signalled the commencement of a trial. Two seconds later, the probe recognition task pattern that was to be subsequently recognised was presented, and following a two and a half second pause, the extracted probe pattern was presented. Participants then responded via the button box within a five-second period, after which the warning tone for the next trial was presented. Responses provided after the warning tone were not included in behavioural analysis.

5.3.2 Reference Task

The reference task consisted of an auditory oddball ‘detect’ task designed to focus subject’s attention on the appearance of a deviant stimulus in the sequence without placing demands on retention of pitch or temporal information. The task required participants to detect the rare occurrence of 2 tones played simultaneously within a sequence of single tones and to remember how many of these 2 tone pairs occurred throughout the sequence. Twice during the sequence, a standard duration tone pitched at G#6 was presented simultaneously as a standard tone. This pitch was chosen in order to present an easily detectable event and demand only low level attention to the sequence. Total duration of the sequence was 180 seconds. The pitch and rhythm sequence used in the baseline task consisted of concatenated probe recognition task patterns. By this approach, participants were exposed to the same pitch and rhythm information in the reference task as presented in the Probe Recognition Task. As for the Probe Recognition Task, longer tones were presented at a probability of $p = 0.15$. As such, differences in task instructions associated with each of the tasks resulted in differential demands for the encoding, retention, and recognition of similar pitch and rhythm information in each task.

5.4 Materials

5.4.1 Research Instruments

In addition to the cognitive tasks developed for the study, the instruments necessary to conduct the study included informed consent and personal details forms, the Edinburgh Handedness Inventory (Oldfield, 1971), a post-experimental response form, a two-button response handset, audiometry testing equipment, audio presentation equipment, four subtests of the Seashore Measures of Musical Talents (Seashore, Lewis, & Saetveit, 1960), EEG recording equipment, the Steady State Visually Evoked Potential stimulus (SSVEP) and the Fourier Analyser. Each of these instruments is discussed in turn.

5.4.1.1 Informed consent form

The informed consent form (Appendix A) provided participants with an outline of procedures pertinent to their involvement in the study. The form did not inform participants of specific hypotheses under investigation in the study.

5.4.1.2 Personal details form

A personal details form (Appendix B) requested participants provide general personal details such as sex, age, handedness, education level, and details of musical education gained by either professional tuition or informal means. These details included whether the musical education (if any) was practical or theoretical, instrument(s) played, numbers of years of involvement and formal level attained. This form also requested details of any known hearing deficits. In addition, the form requested participants provide details of relevance to an electrophysiological investigation. These included any experience of head injuries, neurological or psychiatric disorders, smoking habits, recent caffeine consumption and intake of prescription drugs.

5.4.1.3 Edinburgh Handedness Inventory

The Edinburgh Handedness Inventory (Oldfield, 1971) examined participants' tendencies towards right- or left-handedness. The Inventory assesses which hand participants normally use for each of ten activities, namely, writing, drawing, throwing, using scissors, brushing their teeth, using a knife (without fork), using a spoon, using a broom (upper hand), striking a match or opening a box (lid). Two further questions monitor which foot participants prefer to kick with, and which eye they use when only using one. A preference for using the left or right hand, foot or eye is scored as 1 point towards the tally for that side. Participants' handedness score is calculated by the formula:

$$((R - L)/(R + L)) \times 100$$

so that increasingly positive scores are indicative of stronger trends towards right-handedness whereas increasingly negative scores are indicative of stronger trends towards left-handedness.

5.4.1.4 Post-experimental response form

The post-experimental response form (Appendix C) requested participants describe how difficult they found the probe task, and to also provide brief introspections about strategies they implemented in their performance of the probe and baseline tasks. Questions on this form probed for use of listening strategies in the probe task, the degree rhythm information was used, and whether they felt the probe and baseline tasks elicited similar listening strategies.

5.4.1.5 Seashore Measures of Musical Talents sub-tests

The pitch, rhythm, time and tonal memory sub-tests of the Seashore Measures of Musical Talents Test (Seashore et al., 1960) were used to provide measures of participants' perceptual acuity (pitch and time tests), pitch sequence memory ability (tonal memory test) and rhythm perception and memory ability (rhythm test). Use of the Seashore subtests was incorporated to ensure participants could accurately perceive the stimuli used in the tasks rather than as a test of musical ability per se.

5.4.1.6 Response handset

In order to minimise subject movements that may have contaminated the EEG signal, subject responses in the probe task were recorded with a two button response handset. The response handset consisted of a small square box, containing a right/true and a left/false button.

5.4.1.7 Audiometry equipment

In order to ensure participants' hearing was not deficient in the frequency range used in the study, hearing was tested using an audiometry unit.

5.4.1.8 Audio presentation equipment

Auditory stimuli used in the main study were programmed using Steinberg Cubase SX software, recorded on one channel of a digital audio tape (DAT) and played on a Sony PCM DAT machine through shielded speakers positioned at a 45^{o} angle on either side of the participant at a distance of 1.5 m from each of the participant's ears. Synchronising tones used to time-lock stimulus presentation with data acquisition were recorded on a separate channel of the DAT tape.

5.5 SSVEP Recording

5.5.1 Electrodes and Recording Equipment

The present study utilised a 64-electrode helmet, designed and constructed within the Swinburne Centre for Applied Neurosciences (SCAN). This helmet features spring-loaded electrode mountings which, after scalp preparation and application of conductive gel onto each electrode, allows electrodes to be individually lowered to rest comfortably against the scalp. The recording locations used in this study included all the scalp positions in the International 10-20 System with additional sites located midway between the 10-20 locations. This configuration provides an average inter-electrode separation of 3.2 cm, which is adequate for assessing brain electrical activity responses associated with gross cortical regions (Silberstein et al., 1990). The recording sites are illustrated in Figure 5.5. Silver/silver chloride electrodes were used with electrode impedances ranged between 3 kΩ and 15 kΩ. All recordings were referenced to linked earlobes with nose serving as ground. Brain electrical activity was amplified and bandpass filtered (0.5 Hz low cut and 26 Hz high cut) prior to digitisation to 16-bit accuracy at a 500 Hz sampling rate and stored on hard disk for subsequent off-line analysis. Data acquisition was performed using a Pentium-processor IBM compatible computer.

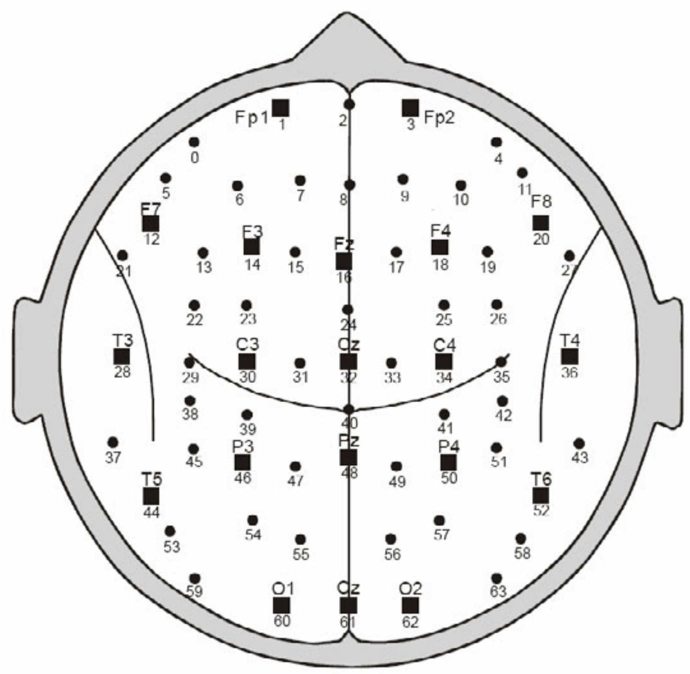

Figure 5.6 Sixty-four scalp electrode locations

Locations of 64 scalp electrodes including all International 10-20 sites (marked with darkened squares).

5.5.2 SSVEP Stimulus

A 13Hz sinusoidal flicker stimulus was used to evoke the SSVEP. A set of goggles was used to present the stimulus (Silberstein et al., 1990) via two sets of light emitting diode (LED) arrays viewed through half-silvered mirrors. The flicker stimulus subtended a horizontal angle of 160 degrees and a vertical angle of 90 degrees. The light intensity generated by the LED arrays was controlled by a 13 Hz sinusoidal voltage wave form, and the non-linearity between voltage input and light intensity was less than 0.5%. In order to eliminate potential confounding effects of irrelevant visual stimuli on the EEG signal, participants performed all experimental tasks with eyes closed. A pilot study was conducted to ensure that the steady-state stimulus luminance delivered through closed eyelids was of sufficient intensity to provide adequate SSVEP signal-noise ratio in the eyes closed condition. In view of results obtained in the steady-state stimulus pilot study, a stimulus luminance of 18 Cd/m^2 was adopted for subsequent use in the main study. Details of the pilot study are provided in Appendix B.

Equipment used to record the 64-channel SSVEP responses is represented in Figure 5.7.

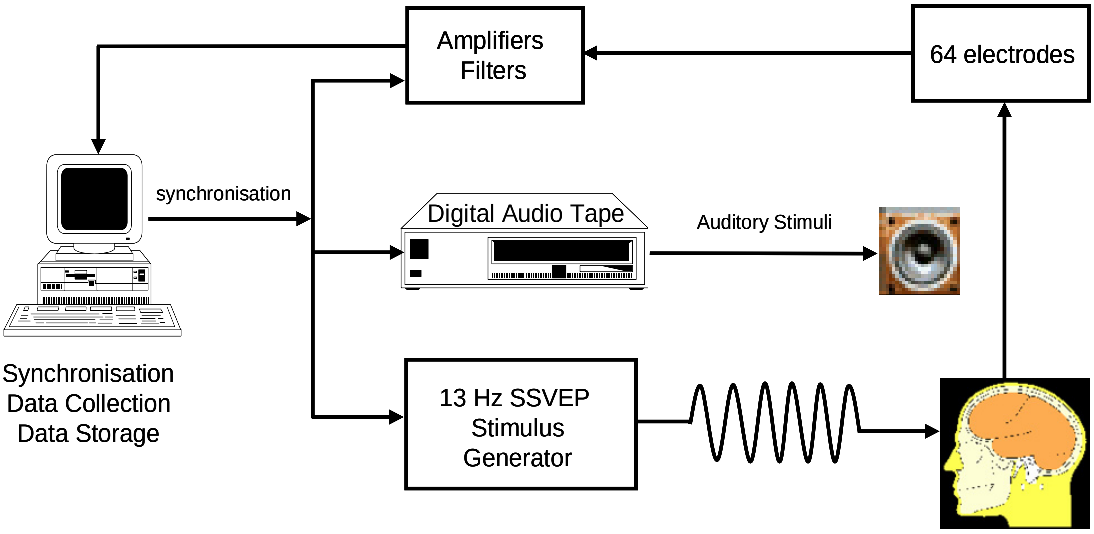

Figure 5.7 Equipment used to record 64-channel SSVEP responses

5.6 Procedure

5.6.1 Preliminary Testing/Orientation

As part of the recruitment process for the research, potential research participants were provided with a general overview of the experimental protocol, informed that the research took place over two separate sessions totalling approximately 2 hours, and that they would be paid $10 for their participation. Following agreement to participate, a preliminary testing/orientation session was conducted individually with each participant prior to involvement in the main study. After completing informed consent, handedness and musical details forms, basic hearing function over the frequency range used in the main study was assessed via audiometric testing of responses to 250 Hz, 500 Hz, 750 Hz and 1000 Hz separately for each ear. Participants then completed the pitch, rhythm, time, and tonal memory sub-tests of the Seashore Measures of Musical Talents Test (Seashore et al., 1960). Finally, participants were instructed on the probe recognition task and completed ten practise trials in order to ensure familiarity with the task and remove the potential confounding influence of practise effects from the main study. Task instructions are included as Appendix C. Total time required for the preliminary testing/orientation session was approximately 45 minutes.

5.6.2 Main Study

Participants attended the main research session approximately one week after completing the initial orientation session. Following a briefing on the experimental protocol and the reconfirmation of informed consent to participate in the research, the 64-channel electrode helmet was fitted to the participant's head. The participants scalp was gently abraded at each electrode site and electrodes were individually lowered to rest on the scalp surface. Conductive gel was then injected into the barrel of each electrode to provide a low impedance contact with the scalp surface. All electrode impedances were tested and subsequently adjusted to ensure adequate contact with the scalp. The set up procedure lasted approximately 30 minutes in total.

Participants responded to probe recognition task trails with a two-button handset by pressing yes/right and no/left buttons. Presentation of the probe recognition task and reference task was counterbalanced across participants, and order of presentation of Probe Recognition Task blocks was rotated across participants. Prior to commencement of each of the two tasks, task instructions were reviewed and two practice trials were provided with the SSVEP stimulus turned on in order to familiarise the participant with the experimental environment. On satisfaction that the participant was ready to commence with a task, data acquisition commenced.

Participants completed the probe recognition task in four separate five-minute blocks and the reference task in a separate 4 minute block. During task performance, the current trial condition, participant response and response timing were collected for each trial to an accuracy of one millisecond by a response computer synchronised to stimulus presentation and data acquisition. Following completion of all tasks and removal of the headset, the participant was given the opportunity to ask questions and debrief the goals of the research, and was paid for their participation. Total time required for the main study session was approximately 75 minutes.

5.7 Signal Processing

5.7.1 SSVEP Calculation

Variations in the 13 Hz SSVEP amplitude and latency from the 13 Hz stimulus frequency were determined at each of the 64 recording sites by extracting SSVEP amplitude and phase time series from the recorded EEG for each task at the stimulus frequency. Coherent demodulation (Regan, 1989) was used to determine the Fourier coefficients of the 13 Hz component of the EEG responses by evaluating the 13 Hz sine and cosine Fourier coefficients at each cycle of the stimulus (i.e. every 1/13th s). As improved signal/noise characteristics may be derived via averaging across multiple points of the data, a moving cosine (Hanning) window was then used to average Fourier coefficients over five cycles of the stimulus. The five-cycle evaluation window was repeatedly shifted by one stimulus cycle across the EEG data and the averaged Fourier coefficients recalculated for each position. This averaging process resulted in the production of averaged sine and cosine Fourier coefficients for the entire continuous EEG file at 1/13th s intervals with improved signal/noise characteristics as compared to single cycle coefficients, and is equivalent to filtering the EEG with a narrow band pass filter centred precisely at the stimulus frequency (Silberstein, 1996). This resulted in the production of 13 Hz SSVEP amplitude and phase time series data at each electrode for each participant with a temporal resolution of approximately five times the stimulus period, or 385 ms. Notably, as the cosine window averaging process maximises contributions to the average from the mid points of the cosine window, the effective temporal resolution of this process can be considered to be close to twice this figure, or approximately 195 ms.

5.7.2 SSVEP Artifact Rejection and Compensation

As described in Section 4.3.1, SSVEP signal power is concentrated at the stimulus frequency (Pipingas & Silberstein, 1996) and as a result SSVEP data possesses high signal-to-noise ratio and is relatively unaffected by EMG, EOG and eye-blink artifact, and 50 Hz mains interference (Silberstein et al., 1993). In order to ensure minimal impact of artifact stemming from clipping of the amplifier input stage as a result of intermittent scalp/electrode contact or residual EMG, EOG, eye-blink artifact, or 50 Hz mains interference, a two-stage process was applied to detect and compensate for artifact.

The first stage correlated the amplitude distribution of the raw EEG data with a Gaussian function. As EEG has a Gaussian amplitude distribution (McEwan & Anderson, 1975), the amplitude distribution of the acquired EEG would be expected to correlate strongly with a Gaussian function. This process effectively detects those electrodes that were subject to clipping of the analogue-to-digital converter during data acquisition. Electrodes with a correlation coefficient below 0.75 were classified as unacceptable.

The second stage of artifact detection correlated data from each electrode with the mean of the four nearest neighbouring electrodes. As data from closely-spaced neighbouring electrodes are expected to be highly correlated due to the effect of spatial smearing of the electrical signal resulting from passage through the scalp and CSF (Nunez, 1981), weak strength correlations may indicate artifact resulting from EMG and 50 Hz mains interference. Through this process, electrodes with correlation coefficients below 0.6 were replaced with the weighted means of the four nearest neighbouring electrodes. Participants were removed from further analysis if eight or more electrodes were flagged through this process.

5.7.3 SSVEP Event Averaging

In order to examine specific aspects of SSVEP responses associated with performance of the probe recognition task and reference task, the timing of the presentation of longer-duration tones associated with probed extracts were identified in each trial, and a five second epoch of SSVEP data was extracted - two seconds prior to the onset of the lengthened tone, and three seconds following the onset – and averaged across presentations of longer-duration tones separately for each electrode. This averaging process is similar to that used in ERP analysis whereby multiple stimulus presentations are averaged in order to improve the signal-noise ratio of the resulting average. In this study, the averaging process for probe recognition task responses incorporated only those tone groups probed by behavioural trials i.e. four- and five-tone groups in the first half of each pattern, and five-tone groups in the second half of the pattern. As a result of this process, averaged five second epochs associated with presentation of 71 longer-duration tones in the probe recognition task were generated for each participant at each electrode. A similar process was conducted for the reference task in order to generate an averaged five second epoch associated with presentation of longer-duration tones at each electrode.

5.7.4 SSVEP Data Normalisation

As the absolute amplitude of SSVEP data is subject to substantial variation across participants (Silberstein et al., 1990), responses of individual participants were normalised prior to averaging SSVEP responses across individuals. Normalisation was carried out by calculating the mean SSVEP amplitude response for the five second reference task epoch for each individual at each electrode, and then averaging across values for all 64 electrodes to determine a single normalisation value for each participant. Probe recognition task SSVEP amplitude time series data of each individual were then divided by their own normalisation factor to produce normalised SSVEP amplitude responses.

5.7.5 SSVEP Group Averaging

Following normalisation, group averaged SSVEP time series were produced for strong-grouping and non-grouping participants. Assignment of participants to groups for electrophysiological analysis is discussed in Section 6.1.4. As a first stage, the mean reference task SSVEP phase value for each respondent was subtracted from each of the SSVEP phase data points for the probe recognition task. This process was carried out as phase values for each participant are arbitrary, varying on a scale from $-\pi$ radians to $+\pi$ radians, and as a result the averaging process may result in cancellation. Instead, offsetting probe recognition task phase values relative to each participants' own reference task responses reduces cancellation effects during the group averaging process, and provides a clearer basis to assess phase variation in the probe recognition task relative to reference task responses. Following phase adjustment, group averages of strong-grouping and non-grouping participants' SSVEP amplitude and phase responses were calculated across participants. Finally, the mean of the group averaged reference task responses were subtracted from the group averaged probe recognition task time series responses to produce SSVEP amplitude and phase time series differences between the tasks. This process of subtracting activity associated with a reference task from that of an activation task to generate topographic difference maps is commonly adopted in functional imaging protocols in order to remove activation common to both tasks and distinguish responses that are unique to the activation task (e.g. Koelsch et al., 2002; Levitin & Menon, 2003; Tillmann et al., 2003). The approach is considered an effective method for use in brain imaging protocols for the identification of functionally active brain regions associated with specific cognitive processes (Friston, 1996). The resultant SSVEP amplitude difference responses were expressed in terms of normalised units, whereas phase responses were rescaled to reflect latency differences in milliseconds between the probe recognition task and mean reference task responses.

5.7.6 Topographic Mapping

The SSVEP amplitude and latency time series differences between the Probe Recognition Task and reference task were used to generate topographic maps that displayed regional features of grouped SSVEP responses at specific points in time (dynamic maps) and as a mean difference between the tasks (tonic maps). As discussed in Section 5.5.1, the use of a 64 electrode montage provided an average inter-electrode distance of 3.2 cm, which is adequate for assessing brain electrical activity responses associated with gross cortical regions (Silberstein et al., 1990). Values mapped between each electrode were calculated using a spherical spline interpolation procedure (Cadusch, Breckon, & Silberstein, 1992). Using difference data as a basis for the generation of topographic maps, these maps effectively represent differences in probe recognition task responses about the mean of reference task responses associated with processing the longer-duration tone. Warmer colours were used to represent reductions in amplitude or latency as compared to the mean reference task level, whereas cooler colours were used to represent amplitude or latency increases. A separate analysis generated self-referenced topographic maps to reflect differences between dynamic probe recognition task responses and the mean probe recognition task response for the five second epoch centred on the longer-duration tone. Separate maps were generated for strong-grouping and non-grouping averaged responses.

5.7.7 Statistical Mapping

Significance Probability Mapping (SPM Duffy, Bartels, & Burchfiel, 1981) based on the Hotelling's T^2 parameter was used to illustrate the topography of the statistical strength of effects. The Hotelling's measures were based on multiple bivariate T tests of the difference between the mean SSVEP in the reference task condition and the probe recognition task SSVEP time series data. Bivariate tests were implemented as statistical testing of SSVEP data must account for the expression of SSVEP amplitude and phase responses as complex numbers with real and imaginary components (Silberstein et al., 1995). Topographic maps of the square root of the Hotelling's T^2 parameter were produced for each comparison. The T value rather than the T^2 parameter itself was mapped as small areas could contain very large T^2 values which would dominate the map scale. Iso-T contours were used to illustrate the regions where the value of T corresponded to single comparison p values of 0.01, 0.005 and 0.001.

Statistical significance associated with T values in SPM maps was corrected for the multiple comparisons inherent in 64-electrode analysis. Whereas a p value of 0.05 is normally considered the threshold for statistical significance, a Bonferroni correction for multiple comparisons involves division of this value by the number of independent comparisons (Abt, 1983). A straightforward application of this principle based on the number of electrode sites would yield an adjusted p value of 0.05/64. However, this application does not account for the high degree of correlation between neighbouring scalp electrodes in the 64-electrode montage, and the fact that these neighbouring scalp sites are not independent (Nunez, 1981; Silberstein et al., 1995). Spatial principal components analysis suggests that a value of 5 is a more accurate representation of the degree of independence for 64 separate but correlated recording sites (Silberstein & Cadusch, 1992). Therefore, a p value of 0.01 was used as the threshold for statistical significance for data associated with the Hotelling's T analysis. Where multiple time points were examined in a task, this value was further divided by the number of time points sampled.

Chapter 6 RESULTS

Results of the Seashore Talents of Music Test sub-tests and probe recognition task experiment are presented in this chapter. Behavioural results will be presented first, followed by the SSPT results.

6.1 Behavioural Data

6.1.1 Seashore Test Results

Mean scores for each of the Seashore Talents of Music Test sub-tests are shown in Table 6.1.

Table 6.1 Percent correct scores for sub-tests of the Seashore Tests of Musical Talents

Seashore sub-test	Mean	SD	Min	Max
Pitch	81.5	14.4	36.0	100
Rhythm	91.3	6.0	73.3	100
Time	83.0	7.6	62.0	96.0
Tonal Memory	86.6	11.4	63.3	100

Participants generally completed the four Seashore sub-tests without difficulty. One exception was a single participant who completed 36% of the pitch sub-test items correctly. The Seashore pitch sub-test provides an indication of pitch acuity. That is, the ability to discriminate fine variations in frequency rather than the ability to distinguish among different tones in a diatonic pitch series, and as a result, this test result was not considered a basis to exclude this participant from analysis of the experimental tasks.

6.1.2 Probe Recognition Score and Response Time Results

Mean percent correct recognition scores and response times for the probe recognition task performed by participants while their brain electrical activity responses were recorded are shown in Table 6.2. The mean percent correct recognition for probes over both pattern halves was 62.6% and the mean reaction time was 905 ms. Correct recognition scores did not differ for trials probing the two halves of the pattern. Repeated measures ANOVAS indicated that response times for trials probing the first pattern half were significantly greater than response times for trials probing the second pattern half across all trials (F(1,49)=36.7; $p<0.001$) and across correct trials only (F(1,49)=24.0; $p<0.001$).

Table 6.2 Percent correct scores and reaction times for valid trials of the probe recognition task

Group means and standard deviations (in parentheses) for probe recognition task percent correct scores, response times across all trials, and response times for correct trials only. Data are presented for overall task performance, and separately for trials that probed the first or second half of patterns.

	Correct (%)	Response Time (ms) All trials	Response Time (ms) Correct Trials
Overall	62.6 (9.9)	905 (284)	867 (277)
1st Group	62.6 (13.3)	968 (303)	935 (309)
2nd Group	62.5 (12.8)	841 (283)	798 (277)

Mean percent correct recognition scores for probe recognition task within-group and across-group probe trials are shown in Table 6.3. Stronger recognition for within-group extracts than across-group extracts was evident in scores for both the first and second halves of the pattern. Probe recognition scores were submitted to a repeated measures analysis of variance with probe type (within-group, across-group) and pattern half (1st half, 2nd half) as factors. This analysis revealed a significant main effect of probe type ($F(1,49) = 12.05$, $p < 0.001$), no significant main effect of pattern half ($F(1,49) = 0.01$, $p = 0.97$), and no significant interaction between probe type and pattern half ($F(1,49) = 2.22$, $p = 0.143$). Trials probing within-group pattern extracts were correctly recognised on significantly more trials than those probing across-group pattern extracts. These findings support the action of relatively lengthened tones in organising working memory representations of the patterns.

Table 6.3 Percent correct scores and reaction times for within-group and across-group trials of the probe recognition task

Group means and standard deviations (in parentheses) of percent correct scores and response times for correct and incorrect trials presented separately for within-group and across-group probe recognition task trials. Data are presented for overall task performance, and separately for trials that probed the first or second half of patterns.

	Within-group probe Correct (%)	Across-group probe Correct (%)	Within-group probe Response Time (ms) (correct)	Across-group probe Response Time (ms) (correct)	Within-group probe Response Time (ms) (incorrect)	Across-group probe Response Time (ms) (incorrect)
Overall	65.4 (11.0)	59.8 (11.9)	846 (280)	884 (297)	936 (319)	1003 (349)
1st Group	64.1 (14.1)	61.2 (16.8)	897 (317)	961 (427)	965 (347)	1127 (489)
2nd Group	66.7 (15.8)	58.5 (15.2)	795 (328)	800 (290)	913 (455)	892 (354)

As presented in Table 6.3, longer response times for correctly recognised across-group extracts were evident in response times for the first half of the pattern, whereas response times for correctly recognised trials in the second half of the pattern showed only a marginal increase for across-group conditions. Response times associated with correct and incorrect responses to probe recognition trials were submitted to a repeated measures analysis of variance with probe type (within-group, across-group), pattern half (1st half, 2nd half) and outcome (correct/incorrect) as factors. This analysis indicated a strong significant main effect of probe type ($\underline{F}(1,49) = 26.13$, $\underline{p} < 0.001$), pattern half ($\underline{F}(1,49) = 4.60$, $\underline{p} < 0.05$), and outcome ($\underline{F}(1,49) = 15.05$, $\underline{p} < 0.001$), and a weakly significant interaction between probe type and pattern half ($\underline{F}(1,49) = 3.936$, $\underline{p} = 0.053$). No other interactions reached significance - probe type and outcome ($\underline{F}(1,49) = 0.09$, $\underline{p} = 0.766$); pattern half and outcome ($\underline{F}(1,49) = 0.667$, $\underline{p} = 0.418$), and probe type, pattern half and outcome ($\underline{F}(1,49) = 1.71$, $\underline{p} = 0.197$). Main effects of this analysis indicate a significant difference in response times for within-group and across-group trials, whereas a weak interaction between probe type and pattern half indicates that differences between response times to probe types weakly differ by pattern half. Significant main effects also indicate that response times were significantly longer for the first half of the pattern, and that response times were significantly longer for incorrect responses. In order to explore the basis of the significant interaction between probe type and pattern half, post-hoc exploration of mean response times was conducted via paired t-tests. This analysis revealed that across-group response times were significantly longer than within-group response times in trials probing the pattern first half (t = -2.80, p < 0.005, one-tailed), whereas differences between within-group and across-group response times in the pattern second half were not significantly different (t = -0.30, p = 0.384, one-tailed).

As indicated by the analysis examining response times for both correct and incorrect responses, correct response to trials probing the first half of the pattern required significantly longer response times than probes extracted from the second half of the pattern. Although correct across-group trials demonstrated longer mean response times than correct within-group trials, across-group trials were associated with substantial variance in response times, and were not significantly greater than within-group probe response times when only correct responses were examined.

6.1.2.1 Impact of musical training on task performance

The extent that the number of years of musical training, and musical perception ability as assessed by the Seashore Talents of Music sub-tests were related to probe recognition task performance was investigated via Pearson’s Correlation Tests, illustrated in Table 6.4. Results presented in Table 6.4 demonstrate that musical training and performance on Seashore Pitch, Rhythm and Tonal Memory subtests was significantly correlated with overall performance on the probe recognition task. However, these significant relationships were predominantly driven by performance for within-group probes; only Seashore Rhythm sub-test performance demonstrated significant correlations with responses for both within-group and across-group probes. While a strong significant relationship was evident between musical training and probe recognition task performance overall, this data indicate that this relationship is driven only by responses to within-group probes occurring in the first group, whereas musical training is not significantly related to other components of the task.

Table 6.4 **Correlations between performance on components of the probe recognition task and musical training**

Correlations between probe recognition task percent correct score, number of years musical training and performance on four Seashore Talents of Music Test sub-tests.

	All probes	Within-group probe	Across-group probe	Within-group probe 1st Group	Across-group probe 1st Group	Within-group probe 2nd Group	Across-group probe 2nd Group
Years Music Training	**.309***	**.422*****	.128	**.347***	.102	.275	.090
Seashore Pitch	**.315***	**.281***	.266	.108	.127	**.296***	**.280***
Seashore Rhythm	**.333***	**.288***	**.288***	.214	.125	.206	**.315***
Seashore Time	.206	.202	.156	.084	.156	.201	.078
Seashore Tonal Memory	**.333***	**.310***	.271	.021	.254	**.410*****	.148

n=50 * $p < 0.05$, two-tailed; ** $p < 0.01$, two-tailed; *** $p < 0.005$, two-tailed

- uncorrected p values

6.1.3 Summary of Behavioural Results

Analysis of relationships between probe recognition task performance, musical training, and musical perception/acuity tasks indicate that performance of the probe recognition task taps aspects of processes developed through musical training and required for performance of the Seashore Tonal Memory task, but only in response to within-group trials of the probe recognition task.

Pitch and note duration information presented in within- and across-groups was balanced across trials, only the position of longer-duration notes varied within the extracted series. This key difference between the conditions modulated the degree that processes developed through musical training and required for performance of the Seashore Tonal Memory subtest were applied to performance of the trials. Trials extracted from a position that does not accord with grouping structure determined by longer notes were less strongly associated with these processes. In particular, the probe type impacted on ability to apply processes supporting working memory for pitch information as required for performance of the Seashore Tonal Memory subtest. The Tonal Memory subtest uses only identical note durations, which may be a key factor in understanding different relationships between Tonal Memory subtest performance and within- and across-group Probe Recognition trials, and indicates a strong impact of the note duration information on the effective use of processes supporting working memory for pitch information. As tone durations used in the experimental task varied by 600 ms, processing of note durations did not tap the fine-grained time-based processing required for successful performance of the Seashore Time Subtest, and significant correlations between the Seashore Subtest and the probe task were not observed.

In summary of behavioural data associated with performance of the probe recognition task, participants demonstrated significantly better recognition of within-group probes than across-group probes, and significantly longer response times for across-group probes than within-group probes, although significant differences in response times were restricted to trials probing the first group. These findings indicate that participants recognised probes conflicting with a rhythmic structure cued by longer-duration notes more slowly, and less accurately than probes that match a rhythmic structure cued by longer notes, and thus support the use of longer notes in structuring working memory representations of tone sequences. As such, these findings support the first experimental hypothesis which proposes that recognition of extracts from tone sequences will be significantly better for those extracts presented in accordance with rhythmically grouped structure compared to extracts that conflict with rhythmically grouped structure.

6.1.4 Use of Scores to Determine Grouping Strength

In order to delineate those participants who demonstrated superior recognition of probe recognition task within-group probes over across-group probes from those participants with a lesser tendency to do so, a grouping score was calculated for each participant to represent the difference in performance between within-group and across-group trials.

In this manner, positive grouping scores represent better recognition performance for within-group probes compared to across-group probes, whereas negative grouping scores represent poorer recognition performance for within-group probes compared to across-group probes, and a grouping score of zero represents no difference in recognition performance for within-group probes compared to across-group probes.

An extensive body of literature discusses use of difference or change scores, predominantly with regard to their use in clinical research designs and educational assessment as a measure of change in pre- and post-test designs. In this context, caution has been noted in conjunction with single-item, single-source longitudinal measures which demonstrate an association between lower pre-test scores and greater likelihood of demonstrating a post-test effect. Further criticism of difference scores used in this longitudinal context are that difference scores fail to take into account the status of the individual at the pre-test stage as a determinant of the difference measure, and that the reliability of the difference score is lower than the reliabilities of the component measures (Cronbach & Furby, 1970). Specific arguments have been raised with regard to use of difference scores as a basis for selection of individuals in change-related contexts. Use of difference scores in clinical research contexts has been proposed to provide a 'spurious advantage' for individuals with low pre-test scores. In these scenarios, baseline free measures that factor in pre-test performance such as residual gain scores have been proposed as a more appropriate measure (Cronbach & Furby, 1970). However, it has also been noted that residual gain scores discard genuine and important change information and as a result, a number of authors have instead argued against their adoption, and affirmed the use of difference scores (Newman, 1994; Rogosa & Willett, 1983; Zimmerman & Williams, 1982).

Difference scores have been extensively used to identify subpopulations in neuroimaging and clinical neuropsychological research (e.g. Fisher, Tierney, Rourke, & Szalai, 2004; Hawkins, Plehn, & Borgaro, 2002; Iverson, Woodward, & Green, 2001; Jacobson, Delis, Bondi, & Salmon, 2002; Murrey, Hale, & Williams, 2005; Purcell, Lewine, Caudle, & Price, 1998). Grouping scores as used in the current research represent the difference in performance between distinct but conceptually linked processes as determined by multiple-item measures obtained at a single point in time. Usage of grouping scores as a selection criterion for individuals in this research design does not equate with use of change scores that are based on single-item, single source, longitudinal measures. In this research, grouping scores draw on multiple-item, multiple-source, cross-sectional measures, and are inherently less susceptible to issues noted with regard to change scores, providing a suitable method for the identification of recognition performance differences in individuals as a function of probe type. Figure 6.1 presents individuals' grouping scores.

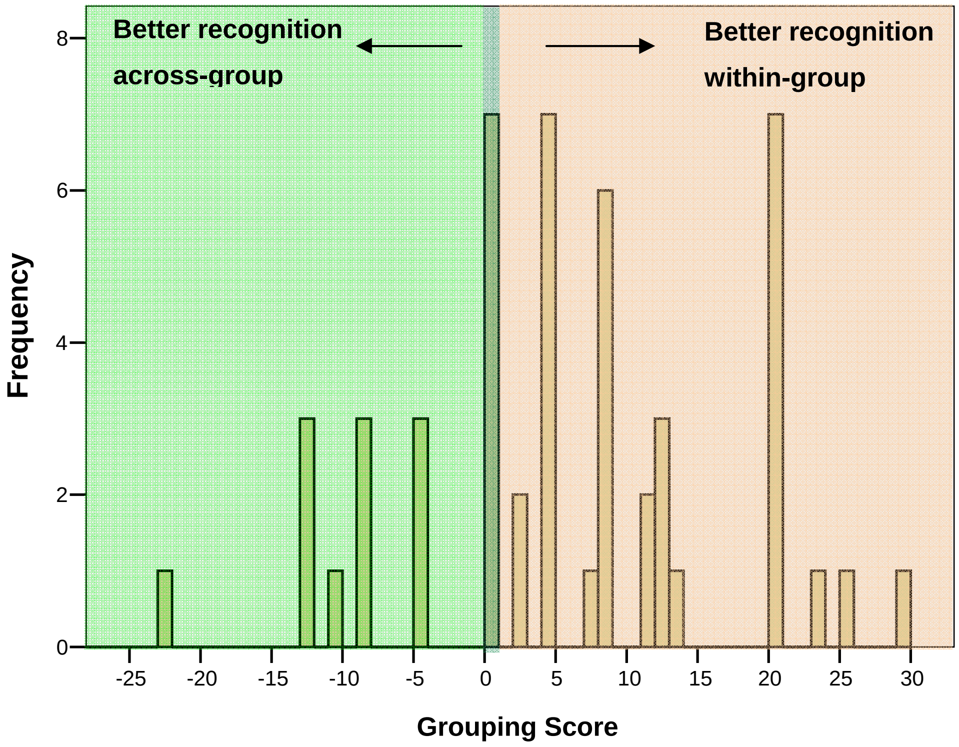

Figure 6.1 **Individual participants' probe recognition task grouping scores**

Frequency distribution of individual participants' grouping scores in the probe recognition test. Scores greater than zero indicate better overall recognition of within-group probes, whereas scores less than zero indicate better recognition of across-group probes.

Table 6.5 presents Pearson's Correlation Coefficients for comparisons between grouping scores, musical training, and performance of the probe recognition task components. Data presented in Table 6.5 reveal that neither overall performance on the probe recognition task nor musical training was significantly related to grouping scores. In the 1st half of the pattern, grouping scores were most strongly related to across-group probe performance, whereas responses to both within-group and across-group probes in the 2nd half of the pattern were strongly related to grouping scores.

Overall results presented in Table 6.4 and Table 6.5 indicate that performance on the probe recognition task is related to musical training and music perceptual acuity as assessed by the Seashore Talents of Music sub-tests. The data also indicate that differences in correct recognition between within-group probes and across-group probes assessed by grouping scores is not significantly related to musical training or overall performance on the probe recognition task.

Table 6.5 **Correlations between probe recognition task grouping scores, years musical training and performance on components of the probe recognition task**

	Years Musical training	All probes	Within-group probe	Across-group probe	Within-group probe 1st Group	Across-group probe 1st Group	Within-group probe 2nd Group	Across-group probe 2nd Group
Grouping Score	0.272	-0.097	**0.433*****	**-0.558*****	0.206	**-0.437*****	**0.419*****	**-0.391****

n=50 * $p < 0.05$, two-tailed; ** $p < 0.01$, two-tailed; *** $p < 0.005$, two-tailed

- uncorrected p values

Grouping scores were used to divide the pool of participants into three groups. Sixteen participants who demonstrated a strong enhancement of recognition performance for within-groups over across-groups and were delineated as ‘strong-grouping’ participants (grouping scores of 1 SD or greater than a score of 0 representing no difference between within- and across-groups, M=18.6%); 17 weak-grouping participants (0 < grouping score < 1 SD, M=4.6%) and 17 ‘non-grouping’ participants (grouping score <= 0, M =-5.6%) were identified. Table 6.6 presents mean grouping scores and unpaired t-test results comparing the mean scores for strong-grouping, weak-grouping and non-grouping participants.

An ANOVA comparing mean grouping scores across the groups indicated a significant difference between mean scores (df=2,47; F=76.18, p<0.001) and subsequent independent t-tests indicated highly significant differences between the mean scores for strong-grouping vs. weak-grouping participants (t=7.64, p<0.001); strong-grouping vs.

non-grouping participants (t=5.26, p<0.001), and weak-grouping vs. non-grouping participants (t=-11.62, p<0.001).

Table 6.6 Mean grouping scores for the three participant groups

Mean scores and ANOVA comparisons for the three participant groups determined by grouping scores.

	Strong-grouping (N=16)	Weak-grouping (N=17)	Non-grouping (N=17)
Mean Grouping Score (%)	18.6	4.6	-5.6
	t=7.64, p<0.001		
		t=5.26, p<0.001	
			t=-11.62, p<0.001

In order to maximise the opportunity for revealing effects related to grouping performance differences in the experimental sub-populations, subsequent analysis examined responses for strong-grouping and non-grouping participants only. As grouping scores were used as a basis to assign participants to separate groups for analysis of neurophysiological responses, independent T-tests were conducted to examine the extent that strong-grouping and non-grouping participants differed on aspects of task performance or ability that may have impacted on neurophysiological responses differentially. These tests explored any potential differences between strong-grouping and non-grouping participants' probe recognition task overall score, degree of musical training and music perceptual abilities as examined by Seashore sub-tests. No significant differences between the groups was observed in probe recognition task overall score (t=-0.442, p=0.661, two-tailed), number of years of musical training (t=1.38, p=0.18, two-tailed), or on Seashore Tonal Memory (t=0.25, p=0.81, two-tailed), Pitch (t=0.96, p=0.34, two-tailed), Rhythm (t=0.50, p=0.62, two-tailed), or Time (t=0.15, p=0.32, two-tailed) sub-test scores. As such, differences in neurophysiological responses between groups would not be significantly associated with differences between groups in overall performance of the probe recognition task, in the degree of musical training, or performance on Seashore subtests. Grouping of individuals into the three grouping score groups is presented in Figure 6.2.

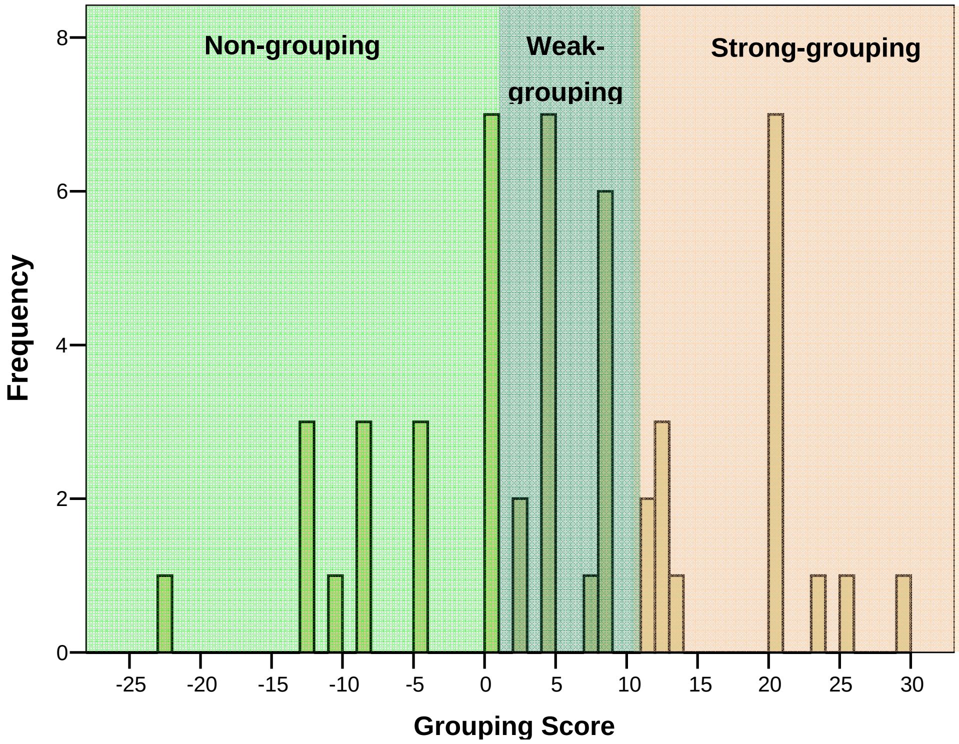

Figure 6.2 Assignment of individuals to the three grouping scores groups

Frequency distribution illustrating assignment of individual participants to three groups based on strength of grouping scores. Participants with grouping scores 1 SD or greater than 0 were assigned as strong-grouping participants, participants with grouping scores greater than 0 and less than 1 SD greater than 0 were assigned as weak-grouping participants, and participants with grouping scores of 0 or less were assigned as non-grouping participants.

6.1.5 Post-Experimental Questionnaire Responses

Although meta-cognition may be influenced by a number of factors and may not always reflect objective cognitive processes under investigation, relationships between respondents' self-reported strategies and grouping performance were examined in order to determine the extent that self-reported strategies impacted on grouping performance.

Post-experiment responses were submitted to independent t-tests. This analysis indicated that although strong-grouping participants noted the inclusion of longer tones in the patterns more often than non-grouping participants, this difference was not significant (t=1.288, p=0.208, two-tailed). Similarly, although strong-grouping participants indicated influence of longer-duration tones on listening to and remembering the patterns more often than non-grouping participants, this difference was not significant (t=1.468, p=0.153, two-tailed). By contrast, non-grouping participants indicated a significantly greater tendency to listen to and remember the patterns on a tone-by-tone basis (t=-3.347, p=0.002, two-tailed). Non-grouping participants also indicated use of pitch contour information to remember patterns more often than strong-grouping participants, although this difference was not significant (t=-1.169, p=0.252, two-tailed). Use of a strategy to remember the patterns were more often noted by strong-grouping participants, although this comparison was not significant (t=1.058, p=0.299, two-tailed). Response frequencies to post-experimental questions for strong-grouping and non-grouping participants appear in Figure 6.3.

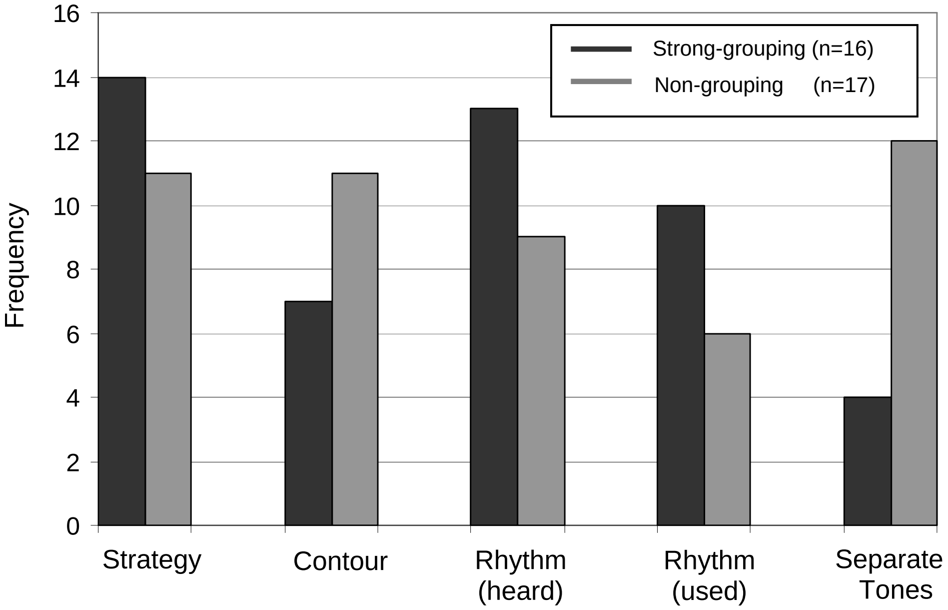

Figure 6.3 Post-experiment responses

Response frequencies to questions probing strategies used by participants in the probe recognition task: strategy – whether any strategy was used in listen to and remember patterns; contour – whether the pitch contour was used to remember patterns; rhythm (heard) – whether longer-duration tones were noted in the patterns; rhythm (used) – whether longer-duration tones were used as a basis to remember the patterns; separate tones – whether patterns were listened to and remembered on a tone-by-tone basis.

6.2 Neurophysiological Data

In this chapter, electrophysiological data is presented in two major sections. The first section is a comparison of responses associated with performance of the probe recognition task and reference task. The second section examines responses of strong-grouping and non-grouping participants in the probe recognition task. For each section, analysis of electrophysiological data is conducted in three stages, each of which is presented separately. These analyses examine the topographic distribution of mean responses associated with task performance; topographic distribution of responses associated with task performance at specific points in time, and time-series responses of specific electrode sites. In each of the analyses examining probe recognition task responses, emphasis will be placed on SSPT responses associated with the *encoding* phase of the task, as the literature indicates that grouping of sequential information in working memory occurs at the encoding stage, and as such, this phase of the task is most likely to demonstrate grouping-related effects.

6.2.1 Topographic Mapping Considerations

As discussed in Section 5.7.5, in keeping with standard practice for presenting electrophysiological data, SSPT responses presented throughout this section are constructed via the subtraction of a reference level from responses associated with the task of interest or ‘activation task’. As such, both topographic maps and single electrode time series reflect differences between an activation task and a reference level.

The colour coding for topographic throughout this section reflects differences between the activation task and the reference level. In keeping with interpretation of the probe-ERP paradigm (Papanicolaou et al., 1987) (see Section 4.2), regions where the SSVEP amplitude was *attenuated* during the activation task with respect to the reference or baseline task are represented by warmer colours and a positive scale, and regions where there were relative SSVEP latency reductions (negative scale) during the activation task are also represented by warmer colours. SSVEP amplitude is expressed as normalised amplitude for the pooled data, due to the normalisation procedure that was performed during cross subject averaging. SSVEP latency is expressed in milliseconds (ms).

6.3 Comparison of Probe Recognition and Reference Tasks

SSVEP data of seven participants failed artifact detection criteria described in Section 5.7.2, and were excluded from subsequent analysis. This left a total of 43 participants available for examination of SSVEP responses, consisting of 15 strong-grouping participants, 13 weak-grouping participants, and 15 non-grouping participants. The initial analysis examined SSPT responses across the entire participant group and examined differences between SSPT responses elicited by longer duration notes in the probe recognition and reference tasks. As stimuli presented in each of these tasks featured equivalent pitch and rhythm information, differences between responses elicited by the tasks may be related to differences in cognitive processes resulting from task demands. Successful performance of the reference task required listening to sequential pitch/rhythm events and responding to a rare highly deviant pitch event, whereas successful performance of the probe task required listening to *and encoding* sequential pitch/rhythm events in working memory for subsequent recognition. As such, differences between SSPT responses elicited by presentation of longer duration notes in these tasks may be linked with differential demands on the encoding of sequential pith/rhythm information in working memory.

6.3.1 Mean SSVEP Topography in the Activation and Reference Tasks for the Entire Participant Group

The topographic distribution of the mean SSVEP amplitude and latency responses and associated Hotelling’s T statistical topographic map are illustrated in Figure 6.4. SSVEP amplitude and latency changes in these maps represent the amplitude and latency difference between the mean SSVEP responses during the probe recognition task and the mean reference task SSVEP response at each electrode for the 5 s period centred on the onset of the longer-duration note in each task. As such, these maps provide an indication of sustained SSVEP differences between the two tasks during the encoding phase of the probe recognition task. Figure 6.4 demonstrates that mean amplitude responses in the probe recognition task were attenuated at all electrode sites compared to mean responses in the reference task. In particular, SSVEP amplitude reductions were strongly evident at temporal and temporoparietal electrode sites in both hemispheres. Latency responses demonstrate clear laterality differences, with latency increases extending throughout the right hemisphere, particularly at right posterior frontal regions. Left hemisphere latency responses demonstrate strong decreases at left temporal and parietal regions and weak latency increases at frontal sites. Differences between the probe recognition and reference tasks are associated with strongly significant Hotelling's T responses at all electrode sites at the $p < 0.001$ level, with a maxima at left temporal regions.

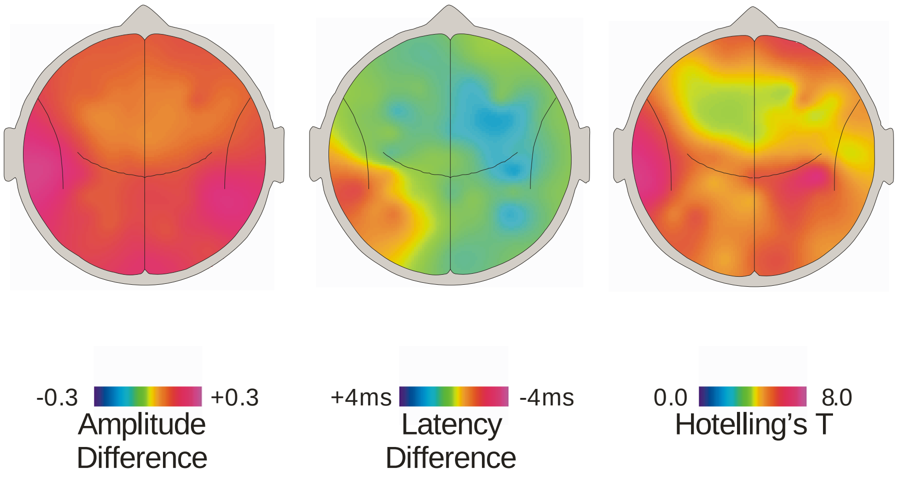

Figure 6.4 **Topography of mean SSVEP differences between the reference task and the probe recognition task for the entire participant group**

Topographic differences for SSVEP amplitude (normalized units) and latency (ms) between the reference task mean and probe recognition task mean for the entire respondent group (n=43). Hotelling's T maps indicate the statistical strength of these differences. Iso-T contours represent uncorrected p values of 0.01, 0.005 and 0.001.

6.3.2 Dynamic SSVEP Topography in the Activation and Reference Tasks for the Entire Participant Group

Examination of mean SSVEP responses provides an indication of sustained differences is task responses. The following section discusses task-related differences in dynamic SSVEP responses.

Topographic distribution of the SSVEP amplitude and latency responses and associated Hotelling's T statistical topographic maps for specific time points during task performance are illustrated in Figure 6.6 for the reference task and Figure 6.7 for the probe recognition task. SSVEP amplitude and latency changes in these maps represent the amplitude and latency difference between dynamic SSVEP responses at each electrode and the mean SSVEP response for that task at each electrode for the five second period centred on the onset of the longer-duration note. Amplitude or latency reductions compared to the mean response in each task are represented by warmer colours, whereas amplitude or latency increases compared to the mean response in each task are represented by cooler colours. The Hotelling's T maps are significance probability maps that indicate the consistency of SSVEP differences between dynamic response to the probe recognition task and mean responses to the reference task across the participants. Higher T values are represented by warmer colours and indicated more consistent responses across the participant group. Contour lines used in the maps represent uncorrected p values of 0.01, 0.005, and 0.001.

The stimulus design used for this research adopted a constant timing between tone offsets and onsets, an inter-tone interval of 50 ms. Throughout discussion of these results, where SSVEP responses are discussed with reference to tone onsets, timings reflect responses evoked in response to the combined sequence of events consisting of a tone offset followed by a tone onset. Maps illustrated in Figure 6.6 and Figure 6.7 present responses at four points in times associated with presentation of a longer-duration note and a subsequent note in the reference task and probe recognition task respectively. The four timings used for maps illustrated in Figure 6.6 and Figure 6.7 are represented graphically in Figure 6.5. Maps in the top row of each figure represent SSVEP responses occurring 770 ms following the onset of a longer-duration note. This timing is equivalent to a period of 170 ms following the timing of when a note onset *would* have occurred if a standard 600 ms IOI was actually presented. For brevity, this timing will be referred to as '170 ms following the missing onset'. Maps in the second row of each figure represent SSVEP responses occurring approximately 1 s (1080 ms) following the onset of a longer-duration note. This timing is equivalent to a period of 480 ms following the timing of when a note onset *would* have occurred if a standard 600 ms IOI was actually presented. For brevity, this timing will be referred to as '480 ms following the missing onset'. Maps in the third row represent responses occurring 185 ms after the onset of a note following the longer-duration note, and maps in the bottom row represent responses occurring 490 ms after the onset of a note following the longer-duration note. For brevity, in accordance with the core proposal of this thesis and behavioural results demonstrating that longer-duration tones may cue perception of group boundaries, and that notes occurring immediately after longer notes may be perceived as initiating a separate group, the tone following the lengthened tone will be referred to as 'the initial tone'.

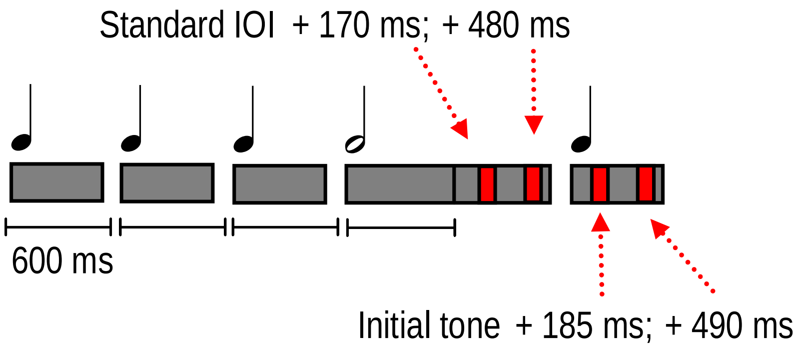

Figure 6.5 **Task timings used for SSVEP topographic maps**

As discussed in Section 5.7.7, adjustment of significance threshold values via a Bonferroni correction of 5 yields a significance threshold of 0.01 for multiple electrode comparisons. Correction for the multiple time points presented in each of Figure 6.6 and Figure 6.7 by dividing 0.01 by 4 yields a significance threshold of 0.0025 for Hotelling's T values presented in each figure. In view of these corrections, areas inside iso-T contours representing a p value of 0.001 demonstrate significant differences from the mean response, whereas areas inside iso-T contours representing a p value of 0.005 approach significant differences from the mean response.

Figure 6.6 presents SSVEP responses obtained in the reference task and demonstrates that when performing a task that requires listening to sequential pitch/rhythm events and responding to a rare highly deviant pitch event, presentation of a rare longer-duration note elicits significant SSVEP responses in lateral left hemisphere and right temporoparietal regions at approximately 170 ms following the timing of when a note onset was expected but did not occur i.e. 170 ms following the missing onset. SSVEP responses occurring at approximately 480 ms following the missing onset approached significance at left and right temporoparietal areas. Significant responses at both timings were as a result of amplitude and latency reductions. In response to a note onset following a longer-duration note (the initial tone), SSVEP amplitude and latency reductions demonstrated significance at a right temporoparietal site at 185 ms post-onset and approached significance in diffuse left and right frontal regions, whereas SSVEP amplitude and latency increases approached significance at left temporal, mid-frontal, and right posterior inferior frontal sites at 490 ms post-onset.

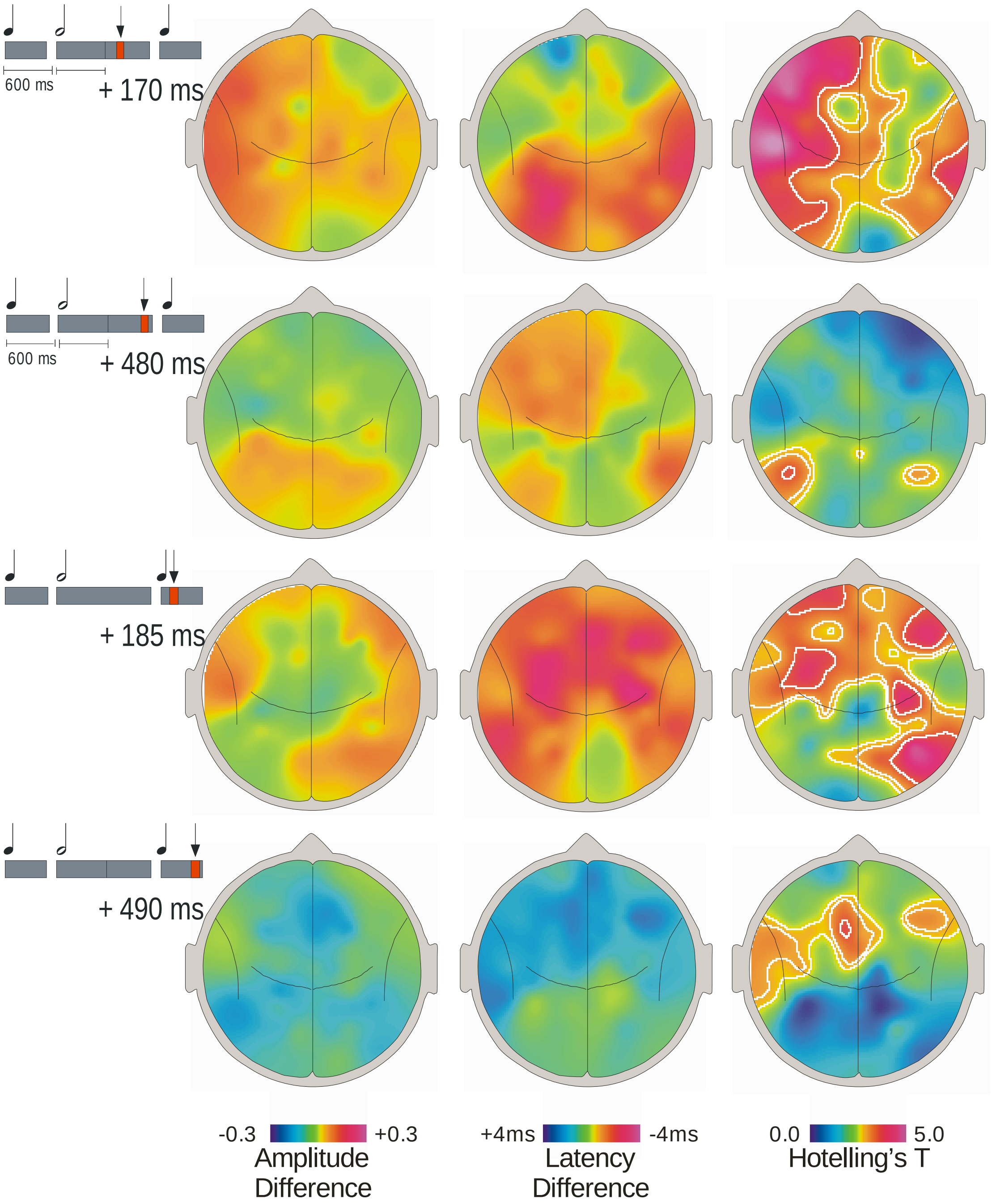

Figure 6.6 **Topography of reference task dynamic SSVEP responses for the entire participant group**

Topographic differences for SSVEP amplitude (normalized units) and latency (ms) between the reference task mean and reference task time series for the entire respondent group (n=43). Hotelling's T maps indicate the statistical strength of these differences. Iso-T contours represent uncorrected p values of 0.01, 0.005 and 0.001. Four time points are shown.

Figure 6.7 illustrates SSVEP maps that examine differences between dynamic probe recognition task responses and mean reference task levels at each electrode.

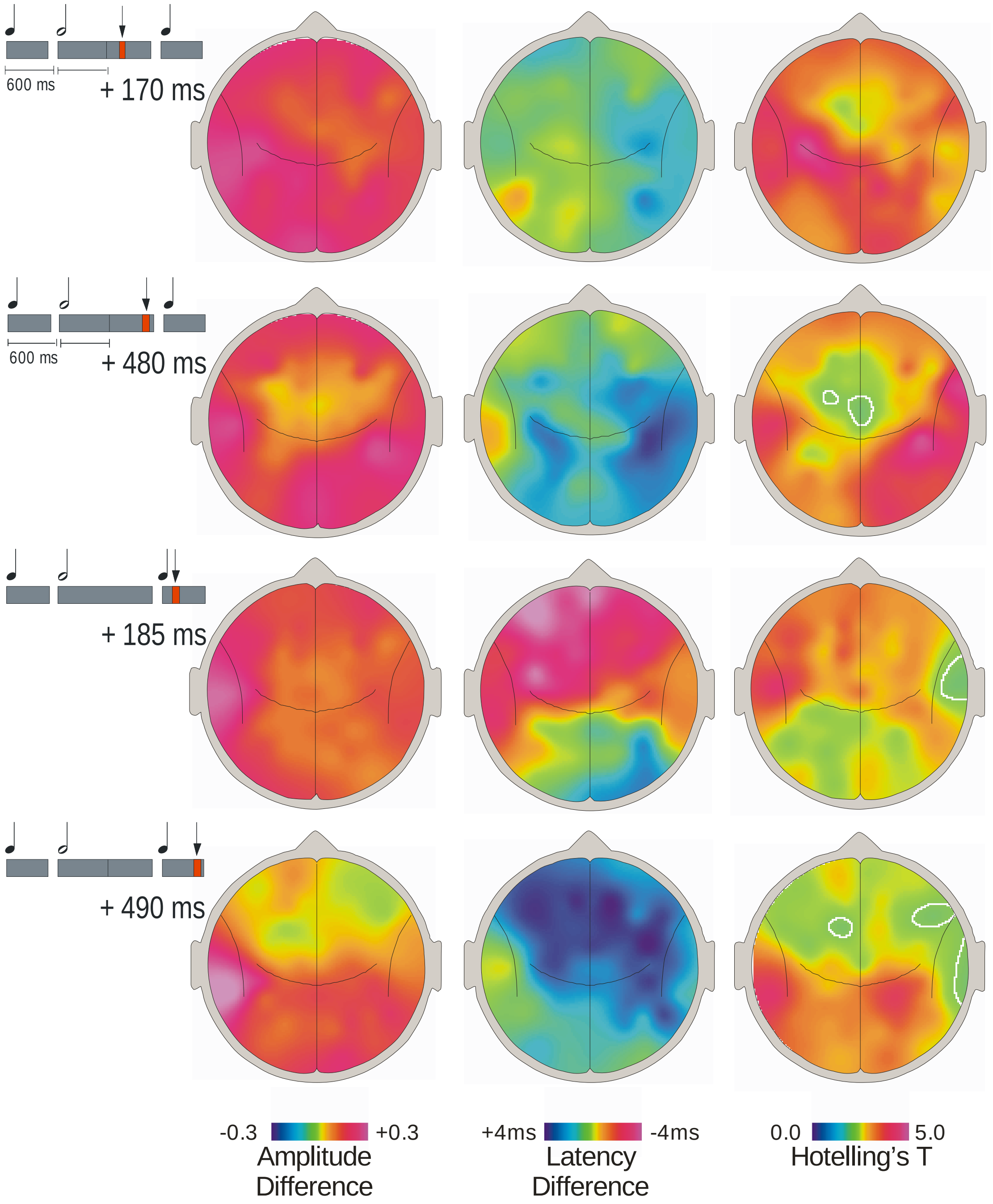

Figure 6.7 **Topography of probe recognition task dynamic SSVEP responses for the entire participant group**

Topographic differences for SSVEP amplitude (normalized units) and latency (ms) between the reference task mean and probe recognition task time series for the entire respondent group (n=43). Hotelling's T maps indicate the statistical strength of these differences. Iso-T contours represent uncorrected p values of 0.01, 0.005 and 0.001. Four time points are shown.

As discussed in Section 5.7.5 with reference to topographic difference maps, amplitude and latency changes in these maps represent the amplitude and latency difference between dynamic SSVEP responses during the probe recognition task and the mean reference task SSVEP response at each electrode for the 5 s period centred on the onset of the longer-duration note in each task. Figure 6.7 illustrates that SSVEP amplitude responses in the probe recognition task during the sustained portion of the longer-duration note are strongly attenuated compared to the mean reference task amplitude levels, whereas SSVEP latency reductions in the probe recognition task are only weakly reduced in comparison to the mean reference task levels. By contrast, SSVEP latency reductions for the initial tone are strongly evident over bilateral temporal and frontal regions at 185 ms post-onset, and latency increases are strongly evident in diffuse frontal, right temporal and right parietal regions at 480 ms post-onset. These responses are associated with diffuse strongly significant responses in Hotelling's T maps indicating that with the exception of responses occurring at right temporal regions during the initial tone, differences between the probe recognition task and reference task were significant at all electrode sites in each of the timings represented during the longer-duration note and subsequent note.

In order to identify significant regional contributions associated with presentation of the tone following a lengthened tone in the probe recognition task, dynamic SSVEP responses in the probe recognition task were compared with the mean level for this task. This analysis removes the impact of strong SSVEP amplitude differences between the probe recognition task and the reference task on the statistical analysis. Figure 6.8 presents topographic SSVEP maps showing differences between dynamic and mean level responses obtained in the probe recognition task for the tone following a lengthened tone in the probe recognition task. The note onset following the longer-duration note in the probe recognition task was associated with amplitude reductions and strong latency reductions in bilateral frontal areas at 185 ms post-onset and these responses were highly significant across bilateral mid- and posterior frontal regions.

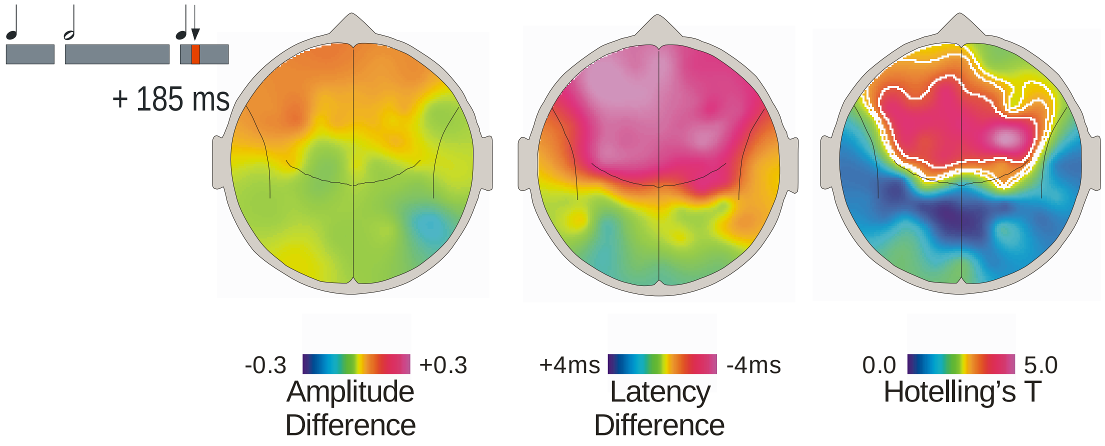

Figure 6.8 **Self-referenced topography of probe recognition task dynamic SSVEP responses for the entire participant group**

Topographic differences for SSVEP amplitude (normalized units) and latency (ms) between the probe recognition task mean and probe recognition task time series for the entire respondent group (n=43) for early responses to a note following the lengthened duration note. Hotelling's T maps indicate the statistical strength of these differences. Iso-T contours represent uncorrected p values of 0.01, 0.005 and 0.001. One point in time is shown representing 185 ms after the onset of a note following the lengthened duration note.

6.3.3 Task-Related Single Electrode Time Series

Dynamic topographic maps provide an overview of SSVEP topography associated with task performance at specific points in time. By comparing topographic differences in task-associated responses, topographic maps indicate specific regions that may differ in response between tasks.

Detailed examination of specific electrode sites that demonstrate differences in responses between tasks may be achieved through examination of single electrode time series. By examining responses obtained at a single electrode site, continuous dynamic responses for a single site may be observed and compared across tasks. Figures 6.9 to 6.11 illustrate single electrode time series responses obtained in the Probe Recognition and reference task centred on presentation of the lengthened-duration note. Unless otherwise indicated, in these Figures both SSVEP latency and amplitude are shown with respect to the mean latency or amplitude during the reference task. These mean reference task levels have arbitrarily been set to zero. Six dashed vertical lines represent timings of standard note onsets, whereas the solid vertical line labelled 'Standard Onset Timing' indicates the mid-point of the lengthened tone, which reflects the point in time in each task where a note onset *would* have occurred had a standard 600 ms IOI occurred rather than a 1200 ms IOI associated with a lengthened-duration note.

Figure 6.9 illustrates a 4.5-second epoch of SSVEP latency responses in the Probe Recognition and reference tasks at electrode 18, a right frontal location equivalent to F4 in the International 10-20 system.

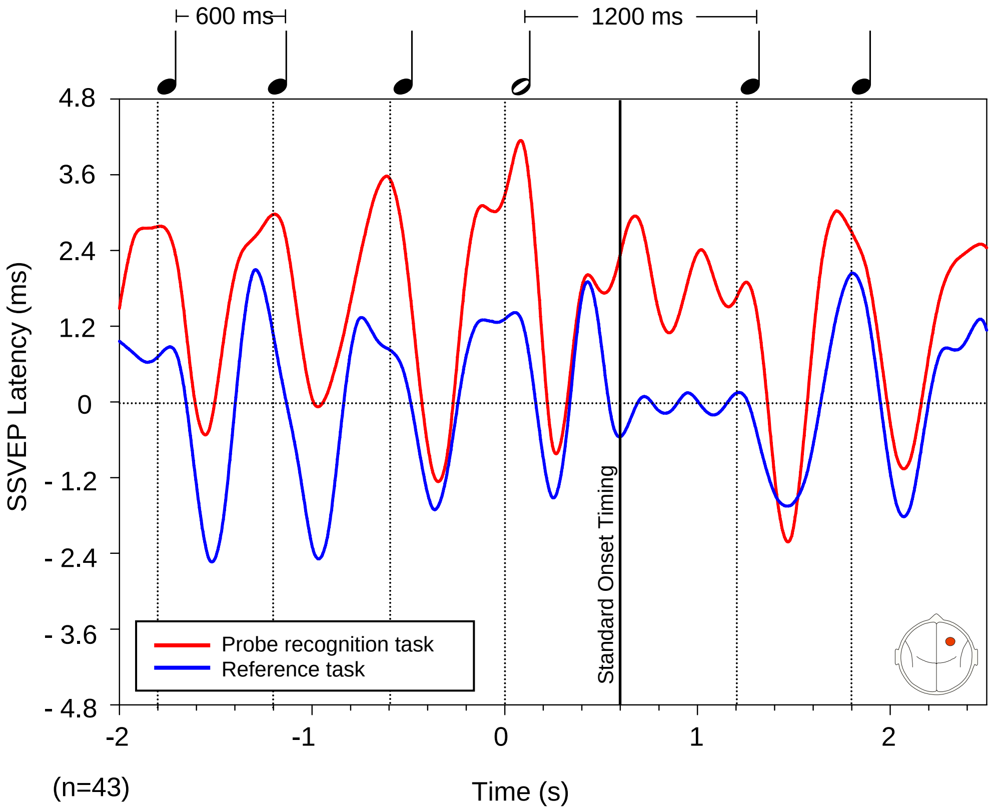

Figure 6.9 **SSVEP latency time series in the probe recognition and reference tasks at electrode 18 (right frontal, F4)**

SSVEP latency time series in the probe recognition task (red) and reference task (blue) at electrode 18, a right frontal location equivalent to F4 in the International 10-20 system. SSVEP latency responses in this figure are referenced to the mean reference task level for this electrode, which has arbitrarily been set to 0.

The right frontal electrode site represented in Figure 6.9 demonstrates dynamic and sustained features in common with responses observed over mid-frontal electrode sites in both tasks. At this electrode site, note onsets in both tasks are typically followed by an SSVEP latency reduction peaking at approximately 200-250 ms post-onset. SSVEP latency increases following onsets demonstrate greater variability in timing, peaking at 500-700 ms post-onset.

The probe recognition and reference task evoke different trends in latency responses associated with tone offsets/onsets leading up to the lengthened tone. Reference task latency responses at 250 ms post-onset demonstrate progressively enhanced latency increases for each tone in the sequence. This succession of progressive increases in latency values is terminated following the lengthened tone compared to previous onset responses. By contrast, probe recognition task latency responses at 250 ms are not associated with a progressive latency increase for each tone in the sequence, with variable latency minima values apparent for each tone in the sequence. However, the latency response at 250 ms post-onset for the tone following a lengthened tone is associated with strongly reduced latency. This response is the only occurrence of probe recognition task latency responses that are associated with greater reductions in frontal regions than reference task responses. In contrast to reference task responses, the probe recognition task is associated with a progressive latency increases for responses at 500-700 ms post-onset. This progressive increase in latency is terminated in response to the onset of the lengthened tone.

As illustrated in Figure 6.4, reference task responses at this site demonstrate a strong and sustained SSVEP latency reduction compared to probe recognition task responses, a difference that is evident across mid-frontal sites. Dynamic task differences are also evident in response to the lengthened-duration note. Probe recognition task responses demonstrate a transient latency decrease with a minima at approximately 250 ms following the timing of where a note onset would have occurred had a standard interval onset occurred rather than a lengthened-duration note, whereas Reference task responses do not show this response.

Figure 6.10 illustrates SSVEP latency responses in the Probe Recognition and reference tasks at electrode 8, a mid-frontal site located anterior to Fz in the International 10-20 system. In order to provide a direct comparison of the degree of latency enhancement for each task in this Figure, responses for each task presented in this Figure are referenced to the mean level for that task, enabling direct comparison of peak sizes. In order to provide a more detailed demonstration of responses occurring in association with the lengthened-duration note, a 3.8-second epoch of SSVEP responses is presented in this Figure rather than the longer 4.5 second epoch presented in previous Figures.

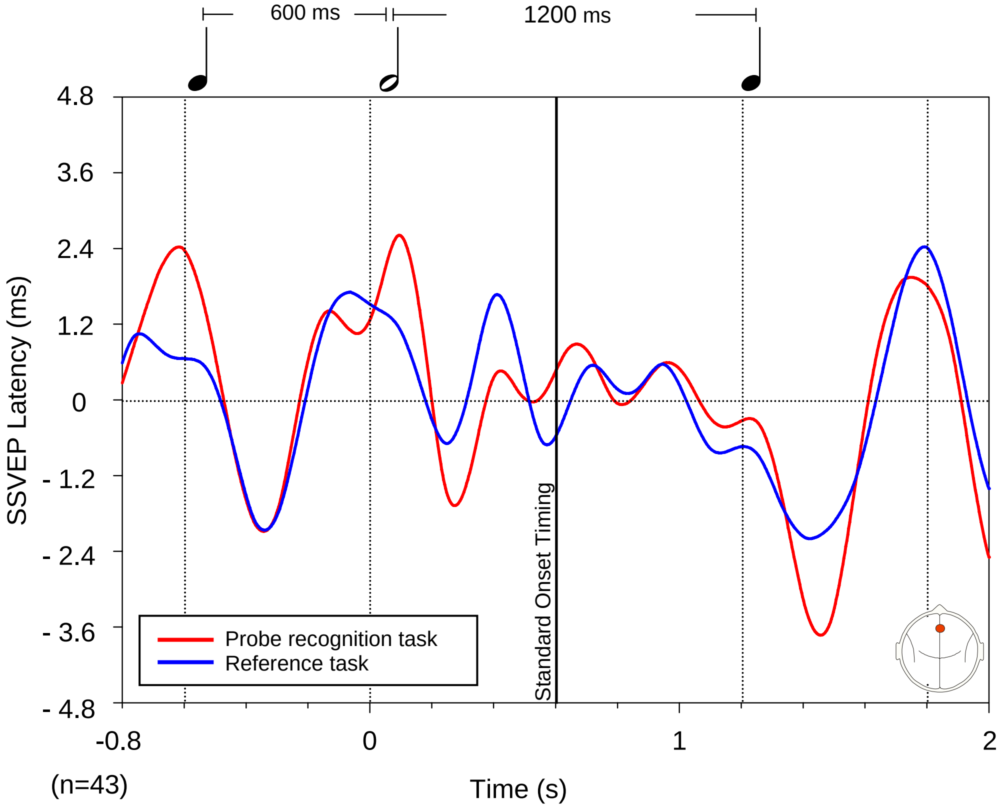

Figure 6.10 **SSVEP latency time series in the probe recognition and reference tasks at electrode 8 (medial frontal, Fz)**

SSVEP latency time series in the probe recognition task (red) and reference task (blue) at electrode 8, a mid-frontal site located anterior to Fz in the International 10-20 system. SSVEP latency responses in this figure are referenced to the mean of each task level for this electrode, each of which have arbitrarily been set to 0.

Following the lengthened-duration note, a subsequent note onset elicits a markedly stronger SSVEP latency decrease in the probe recognition task than the reference task at approximately 250 ms post-onset. This enhanced latency reduction in the probe recognition task is representative of responses occurring at this timing across bilateral frontal electrodes, and is associated with significant Hotelling’s T responses in diffusely distributed bilateral mid- and posterior frontal electrode sites.

Figure 6.11 illustrates 3.8-second epoch SSVEP amplitude responses in the probe recognition and reference tasks at electrode 37, a left posterior temporal site located midway between T3 and T5 in the International 10-20 system.

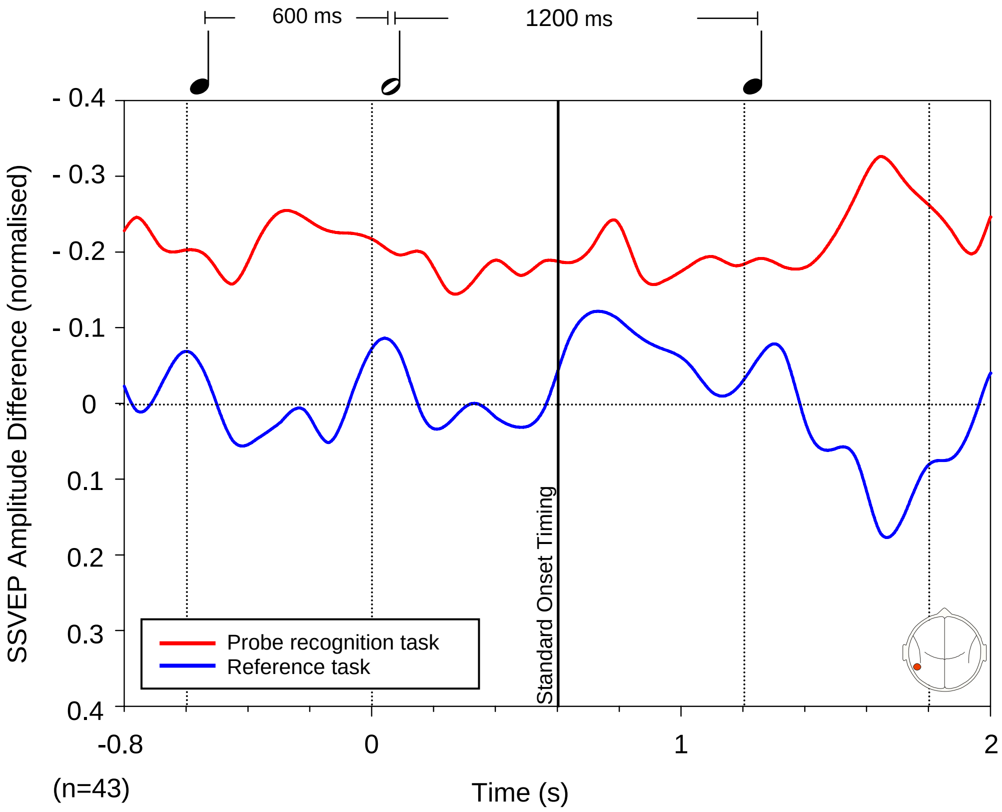

Figure 6.11 **SSVEP amplitude time series in the probe recognition and reference tasks at electrode 37 (left posterior temporal)**

SSVEP amplitude difference time series in the probe recognition task (red) and reference task (blue) at electrode 37, a left posterior temporal site located midway between T3 and T5 in the International 10-20 system. SSVEP amplitude responses in this figure are referenced to the reference task mean level, which has arbitrarily been set to 0.

Left posterior temporal SSVEP data represented in Figure 6.11 demonstrates that following the lengthened-duration note, a subsequent note onset elicits a markedly stronger SSVEP amplitude attenuation in the probe recognition task at approximately 450 ms post-onset, whereas reference task responses demonstrate a strong SSVEP amplitude increase at this timing. SSVEP amplitude attenuation in the probe recognition task is associated with significant Hotelling's T responses in this left posterior temporal location.

6.3.4 Summary of Task-Related Neurophysiological Differences

SSVEP amplitude and latency responses associated with performance of the probe recognition task and reference task demonstrate task-related differences in both sustained and transient responses. Performance of the probe recognition task was associated with sustained SSVEP amplitude attenuation at all electrode sites relative to the mean reference task level, with maximally attenuated responses occurring at left temporal and temporoparietal electrode sites. Mean SSVEP latency responses in the probe recognition task demonstrated sustained latency reductions at left posterior temporal and temporoparietal sites and sustained latency increases over broadly distributed mid-right posterior frontal regions relative to the reference task mean level. Dynamic SSVEP responses demonstrated that attenuation of the left temporal and temporoparietal regions was maximal at 490 ms post-onset for the tone following the lengthened tone.

SSVEP latency responses in the probe recognition task demonstrated a sustained latency increase compared to the mean reference task level in a broad range of neural regions. Only left temporal and temporoparietal regions demonstrated a sustained latency decrease compared to the reference task. Dynamic responses demonstrated that these latency decreases were associated with responses to the lengthened tone, and initial responses to the following tone. In both the probe recognition task and reference task, SSVEP latency responses demonstrated a pattern of dynamic responses in frontal electrodes synchronised with tone presentations leading up to the lengthened-duration note, whereas presentation of the lengthened tone and the following note elicited differences in SSVEP latency responses between the tasks. In particular, the note onset response at 250 ms following a lengthened-duration note demonstrates a strong significant latency reduction in the probe recognition task relative to the reference task across a broad distribution of left and right posterior frontal electrode locations.

Together, these findings indicate strong and significant differences in regional neural contributions towards the two tasks. Left hemisphere temporal and temporoparietal regions are more strongly associated with processing of the probe recognition task than the reference task on a sustained basis, and more strongly associated with presentation of the longer-duration tone and the following tone in the probe recognition task compared to contributions of these regions during the reference task. Following the longer-duration tone, bilateral frontal regions are more strongly involved in processing the initial tone in the probe recognition task than in the reference task. These findings point to a role for these left hemisphere temporal regions and bilateral frontal regions in processing of the longer-duration tone and the following tone in a task when establishment of a working memory trace for the tone sequence is required, whereas the same regions are less strongly involved in processing of the tone sequence when task demands place no requirement on the formation of the working memory trace. To clarify the role of these regions in the establishment of a working memory trace for the tone sequences, separate examination of SSPT responses of strong-grouping and non-grouping respondents during performance of the probe recognition task was undertaken.

6.4 Probe Recognition Task Responses Associated with Grouping

This section examines differences in SSPT responses of the strong-grouping and non-grouping participants defined in Section 6.1.4. In contrast to the previous section which compared responses for the entire respondent group associated with the probe recognition and reference tasks, this section will compare responses of strong-grouping and non-grouping participants associated with presentation of longer duration notes in the probe recognition task using the reference task as a baseline measure. Demonstration of different impact of longer duration notes on strong-grouping and non-grouping SSPT responses may then be linked with differential cognitive strategies underlying the different grouping strength responses associated with task performance of each group.

6.4.1 Mean SSVEP Topography of Strong-Grouping and Non-Grouping Responses in the Probe Recognition Task

The topographic distribution of the mean SSVEP amplitude and latency responses and associated Hotelling’s T statistical topographic maps for strong grouping and non-grouping participants are illustrated in Figure 6.12. As presented in the previous section, SSVEP amplitude and latency changes in these maps represent the amplitude and latency difference between the mean SSVEP responses during the probe recognition task and the mean reference task SSVEP response at each electrode for a five second period centred on the onset of the longer-duration note in each task. As such, these maps provide an indication of sustained SSVEP differences between probe recognition task responses of strong-grouping and non-grouping participants. Mean amplitude or latency reductions in the probe recognition task compared to the mean response in the reference task are represented by warmer colours, whereas mean amplitude or latency increases in the probe recognition task compared to the mean response in the reference task are represented by cooler colours. Figure 6.12 demonstrates strong differences in sustained SSPT responses of strong-grouping and non-grouping participants.

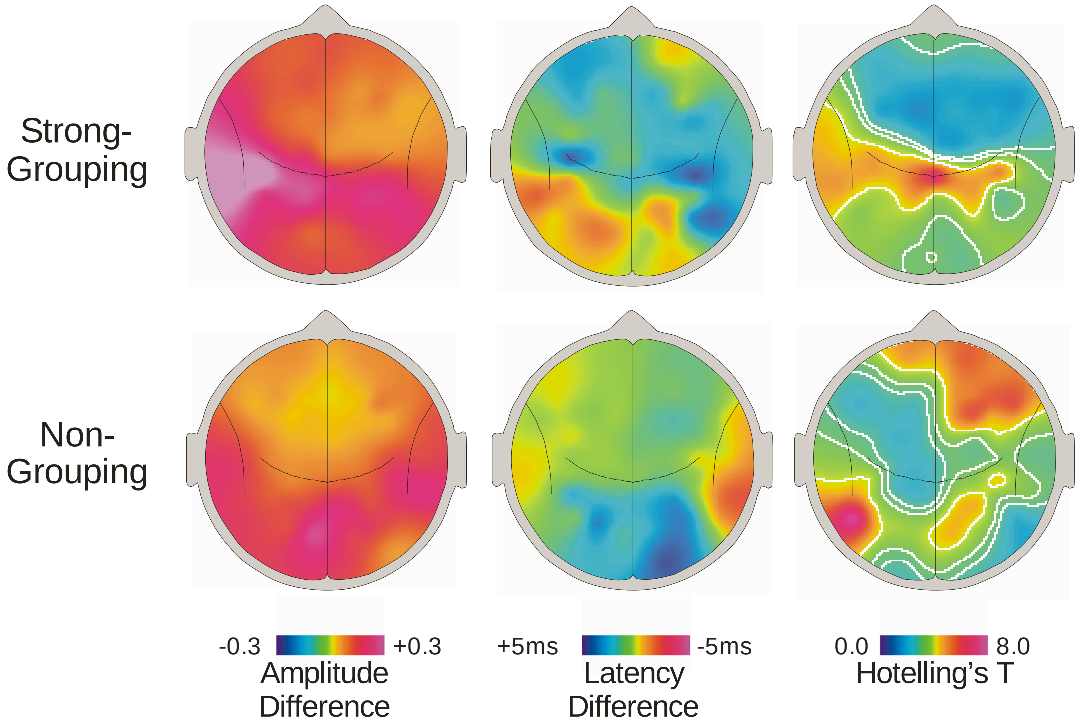

Figure 6.12 **Topography of mean probe recognition task responses for strong-grouping and non-grouping participants**

Strong-grouping participants' (top row)(n=15) and non-grouping participants' (bottom row)(n=15) topographic differences for SSVEP amplitude (normalized units) and latency (ms) between the reference task mean and probe recognition task mean. Hotelling's T maps indicate the statistical strength of these differences. Iso-T contours represent uncorrected p values of 0.01, 0.005 and 0.001.

As illustrated in Figure 6.12, both respondent groups demonstrate SSVEP amplitude attenuation in the probe recognition task in most electrode locations relative to the reference task. However, strong-grouping participants demonstrate strong SSVEP amplitude attenuation at left temporal, temporoparietal and post-central electrode sites and weaker attenuation at right parietal sites, whereas non-grouping participants show SSVEP amplitude attenuation predominantly at right posterior temporal and mid-parietal electrode sites accompanied by weaker left temporal amplitude attenuation. Sustained SSVEP latency responses also differ markedly between strong-grouping and non-grouping participants. Strong-grouping participants demonstrate sustained SSVEP latency reductions in left posterior temporal, temporoparietal, and bilateral parietal locations and latency increases in right temporal, temporoparietal and broadly distributed frontal areas. By contrast, non-grouping participants demonstrate SSVEP latency *increases* at left temporoparietal and bilateral parietal electrode sites, and latency reductions at right temporal and temporoparietal locations.

Differences noted in SSVEP amplitude and latency responses between strong-grouping and non-grouping participants' task performance are strongly evident in Hotelling's T maps which demonstrate clear differences in significant responses between the two groups. Strong-grouping participants show significant differences compared to the reference task over bilateral parietal and temporal regions, with strong significant differences at the $p < 0.001$ level focused at left temporal and bilateral post-central regions; non-grouping participants' probe recognition task responses demonstrate strong significant differences compared to the reference task at the $p < 0.001$ level at right anterior medio-frontal, right frontal, left temporoparietal, and right parietal regions.

6.4.2 Dynamic SSVEP Topography of Strong-Grouping and Non-Grouping Responses During the Lengthened Note

Maps illustrated in Figure 6.14 and Figure 6.15 present SSVEP amplitude, latency, and Hotelling's T responses at three points in times associated with presentation of a longer-duration note in the probe recognition task. These timings have been selected to represent key dynamics of electrophysiological responses through the longer-duration note, and provide greater temporal specificity than those time points used to provide an overview of responses of the entire respondent group in Section 6.3.2. The three timings used for these topographic maps are represented graphically in Figure 6.13. Maps in the top row of each figure represent SSVEP responses occurring 770 ms following the onset of a longer-duration note. This timing is equivalent to a period of 170 ms following the timing of when a note onset would have occurred if a standard 600 ms IOI was actually presented. Maps in the middle row of each figure represent SSVEP responses occurring 920 ms after the onset of the lengthened duration note, and are equivalent to a period of 320 ms following the timing of when a note onset would have occurred if a standard 600 ms IOI was actually presented. Maps in the bottom row of each figure represent SSVEP responses occurring 1080 ms following the onset of a longer-duration note. This timing is equivalent to a period of 480 ms following the timing of when a note onset *would* have occurred if a standard 600 ms IOI was actually presented. As for topographic maps presented in Section 6.3.2, warmer colours (pink/red) indicate reduced amplitude and latency in the probe recognition task relative to the reference task, whereas cooler colours (blue) represent increases. Hotelling's T maps indicate the statistical strength of these differences; warmer colours indicate higher T values. Iso-T contours represent uncorrected p values of 0.01, 0.005 and 0.001.

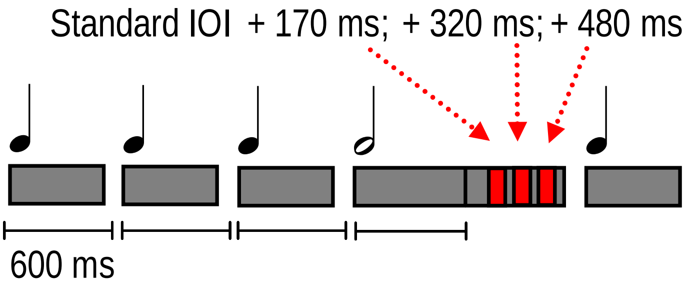

Figure 6.13 **Task timings used for SSVEP topographic maps illustrating lengthened tone responses**

As discussed in Section 5.7.7 and Section 6.3.2, adjustment of significance threshold values via a Bonferroni correction of 5 yields a significance threshold of 0.01 for multiple electrode comparisons. Correction for the multiple time points presented in Figure 6.14 and Figure 6.15 by dividing 0.01 by 3 yields a significance threshold of 0.0033 for Hotelling's T values presented in each figure. In view of these corrections, areas inside iso-T contours representing a p value of 0.001 demonstrate significant differences from the mean response, whereas areas inside iso-T contours representing a p value of 0.005 approach significant differences from the mean response.

Figure 6.14 illustrates strong-grouping participants' (n=15) topographic differences for SSVEP amplitude (normalized units) and latency (ms) between the probe recognition task time series and reference task mean during the second half of the lengthened-duration note. This timing represents the 600 ms period following the timing of when a note onset *would* have occurred if a standard 600 ms IOI was actually presented.

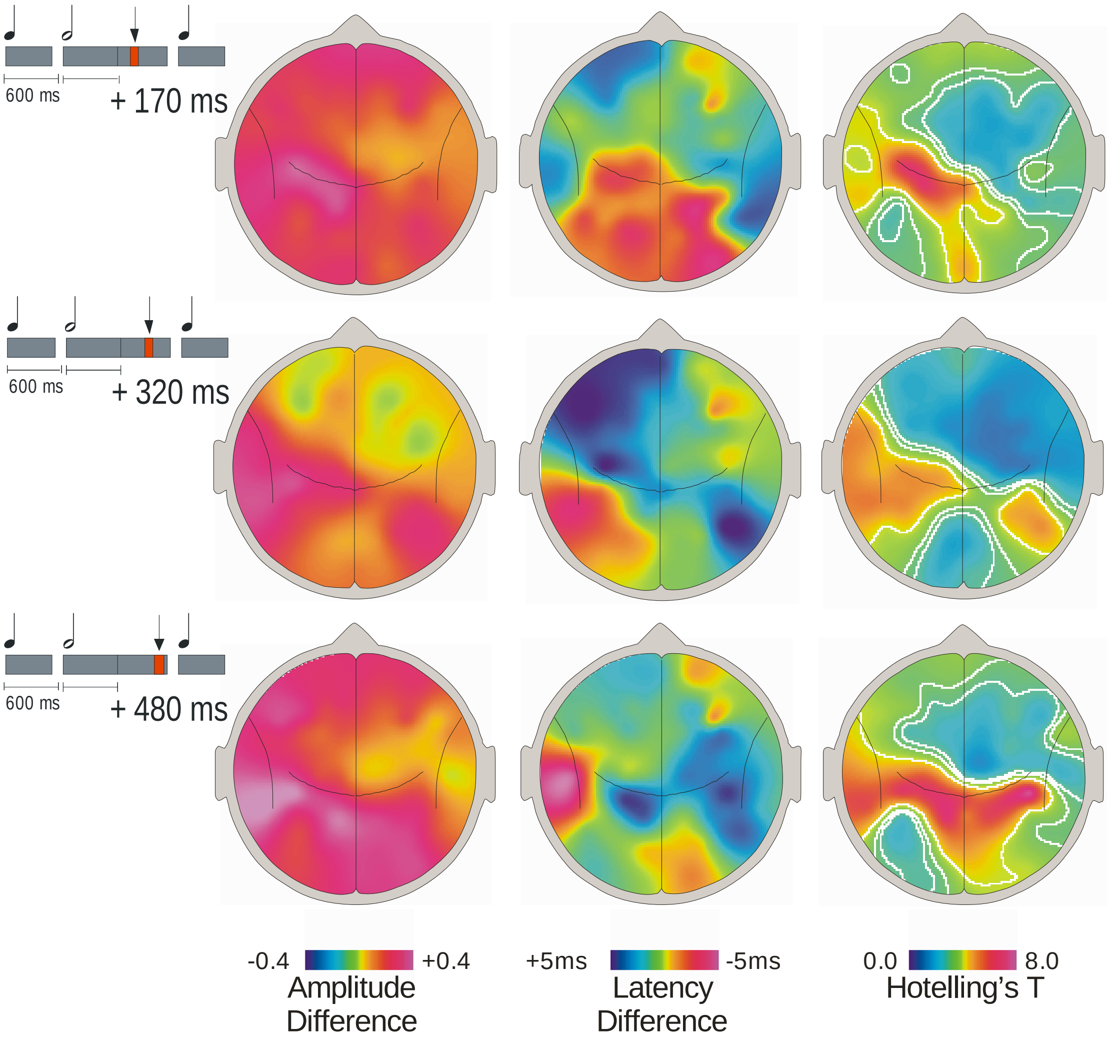

Figure 6.14 **Topography of strong-grouping participants' probe recognition task dynamic SSVEP responses during the lengthened tone**

Strong-grouping participants' (n=15) topographic differences for SSVEP amplitude (normalized units) and latency (ms) between the reference task mean and probe recognition task time series during the lengthened-duration note. Hotelling's T maps indicate the statistical strength of these differences. Iso-T contours represent uncorrected p values of 0.01, 0.005 and 0.001. All three time points occur during the lengthened-duration note.

Figure 6.14 shows that strong-grouping participants SSVEP amplitude responses are characterised by sustained attenuation of left temporal, left temporoparietal, left post-central and right temporoparietal electrode sites. Additionally, transient amplitude attenuation at medial prefrontal electrode sites occurs 170 ms after the standard 600 ms IOI timing, and at both medial prefrontal, and superior and right parietal electrode sites 480 ms after the standard 600 ms IOI timing. A progressive shift in topography of SSVEP latency is demonstrated in responses of strong-grouping participants. Following the absence of the standard 600 ms IOI onset, latency responses 170 ms later show strong reductions at bilateral parietal, left central and vertex electrode sites, and to a lesser extent at left temporoparietal sites, whereas temporal and frontal locations predominantly show latency increases. SSVEP latency reductions shift from vertex and parietal regions to left temporoparietal sites 320 ms following the absent note onset, and subsequently to left temporal sites at 480 ms following the absent note onset. Throughout this period, left frontal electrodes demonstrate strong SSVEP latency increases, whereas right frontal electrodes – particularly lateral sites demonstrate relatively faster latency responses. Hotelling's T responses reflect the strong amplitude differences between the probe recognition task and reference task and demonstrate relatively sustained significant differences at the $p < 0.001$ level at left temporal, left central, vertex and superior parietal locations.

Figure 6.15 illustrates non-grouping participants' (n=15) topographic differences for SSVEP amplitude (normalized units) and latency (ms) between the probe recognition task time series and reference task mean during the second half of the lengthened-duration note. As presented in Figure 6.14, this timing represents the 600 ms period following the timing of when a note onset *would* have occurred if a standard 600 ms IOI was actually presented. Strength of statistical differences between the tasks is represented by Hotelling's T maps.

In contrast to response of strong-grouping participants, non-grouping participants do not demonstrate sustained SSVEP amplitude attenuation at left temporal and temporoparietal sites. Instead, non-grouping participants show strongest attenuation of superior parietal sites through this timing, and transient attenuation of right lateral posterior frontal sites 320 ms after the absent onset, and at right posterior temporal sites at 480 ms after the absent onset.

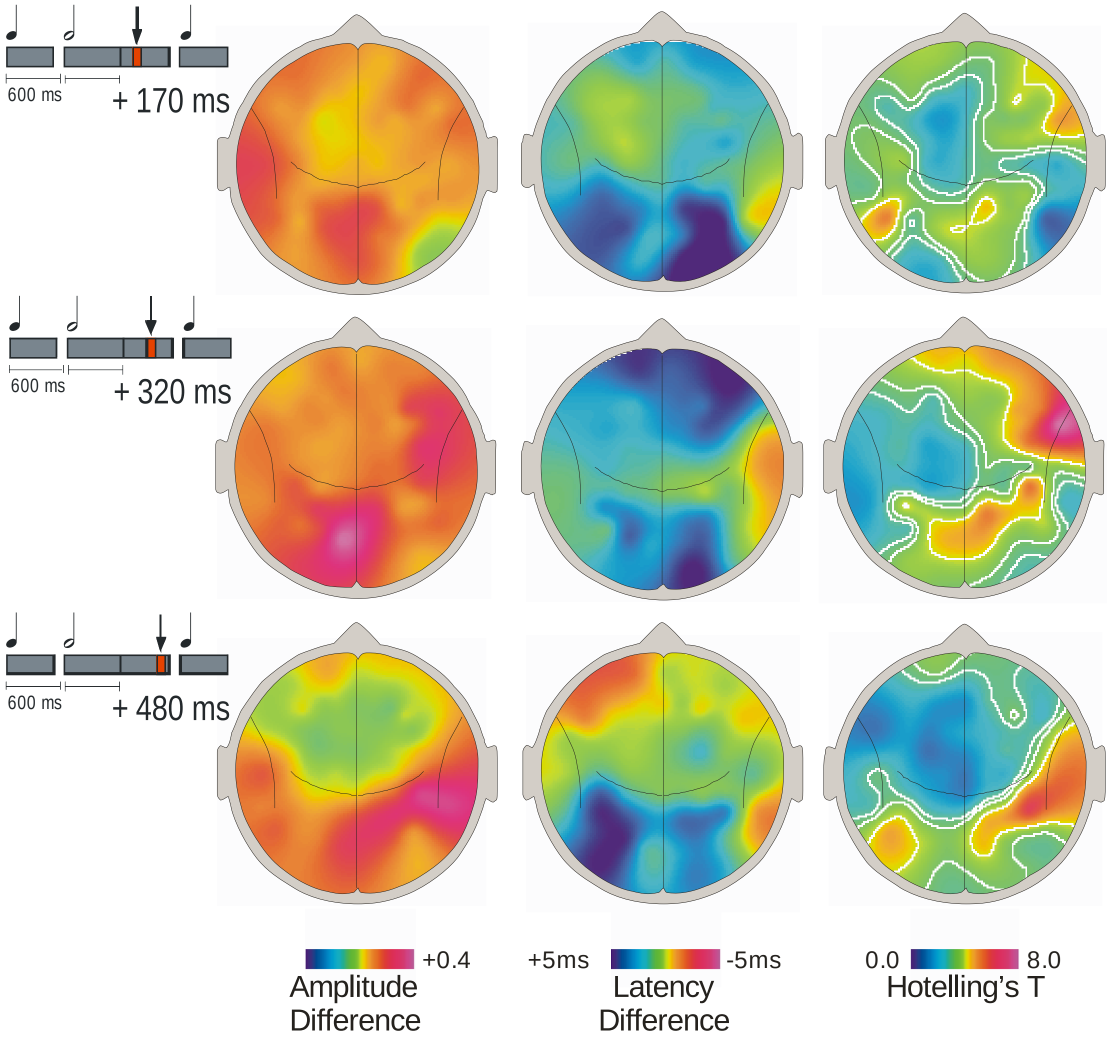

Figure 6.15 **Topography of non-grouping participants' probe recognition task dynamic SSVEP responses during the lengthened tone**

Non-grouping participants' (n=15) topographic differences for SSVEP amplitude (normalized units) and latency (ms) between the reference task mean and probe recognition task time series during the lengthened-duration note. Hotelling's T maps indicate the statistical strength of these differences. Iso-T contours represent uncorrected p values of 0.01, 0.005 and 0.001. All three time points occur during the lengthened-duration note.

SSVEP latency responses of non-grouping participants demonstrate reductions in contralateral locations to those of the strong-grouping participants. While strong-grouping participants showed latency reductions in parietal regions shifting towards left temporal locations through this timing, non-grouping participants show latency reductions at *right* temporoparietal locations and to a lesser extent, right anterior temporal regions, accompanied by parietal latency *increases* throughout this period. Additionally, left anterior prefrontal sites demonstrate a transient latency reduction at 480 ms following the absent note onset.

As demonstrated in responses of strong-grouping participants, Hotelling's T responses predominantly reflect the regions showing strong amplitude differences between the probe recognition task and reference task and demonstrate significant responses at the $p < 0.001$ level at superior parietal, left temporoparietal, and right lateral posterior frontal sites at 170 ms and 320 ms after the absent onset, and right temporal and parietal sites at 480 ms after the absent onset.

6.4.2.1 Lengthened Note - Single Electrode Time Series

Examination of single electrode time series responses provides the opportunity to examine continuous dynamic responses for a single site and enables direct comparison of responses elicited by different tasks. Time series responses also provide the opportunity of examining differences in responses of pooled respondent groups within the same task. Figures 6.16 to 6.18 illustrate single electrode time series responses for strong-grouping and non-grouping participants in the probe recognition task centred on the mid-point of the lengthened-duration note.

With the exception of Figure 6.16, which is self-referenced, SSVEP latency is shown with respect to the mean latency during the reference task in these figures. These mean reference task levels have arbitrarily been set to zero. Six dashed vertical lines represent timings of standard note onsets, whereas the solid vertical line labelled 'Standard Onset Timing' indicates the point in time in each task where a note onset *would* have occurred had a standard 600 ms IOI occurred rather than a 1200 ms IOI associated with a lengthened-duration note.

Figure 6.16 illustrates a 4.5-second epoch of strong-grouping (red) and non-grouping (blue dotted) participants' SSVEP latency responses in the probe recognition task at electrode 26, a right posterior frontal site located mid-way between C4 and F8 in the

International 10-20 system. Data in this figure is self-referenced for each participant group, providing an indication of dynamic latency variations about the mean task level. Strong-grouping participants' dynamic responses at this right frontal site at approximately 250 ms after the standard onset timing during the lengthened tone demonstrate a transient latency decrease similar to latency responses obtained at this timing for actual tone onsets. This transient response reflects the constant IOI used in the task, and is suggestive of processing that tracks or generates temporal expectations in view of constant temporal features of the stimulus, this latency decrease is not associated with a significant Hotelling's T response.

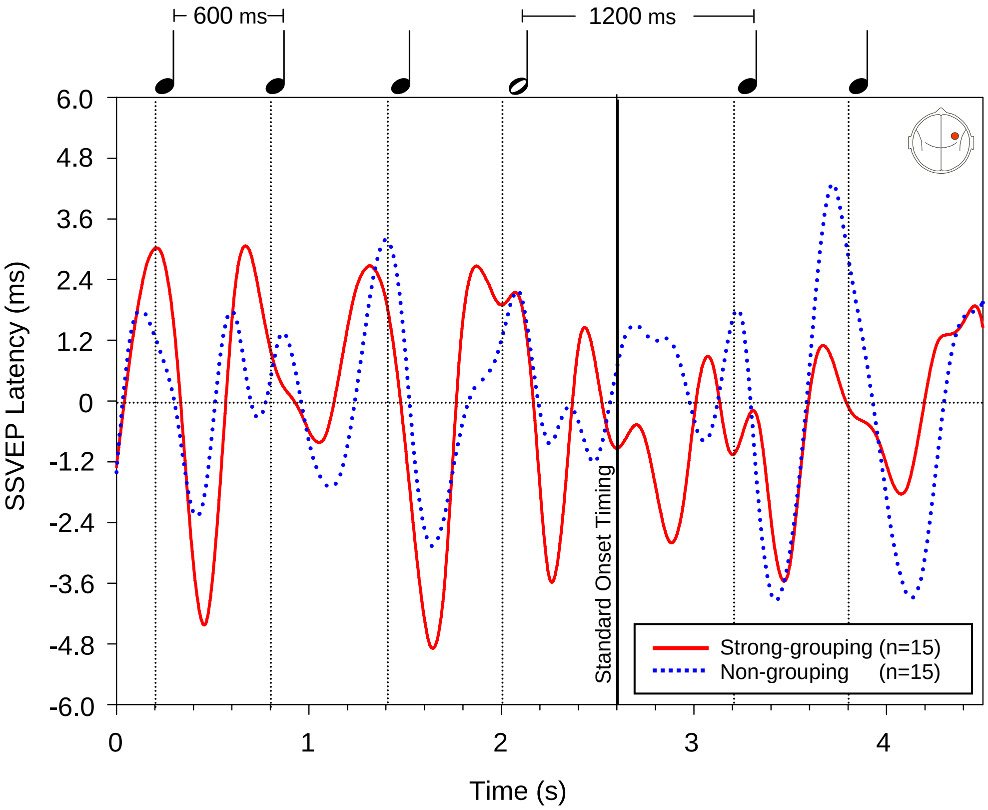

Figure 6.16 **Self-referenced SSVEP latency time series of strong-grouping and non-grouping participants in the probe recognition task at electrode 26 (right frontal)**

SSVEP latency time series in the probe recognition task for strong-grouping participants (red) and non-grouping participants (blue) at electrode 26, a right posterior frontal site located mid-way between C4 and F8 in the International 10-20 system. SSVEP latency responses in this figure are referenced to the mean of the probe recognition task, which has been arbitrarily set to 0 for each group.

Figure 6.17 illustrates a 2.8-second epoch of strong-grouping (red) and non-grouping (blue dotted) participants' SSVEP latency responses in the probe recognition task at electrode 44, a left temporoparietal site equivalent to T5 in the International 10-20 system.

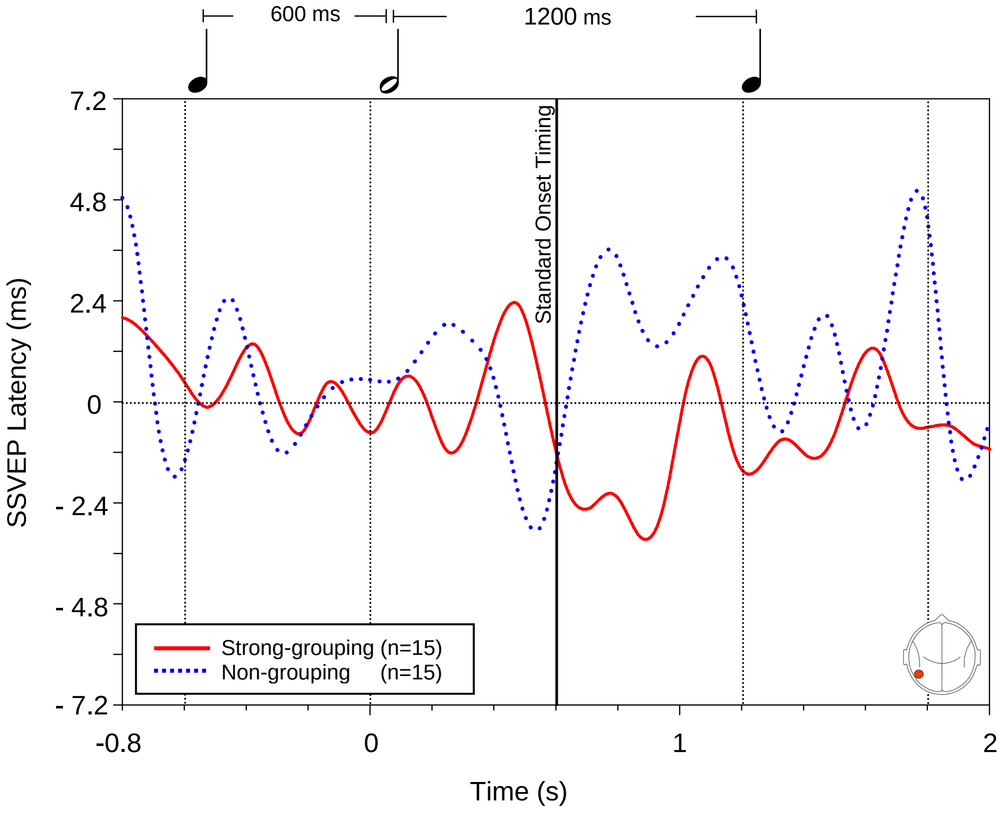

Figure 6.17 **SSVEP latency time series of strong-grouping and non-grouping participants in the probe recognition task at electrode 44 (left temporoparietal, T5)**

SSVEP latency time series in the probe recognition task for strong-grouping participants (solid red) and non-grouping participants (dotted blue) at electrode 44, a left temporoparietal site equivalent to T5 in the International 10-20 system. SSVEP latency responses in this figure are referenced to the mean of the reference task, which has been arbitrarily set to 0 ms for each group.

Dynamic responses of strong-grouping and non-grouping participants at this left temporoparietal site diverge strongly during the lengthened note following the standard 600 ms IOI timing. While both strong-grouping and non-grouping participants demonstrate a latency decrease within 100 ms either side of the standard onset timing, strong-grouping participants demonstrate a further latency decrease at approximately 300 ms following the standard onset timing, whereas non-grouping participants show a strong latency *increase* from 200 ms after the standard onset timing which is sustained through the lengthened note to the onset of the subsequent note. The strong latency decrease demonstrated by strong-grouping participants is associated with a significant Hotelling's T response at the *p* < *0*.001 level.

Figure 6.18 illustrates a 2.8-second epoch of strong-grouping (red) and non-grouping (blue) participants' SSVEP latency responses in the probe recognition task at electrode 28, a left temporal site equivalent to T3 in the International 10-20 system. Responses of strong-grouping and non-grouping participants demonstrate striking morphological differences at this left temporal site.

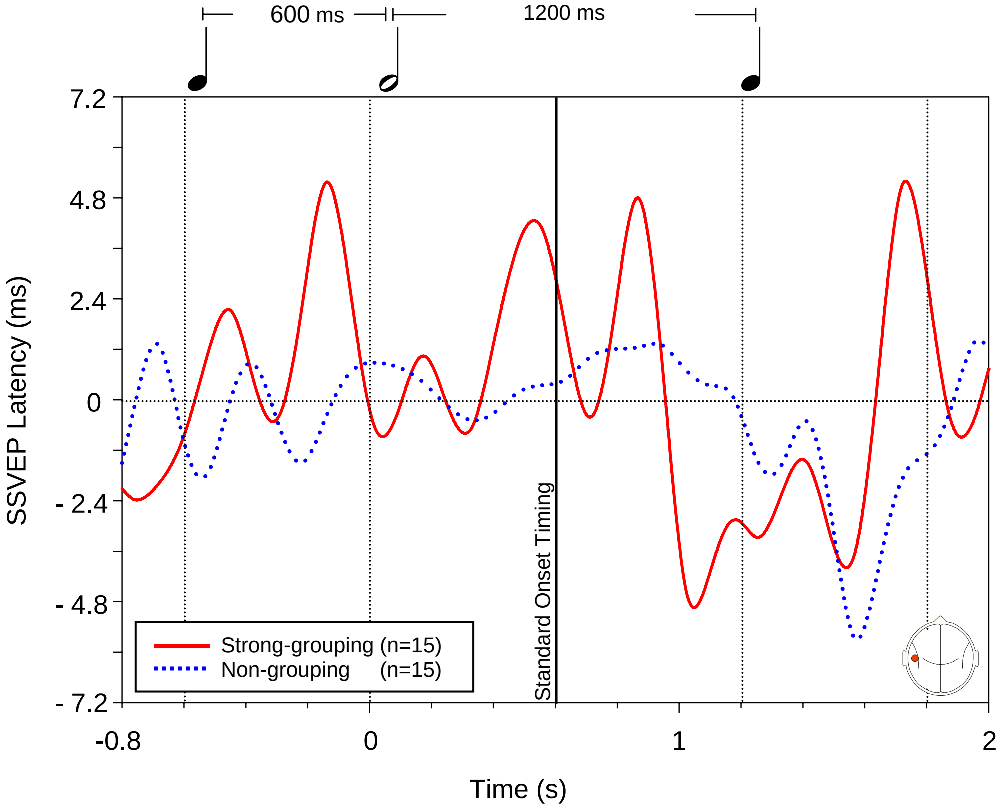

Figure 6.18 **SSVEP latency time series of strong-grouping and non-grouping participants in the probe recognition task at electrode 28 (left temporal, T3)**

SSVEP latency time series in the probe recognition task for strong-grouping participants (solid red) and non-grouping participants (dotted blue) at electrode 28, a left temporal site equivalent to T3 in the International 10-20 system. SSVEP latency responses in this figure are referenced to the mean of the reference task, which has been arbitrarily set to 0 for each group.

In Figure 6.18, Strong-grouping participants demonstrate dynamic changes in SSVEP latency responses throughout this epoch, with responses to each note onset characterised by a series of biphasic latency responses consisting of a latency increase at 150 ms, a latency decrease at 300 ms, and a latency increase at 450-500 ms post-onset. This pattern of biphasic response is interrupted during the lengthened note following the standard 600 ms IOI timing by a strong latency increase 250 ms after the absent onset, followed by a markedly strong latency decrease 450 ms after the absent onset. The magnitude of this latency decrease at 450 ms after the absent onset is particularly notable in view of three factors:

1. Latency responses of strong-grouping participants prior to this timing demonstrate a trend towards an *increased* latency offset relative to the reference task
2. The peak-to-peak range of latency variations prior to this timing demonstrates a maxima of 6 ms; the peak-to-peak range of the latency variation resulting in the latency decrease at 450 ms is substantially greater at approximately 10ms;
3. Dynamic responses of non-grouping participants show a trend towards *decreasing* peak-to-peak variations leading up to the absent 600 ms IOI onset. Non-grouping participants' latency responses at 450 ms after the absent onset and through to the subsequent note onset show only minimal latency shifts within a rage of approximately 1 ms.

This strong latency decrease evident in the strong-grouping responses at this timing is associated with a significant Hotelling's T response at the $p < 0.001$ level.

6.4.3 Summary of Responses during the Lengthened Note

Topographic maps illustrated in Section 6.4.2 together with time series Figures 6.16, 6.17, and 6.18 demonstrate a pattern of responses during the lengthened note which differ strongly between strong-grouping and non-grouping participants. These findings demonstrate that approximately 170 ms after the non-presentation of the onset, strong-grouping participants demonstrate strong and transient left central/vertex and parietal latency decreases, indexing increased processing speed in these region (Silberstein et al., 1996, 1998), which progressively shift laterally over the course of 300 ms through left temporoparietal regions, to left temporal regions. By contrast, non-grouping participants demonstrate latency *increases,* indexing decreased processing speed in these regions (Silberstein et al., 1996, 1998), throughout parietal and left temporal/temporoparietal regions during the lengthened note, and demonstrate latency *decreases* in the contralateral right temporal and temporoparietal regions.

This lateralisation of SSVEP responses during the lengthened note is further demonstrated in SSVEP amplitude responses, which show relatively stronger amplitude attenuation throughout strong-grouping participants' lengthened note responses at left temporal, temporoparietal and left central locations. By contrast, non-grouping participants show relatively stronger amplitude attenuation throughout lengthened note responses at *right* temporal and temporoparietal regions. These contralateral patterns of reductions in SSVEP amplitude relative to the reference task, suggesting increased levels of regional cortical activation (Silberstein et al., 1990) in strong-grouping and non-grouping participants further support involvement of opposing temporal and temporoparietal networks in response to lengthened notes during probe recognition task performance by strong-grouping and non-grouping participants.

Together, these findings indicated strong and significant differences in regional contributions towards task-related processing in strong-grouping and non-grouping respondents. The sustained focus of amplitude and latency reductions in left temporal and temporoparietal regions associated with the use of tone duration cues in the formation of a grouped working memory structure provides partial support for the second experimental hypothesis which proposed that participants who had demonstrated use of lengthened tones as a cue to rhythmically group the tone sequences would demonstrate a tendency towards use of left hemisphere frontal and temporal neural regions in encoding tone sequences, whereas participants who did not rhythmically group the tone sequences would demonstrate a tendency towards use of right hemisphere frontal and temporal neural regions in encoding sequence material. Furthermore, dynamic responses over left central/vertex, temporal and temporoparietal regions associated with presentation of the longer-duration note in those respondents who demonstrated greater use of the note as a cue for the generation of working memory structure partially supports the third experimental hypothesis which proposes that presentation of relatively longer tones in a tone sequence would be associated with dynamic responses in brain regions that are sensitive to deviations of temporal structure in frontal, temporal and parietal regions, and that activity in these regions would be greater for participants who demonstrated use of lengthened tones as a cue to rhythmically group the tone sequences.

6.4.4 First Note Responses

Maps illustrated in Figure 6.20 and Figure 6.21 present SSVEP amplitude, latency, and Hotelling's T responses at three points in time associated with presentation of the 1st note onset following the lengthened note in the probe recognition task. The three timings used for these maps are represented graphically in Figure 6.19. Maps in the top row of each figure represent SSVEP responses occurring 185 ms after the note onset; maps in the middle row of each figure represent SSVEP responses occurring 340 ms after the note onset; and maps in the bottom row of each figure represent SSVEP responses occurring 490 ms after the note onset. These times represent equivalent post-onset timings as for those presented in response to an absent note onset in Figure 6.14 and Figure 6.15. As for topographic maps presented in Section 6.4.2, warmer colours (pink/red) indicate reduced amplitude and latency in the probe recognition task relative to the reference task, whereas cooler colours (blue) represent increases. Hotelling's T maps indicate the statistical strength of these differences; warmer colours indicate higher T values. Iso-T contours represent uncorrected p values of 0.01, 0.005 and 0.001.

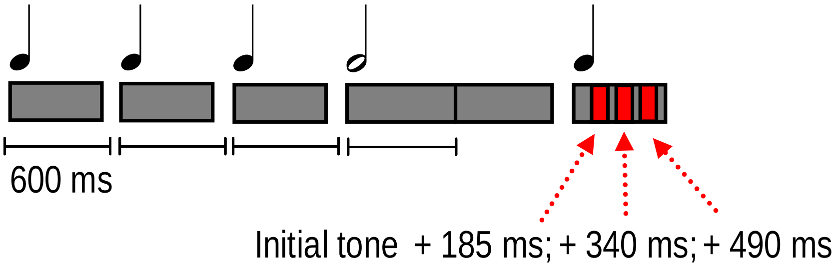

Figure 6.19 **Task timings used for SSVEP topographic maps illustrating initial tone responses**

As discussed in Section 6.4.2, a significance threshold of 0.0033 is an appropriate value for Hotelling's T values presented in each of the three figures. In view of these corrections, areas inside iso-T contours representing a p value of 0.001 demonstrate significant differences from the reference task mean response, whereas areas inside iso-T contours representing a p value of 0.005 approach significant differences from the reference task mean response.

Figure 6.20 illustrates strong-grouping participants' (n=15) topographic differences for SSVEP amplitude (normalized units) and latency (ms) between the probe recognition task time series and reference task mean during the 1st note following the lengthened note in the probe recognition task. Strength of statistical differences between the tasks is represented by Hotelling's T maps.

SSVEP amplitude responses of strong-grouping participants demonstrate lateralisation towards left hemisphere regions throughout the timing represented in both lengthened note and first note maps. In common with responses to the lengthened note, SSVEP amplitude responses during the first note after the lengthened note are characterised by sustained attenuation of left temporal and left post-central sites. Transient amplitude attenuation is evident at left posterior frontal regions occurring 185 ms post-onset, and at bilateral parietal regions occurring at 340 ms post-onset. SSVEP amplitude attenuation is particularly strong at left temporal, temporoparietal and post-central sites at 490 ms post-onset, and whilst amplitude attenuation in these regions was evident during this timing in the lengthened tone, the strength of this effect is notably stronger during the first note following the lengthened note than the lengthened note itself. This dynamic SSVEP amplitude attenuation at left posterior temporal regions is illustrated in the single electrode time series presented in Figure 6.11. The distribution of SSVEP amplitude attenuations occurring during the first note at 490 ms post-onset is clearly more limited than for those associated with the missing onset, and is not evident in frontal or superior parietal regions during the first note, as was clearly evident at this timing during the lengthened note. Instead, frontal regions demonstrate a weak SSVEP amplitude increase at this timing.

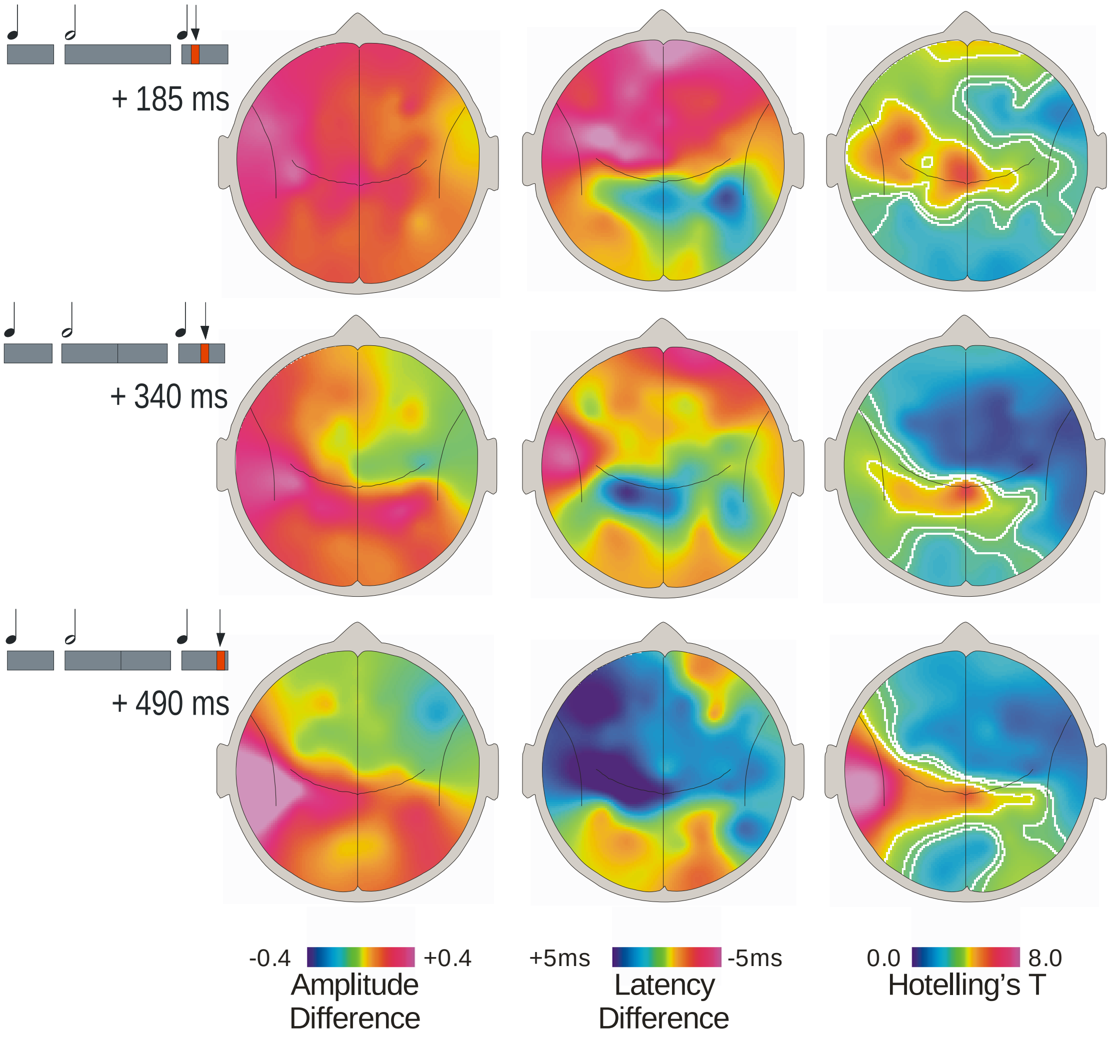

Figure 6.20 **Topography of strong-grouping participants' probe recognition task dynamic SSVEP responses during the tone following a lengthened tone**

Strong-grouping participants' (n=15) topographic differences for SSVEP amplitude (normalized units) and latency (ms) between the reference task mean and probe recognition task time series during the first note following the lengthened-duration note. Hotelling's T maps indicate the statistical strength of these differences. Iso-T contours represent uncorrected p values of 0.01, 0.005 and 0.001. All three time points occur during the first note following the lengthened-duration: labelling reflects response latency after the onset of the note following the lengthened duration note

During 185 ms post-onset responses, strong-grouping participants demonstrate strong SSVEP latency reductions compared to the reference task mean across a broad range of bilateral frontal and left temporal and temporoparietal regions, with strong latency reductions evident at left posterior frontal and right anterior pre-frontal regions. An additional transient latency reduction is evident in the left anterior temporal region at

340 ms post-onset and at 490 ms post-onset, and in contrast to other task phases, strong latency *increases* are evident throughout bilateral frontal regions (with the exception of right anterior prefrontal sites) and bilateral temporal regions. SSVEP latency increases are noticeable stronger at left frontal sites than right frontal sites.

SSVEP Hotelling's T maps associated with amplitude and latency responses during the first note following a lengthened note illustrate that at around 80 ms post-onset, amplitude attenuation and latency decreases at left and mid-posterior frontal and left anterior temporal regions were significantly different from the reference task at the $p < 0.001$ level, with left anterior frontal responses generally approaching significance. SSVEP amplitude attenuations and latency *increases* in left-mid post-central regions were significantly different from the reference task at 340 ms post-onset, whereas left temporal and temporoparietal regions approached significance. At 490 ms post-onset, left temporal and temporoparietal amplitude attenuations and latency increases were strongly significantly different from the reference task.

Figure 6.21 illustrates equivalent maps for non-grouping participants (n=15) as demonstrated for strong-grouping participants in Figure 6.15. As noted for strong-grouping participants, SSVEP amplitude responses of non-grouping participants also show common features between the lengthened note and responses to the following note.

In particular, similarities are evident in amplitude responses at 170 ms following the missing onset (in the case of lengthened note responses) and 185 ms post-onset (in the case of first note responses) where both sets of responses demonstrate diffuse amplitude attenuation with maxima at left temporal and mid parietal locations. Responses at 480 ms following the missing onset (in the case of lengthened note responses) and 480 ms post-onset (in the case of first note responses) also show strong similarities with both demonstrating diffuse posterior amplitude attenuation with clear maxima at mid-parietal and right posterior temporal locations.

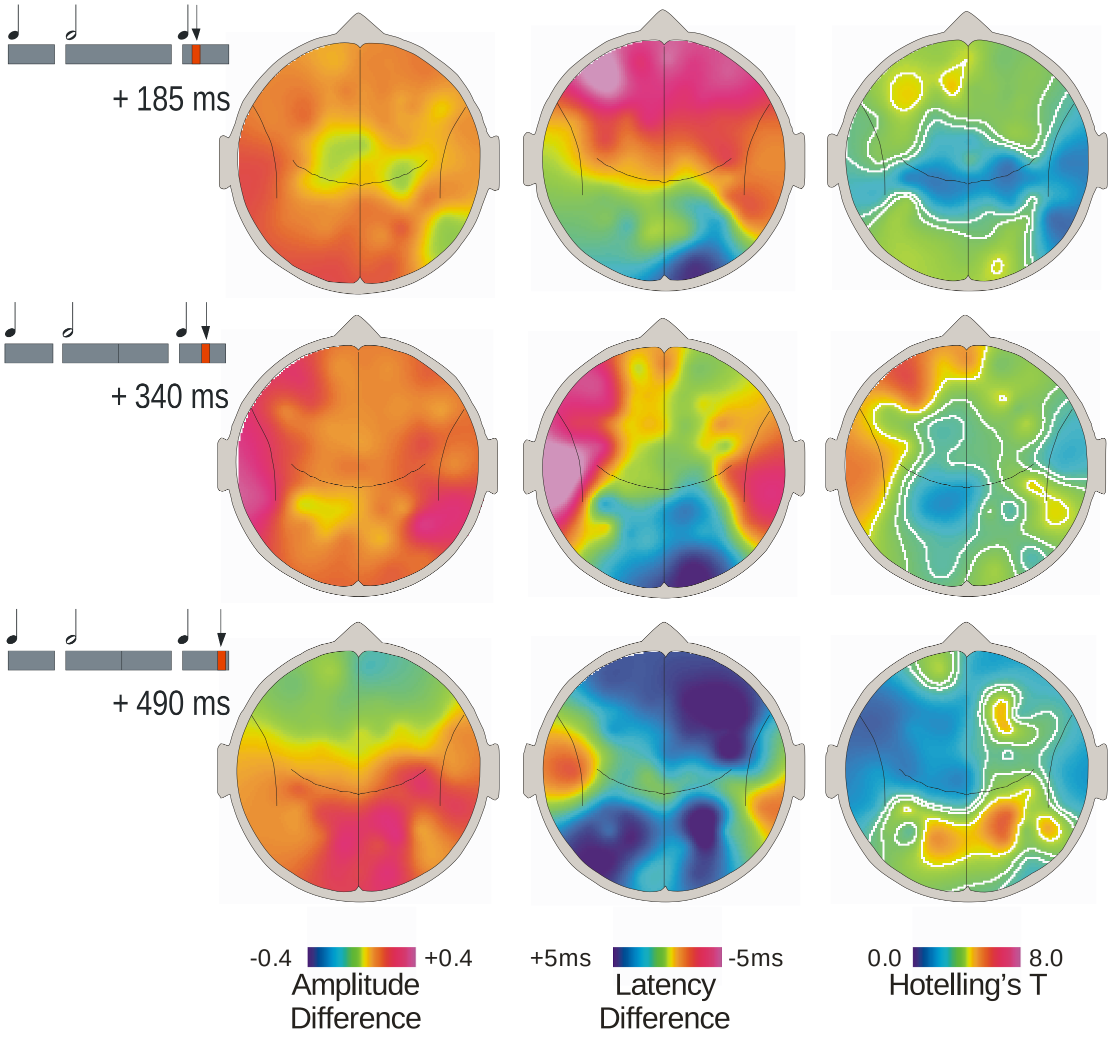

Figure 6.21 **Topography of non-grouping participants' probe recognition task dynamic SSVEP responses during the tone following a lengthened tone**

Non-grouping participants' (n=15) topographic differences for SSVEP amplitude (normalized units) and latency (ms) between the reference task mean and probe recognition task time series during the first note following the lengthened-duration note. Hotelling's T maps indicate the statistical strength of these differences. Iso-T contours represent uncorrected p values of 0.01, 0.005 and 0.001. All three time points occur during the first note following the lengthened-duration: labelling reflects response latency after the onset of the note following the lengthened duration note

In common with strong-grouping participants' SSVEP latency responses in early responses to the first note following a lengthened note, non-grouping participants' SSVEP latency responses at 185 ms post-onset are initially reduced across a broad range of bilateral frontal sites with maxima at anterior prefrontal locations. However, in contrast to the left hemisphere latency reductions demonstrated by strong-grouping participants at this timing, non-grouping participants demonstrate *right* temporal latency reductions which are sustained throughout the first note. Also in common with strong-grouping participants, a strong transient left temporal latency reduction is evident in the left temporal region at 340 ms post-onset, whereas parietal and occipital latency *increases* are also evident at this timing. Also in common with strong-grouping participants at 490 ms post-onset, diffuse frontal latency increases are evident - stronger in left hemisphere for strong-grouping participants, and stronger in the right hemisphere for non-grouping participants. Unlike strong-grouping participants, however, strong latency increases are also evident at bilateral parietal and occipital sites, whereas temporal regions demonstrate latency decreases.

Hotelling's T maps associated with non-grouping participants' SSVEP amplitude and latency responses during the first note following a lengthened note illustrate that a diffuse range of bilateral frontal and parietal regions approach significance during the initial 180 ms post-onset period, although only two left anterior frontal electrode sites demonstrate a significant difference with the reference task at the $p < 0.001$ level. One of these two significant regions overlaps with significant regions at this timing demonstrated by strong-grouping participants. Amplitude attenuation and latency reductions demonstrated at 340 ms post-onset at left temporal, left lateral frontal and right posterior temporal regions are significantly different from the reference task at the $p < 0.001$ level, and at 490 ms post-onset, bilateral parietal amplitude and latency increases are significantly different from the reference task at the $p < 0.001$ level.

Comparison of regions demonstrating significant Hotelling's T responses in strong-grouping and non-grouping participants indicates strong and significant differences in regional contributions towards task-related processing for the initial tone in the sequence for the two groups. In particular, strong SSVEP amplitude attenuation and latency increases at left temporal and temporoparietal regions during late responses in strong-grouping respondents contrast strongly with the weak SSVEP amplitude attenuation and latency increase demonstrated in responses of non-grouping respondents. These findings provides partial support for the fourth experimental hypothesis which was proposed in view of research demonstrating that perception of rhythmic phrase boundaries may be associated with a characteristic electrophysiological response following the phrase boundary cue. This hypothesis proposed that the presentation of tones immediately after relatively longer-duration tones in a to-be-remembered pitch sequence would evoke an SSVEP response in strong-grouping respondents associated with the closure of grouping-related processing in temporal and parietal regions. This response may reflect contribution of neural regions supporting CPS-related closure processes following detection of group boundaries evident in late central or parietal responses.

Figure 6.22 and Figure 6.24 illustrate 4.5-second epoch single electrode time series responses for strong-grouping and non-grouping participants in the probe recognition task centred on the mid-point of the lengthened-duration note. As discussed in reference to time series Figures 6.17 and 6.18, SSVEP latency responses in these figures are shown with respect to the mean latency during the reference task which has arbitrarily been set to zero.

Figure 6.22 illustrates a 4.5-second epoch of strong-grouping (red) and non-grouping (blue) participants' SSVEP latency responses in the probe recognition task at electrode 23, a left posterior frontal location located between F3 and C3 in the International 10-20 system. Dynamic responses at this left posterior frontal site are noticeably different between strong-grouping and non-grouping participants. Strong-grouping participants demonstrate a progressive enhancement of peak latency reductions leading up to the lengthened note. Following the onset of the first note following the lengthened note, strong-grouping participants show a strongly enhanced latency reduction at approximately 250 ms post-onset, whereas responses of non-grouping participants show no specific latency enhancement relative to other timings. The strong latency decrease at this timing demonstrated by strong-grouping participants is associated with a significant Hotelling's T response at the $p < 0.001$ level.

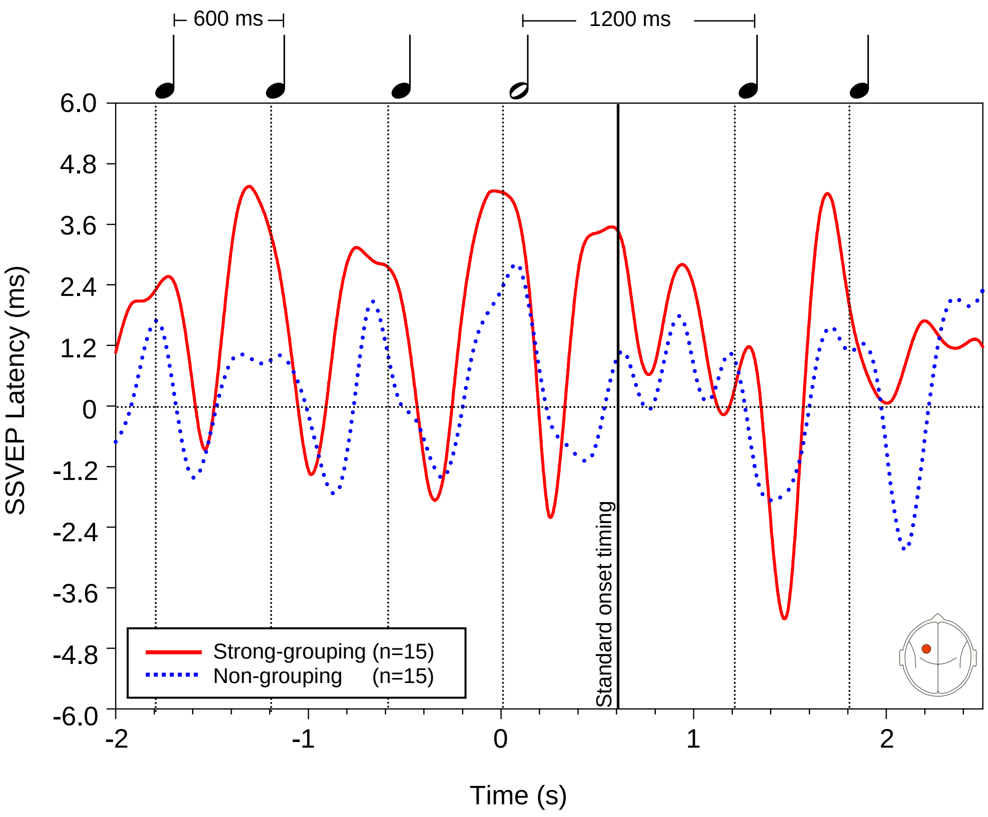

Figure 6.22 **SSVEP latency time series of strong-grouping and non-grouping participants in the probe recognition task at electrode 23 (left frontal)**

SSVEP latency time series in the probe recognition task for strong-grouping participants (solid red) and non-grouping participants (dotted blue) at electrode 23, a left posterior frontal site located mid-way between C3 and F3 in the International 10-20 system. SSVEP latency responses in this figure are referenced to the mean of the reference task, which has been arbitrarily set to 0 for each group.

Figure 6.23 illustrates a 4.5-second epoch of strong-grouping participants' SSVEP latency responses in the probe recognition task (red) and reference task at electrode 23, a left posterior frontal location located between F3 and C3 in the International 10-20 system. Figure 6.23 demonstrates data acquired only from strong-grouping participants at the same electrode location as presented in Figure 6.22. Reference task responses at this left posterior frontal site do not demonstrate the strongly enhanced latency reduction for the initial tone at approximately 250 ms post-onset evident in probe recognition task responses.

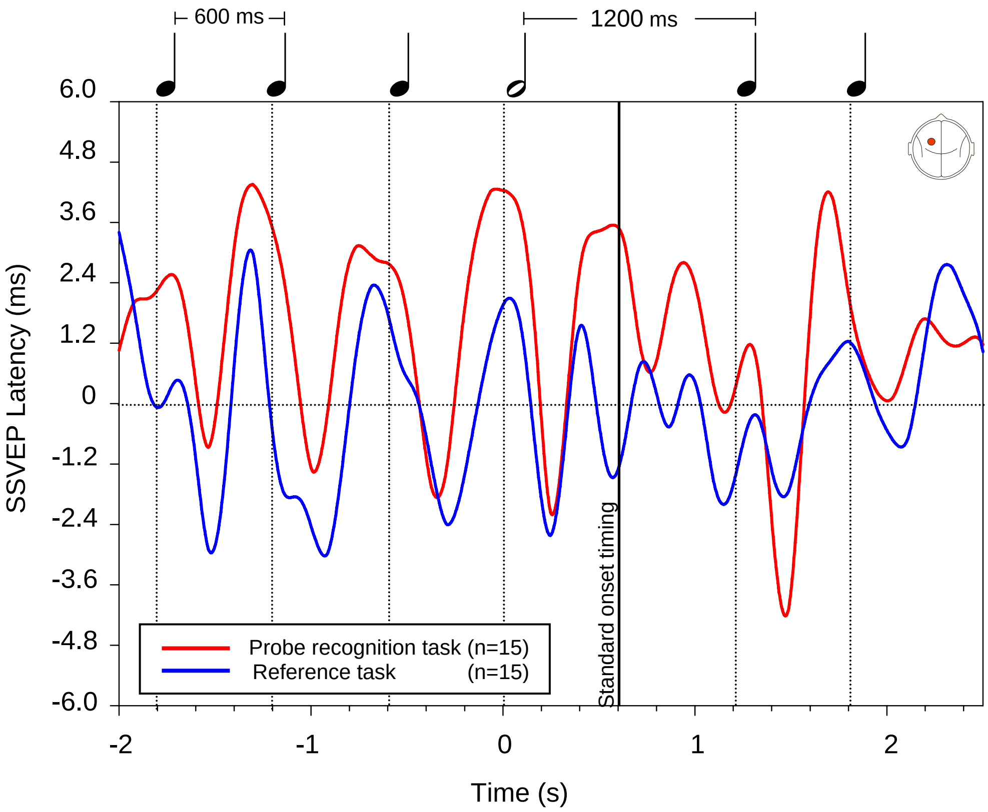

Figure 6.23 **SSVEP latency time series of strong-grouping participants in the probe recognition task and reference task at electrode 23 (left frontal)**

SSVEP latency time series for strong-grouping participants in the probe recognition task (solid red) and reference task (blue) at electrode 23, a left posterior frontal site located mid-way between C3 and F3 in the International 10-20 system. SSVEP latency responses in this figure are referenced to the mean of the reference task, which has been arbitrarily set to 0 for each group.

Figure 6.24 illustrates a 4.5-second epoch of strong-grouping (red) and non-grouping (blue dotted) participants' SSVEP latency responses in the probe recognition task at electrode 26, a right posterior frontal site located mid-way between C4 and F8 in the International 10-20 system. As noted with reference to the left posterior frontal electrode responses in Figure 6.22, dynamic responses at the right posterior frontal site represented in Figure 6.24 differ between strong-grouping and non-grouping participants, although at this right hemisphere site, non-grouping participants show an enhanced latency reduction at approximately 250 ms post-onset as compared to latency responses leading up to the lengthened note, whereas responses of strong-grouping participants show no specific latency enhancement relative to other timings.

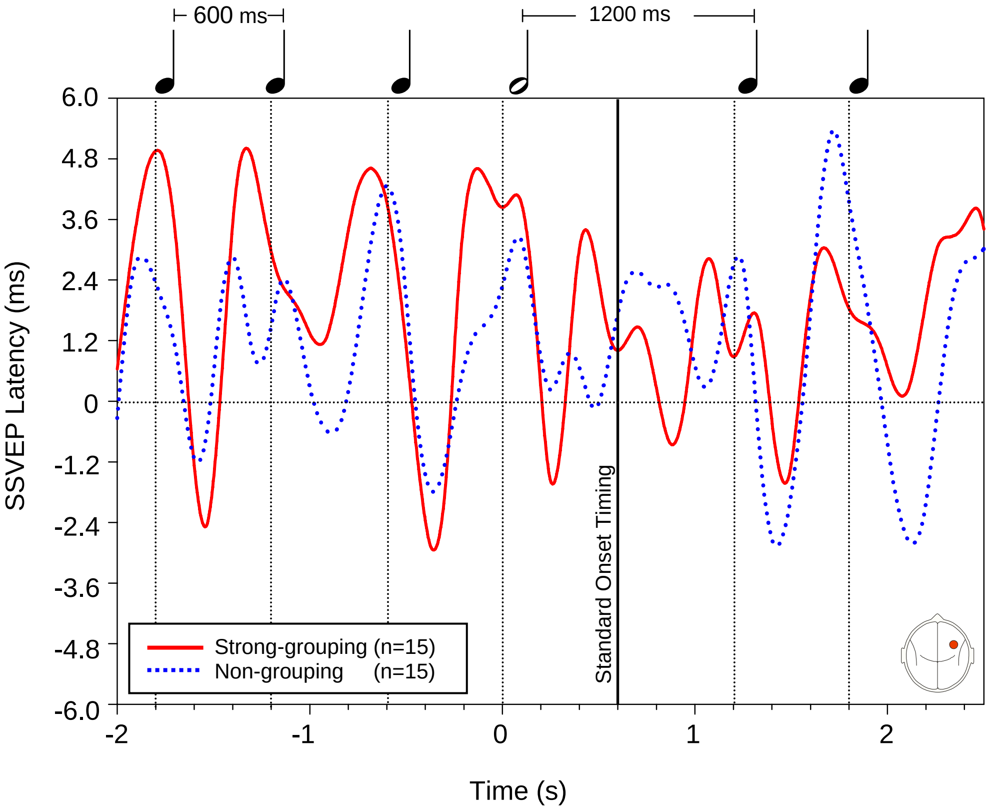

Figure 6.24 **SSVEP latency time series of strong-grouping and non-grouping participants in the probe recognition task at electrode 26 (right frontal)**

SSVEP latency time series in the probe recognition task for strong-grouping participants (red) and non-grouping participants (blue) at electrode 26, a right posterior frontal site located mid-way between C4 and F8 in the International 10-20 system. SSVEP latency responses in this figure are referenced to the mean of the reference task, which has been arbitrarily set to 0 for each group.

Notably, non-grouping participants also demonstrate a strongly-enhance latency *increase* at approximately 550 ms post-onset. SSVEP latency enhancements demonstrated by non-grouping participants at 250 ms and 550 ms post-onset are associated with Hotelling's T responses at the $p < 0.005$ level. SSVEP latency responses occurring at approximately 180-250 ms following the onset of the initial tone demonstrate enhanced reductions for strong-grouping participants at left posterior frontal regions, and for non-grouping participants at right posterior frontal regions. In order to examine the relationship between these early latency reductions and the position of the tone in the sequence, SSVEP latency responses for the initial tone were compared with latency responses at the same timing averaged across other positions in the sequence. Figure 6.25 illustrates topographic maps for initial and standard tones.

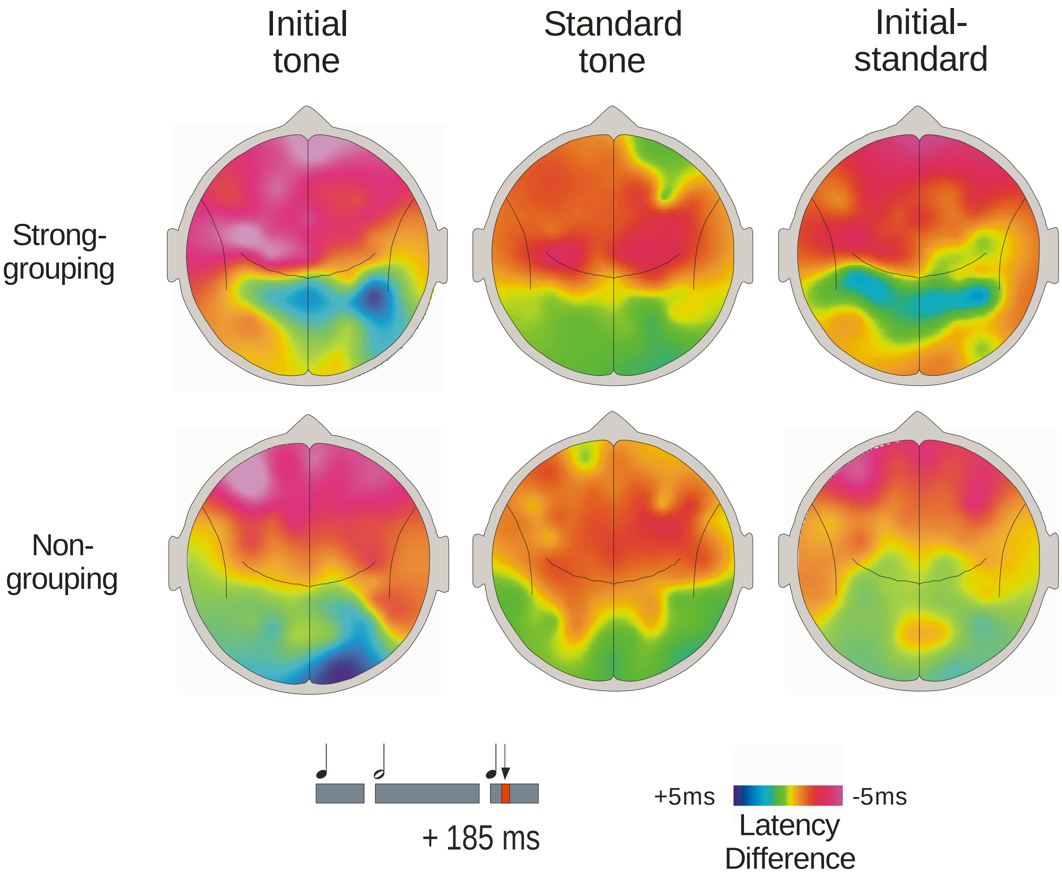

Figure 6.25 **Topography of SSVEP latency responses for initial and standard tones**

Topographic maps representing probe recognition task SSVEP latency responses at 185 ms post-onset for initial and standard tones. Maps in the first column represent strong-grouping and non-grouping responses in the probe recognition task for the first tone following a lengthened tone; maps in the second column represent strong-grouping and non-grouping SSVEP latency responses averaged across the second, third, and fourth positions following a lengthened tone; maps on the third column represent the difference between SSVEP latency responses for the first tone and the average of second, third and fourth positions following the lengthened tone.

Maps illustrated in Figure 6.25 demonstrate that responses of both strong-grouping and non-grouping respondents feature relative latency reductions for the initial tone compared to subsequent tones. However, only strong-grouping respondents demonstrate relative latency reductions in left posterior frontal regions for the initial tone.

Figure 6.26 illustrates averaged peak SSVEP latency responses analysed within a 100-300 ms window following tone onsets for sequence positions following a lengthened tone at electrode 22 (red), a left frontal electrode located midway between C3 and F7 and at electrode 26 (blue), the equivalent right frontal electrode located midway between C4 and F8.

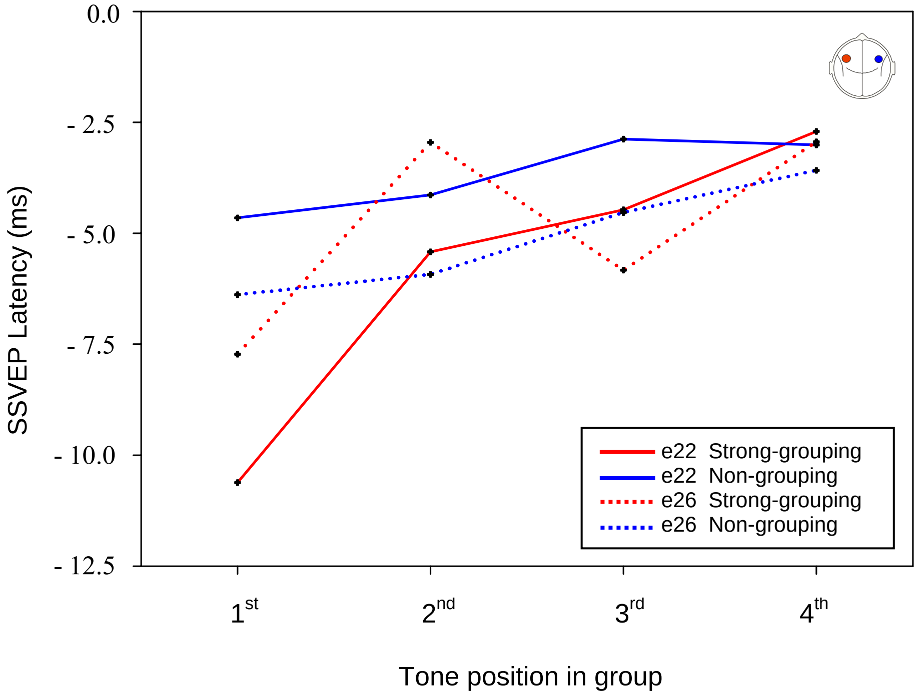

Figure 6.26 **Peak SSVEP latency tone onset responses for each tone position in a group**

Peak SSVEP latency responses analysed in a 100-300 ms window following tone onsets for each sequence position following a lengthened tone. Solid lines represent strong-grouping (red) and non-grouping (blue) peak responses obtained at electrode 22, a left frontal electrode located midway between C3 and F7. Dotted lines represent strong-grouping (red) and non-grouping (blue) peak responses obtained at electrode 26, the equivalent right frontal electrode located midway between C4 and F8. The head template located at the upper right of the figure indicates the topographic location of these electrode sites.

Responses in Figure 6.26 are presented separately for strong-grouping (solid lines) and non-grouping (dotted lines) participants. SSVEP latency responses demonstrate increases from the initial tone to the subsequent tones for both groups at both electrode sites. In particular, strong-grouping participants demonstrate an enhanced reduction in SSVEP latency responses for the initial tone in a group compared to other sequence positions at the left posterior frontal region. This strongly enhanced response is not evident in responses of non-grouping participants, or in responses of either strong-grouping or non-grouping participants at the equivalent right posterior frontal region.

SSVEP latency responses in a 100-300 ms window following tone onsets at left and right posterior frontal regions (electrodes 22 and 26) in first, second, third and fourth positions following a lengthened tone were submitted to a repeated measures ANOVA. This analysis, presented in Table 6.7 demonstrates that SSVEP latency responses for the initial tone in a group are significantly reduced compared to other sequence positions at the left posterior frontal region for strong-grouping participants, but not non-grouping participants. No significant differences were observed between tone positions for either strong-grouping or non-grouping participants at the equivalent right posterior frontal region.

Table 6.7 Significance tests for SSVEP latency differences between standard and initial tone responses

Repeated measures ANOVA analysis of SSVEP latency responses at left and right posterior frontal regions (electrodes 22 and 26) for tones in first, second, third and fourth positions following a lengthened tone.

	Left Frontal (e22)	Right Frontal (e26)
Strong-grouping		
df	3,42	
F	3.182	0.602
p	0.034*	0.617
Non-grouping		
df	3,42	
F	0.447	1.047
p	0.720	0.382

n=43 * $p < 0.05$

In order to examine the relationship between SSVEP latency responses at the left posterior frontal region and structural organisation of participants working memory, a Pearson's correlation analysis was conducted between behavioural grouping scores and peak SSVEP latency responses analysed within a 100-300 ms window following tone onsets for tone positions following the lengthened tone. Pearson's r correlation coefficients illustrated in Figure 6.27 demonstrate that peak SSVEP latency responses in this 100-300 ms window following tone onsets are significantly correlated with grouping scores only for the initial tone following a lengthened tone. The strength of this relationship between left frontal SSVEP early latency responses and strength of grouping demonstrates a progressive weakening through each subsequent position in the sequence.

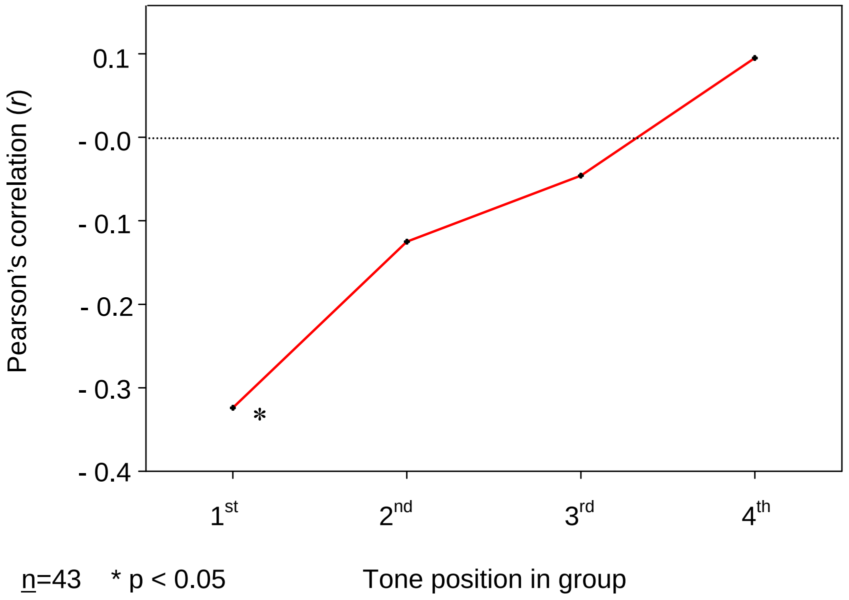

Figure 6.27 **Correlations between peak SSVEP latency responses and grouping scores**

Pearson's r correlations between grouping scores for the entire participant group (N=43) and peak SSVEP latency responses analysed in a 100-300 ms window following tone onsets for each sequence position following a lengthened tone at electrode 22, a left frontal electrode located midway between C3 and F7.

6.4.5 Summary of Responses During the First Note in a Group

Both strong-grouping and non-grouping participants demonstrate an initial transient SSVEP latency reduction in frontal and temporal regions in response to a note that follows a lengthened note. While both respondent groups demonstrate frontal latency reductions bilaterally, strong-grouping participants demonstrate latency reductions most strongly in left posterior frontal and left temporal regions, whereas non-grouping participants demonstrate latency reductions most strongly in right frontal and temporal areas. Latency reductions at the left posterior frontal region were weakly but significantly related to behavioural scores reflecting strength of grouping, suggesting a relationship between responses at the left posterior frontal region and the use of rhythmic grouping cues in the structural organisation of working memory for tone sequences.

Frontal laterality differences in strong- and non-grouping participants' initial latency responses are also evident in latency responses occurring 490-500 ms post-onset. These late responses demonstrate increased left frontal latency for strong-grouping participants at this timing and increased *right* frontal latency for non-grouping participants. The two respondent groups also differ in the extent of left temporal and temporoparietal SSVEP amplitude attenuation evoked by the first note, with strong-grouping participants demonstrating stronger attenuation throughout the first note and particularly during late responses at 490-550 ms post-onset.

SSVEP responses associated with presentation of the first note in a group provide further support for the second experimental hypothesis which proposed that participants who had demonstrated use of lengthened tones as a cue to rhythmically group the tone sequences would demonstrate a tendency towards use of left hemisphere frontal and temporal neural regions in encoding tone sequences, whereas participants who did not rhythmically group the tone sequences would demonstrate a tendency towards use of right hemisphere frontal and temporal neural regions in encoding sequence material.

Dynamic responses over left central/vertex, temporal and temporoparietal regions associated with presentation of the longer-duration note in those respondents who demonstrated greater use of the note as a cue for the generation of working memory structure partially supports the third experimental hypothesis which proposed that presentation of relatively longer tones in a tone sequence would be associated with dynamic responses in brain regions that are sensitive to deviations of temporal structure in frontal, temporal and parietal regions, and that activity in these regions would be greater for participants who demonstrated use of lengthened tones as a cue to rhythmically group the tone sequences.

Furthermore, inhibitory SSVEP changes at left temporal and temporoparietal regions which occur at the timing demonstrated in music phrase processing tasks to be associated with the CPS-related chunking of the prior phrase support the fourth experimental hypothesis which proposed that presentation of tones immediately after relatively longer-duration tones in a to-be-remembered pitch sequence will evoke an SSVEP response in strong-grouping respondents associated with the closure of grouping-related processing in temporal and parietal regions.

6.5 Summary of Results

6.5.1 Behavioural

In summary of behavioural data associated with performance of the probe recognition task, participants demonstrated significantly better recognition of within-group probes than across-group probes, and significantly longer response times for across-group probes than within-group probes. These findings support the use of longer notes in structuring working memory representations of tone sequences. Behavioural responses suggested that the probe recognition task drew on processes developed through musical training and required for performance of the Seashore Tonal Memory task, but only in response to within-group trials. No significant relationships were observed between grouping scores and scores associated with musical training or musical perceptual skills as assessed by the research tasks.

6.5.2 Electrophysiological

Electrophysiological responses associated with presentation of relatively longer-duration notes demonstrated a pattern of responses during the lengthened note which differed strongly between strong-grouping and non-grouping participants. Strong-grouping participants demonstrated strong and transient left central/vertex and parietal latency decreases approximately 170 ms after the non-presentation of the onset, which progressively shifted laterally over the course of 300 ms through left temporoparietal regions, to left temporal regions. These responses were proposed to index increased processing speed in these central and left hemisphere regions (Silberstein et al., 1996, 1998). By contrast, non-grouping participants demonstrate latency increases throughout parietal and left temporal/temporoparietal regions during the lengthened note, indexing decreased processing speed in this region (Silberstein et al., 1996, 1998), and demonstrated latency decreases in right temporal and temporoparietal regions. These findings suggest distinct differences in lateralisation of temporal and temporoparietal networks activated by lengthened notes during performance of the probe recognition task by strong-grouping and non-grouping participants.

In response to the tone following a lengthened tone, both strong-grouping and non-grouping participants demonstrate more strongly reduced early frontal latency responses than responses at similar timings for subsequent tones. Latency reductions at this timing were maximal in left frontal regions for strong-grouping participants, and right frontal regions for non-grouping participants. Only strong-grouping participants demonstrated left posterior frontal latency reductions that were significantly related to behavioural scores reflecting strength of grouping. These responses were proposed to reflect a relationship between left posterior frontal responses and the use of rhythmic grouping cues in the structural organisation of working memory for tone sequences.

Finally, late responses occurring during the tone following a lengthened tone were associated with strong left temporal and temporoparietal SSVEP amplitude attenuation in strong-grouping participants which was accompanied by strong latency increases in this region. By contrast, non-grouping participants demonstrated more right-sided temporal and parietal SSVEP amplitude attenuation. These lateralised responses were accompanied by similarly lateralised left frontal latency for strong-grouping participants at this timing and increased *right* frontal latency for non-grouping participants.

Together, these electrophysiological responses demonstrated sustained differences in lateralisation of regions associated with processing of the lengthened tone and the following tone in strong-grouping and non-grouping participants, suggesting sustained differences in neural regions associated with different structural organisations of the tone sequences. In parallel with these processes, frontal, central and temporal regions dynamically activated by the task differed between strong-grouping and non-grouping participants, and point to specific neural processes during the lengthened tone and subsequent tone involved in the rhythmic structuring of working memory traces of the sequences.

Chapter 7 DISCUSSION

This chapter presents a discussion of the findings detailed in the previous chapter. Discussion of findings is presented in seven sections. Behavioural responses associated with performance of the Seashore Measures of Music Talents subtests and the probe recognition task are discussed in Section 7.1. Discussion of the electrophysiological results associated with performance of the probe recognition task and reference task are presented in Section 7.2, whereas discussion of electrophysiological responses of strong-grouping and non-grouping participants associated with performance of the probe recognition task are presented in Sections 7.3 – 7.5. Section 7.3 discusses sustained SSVEP responses associated with grouping, whereas discussion of dynamic SSVEP responses associated with the lengthened tone, and initial tone are presented in Sections 7.4 and 7.5, respectively. Major conclusions relating to this study are provided in Section 7.6, and future directions are discussed in Section 7.7.

7.1 Behavioural Findings

The first section of this chapter discusses behavioural responses associated with performance of the Seashore Measures of Music Talents subtests and the probe recognition task. Within this section, findings will be discussed associated with the first experimental hypothesis - that recognition of extracts from tone sequences will be significantly better for those extracts presented in accordance with grouped structure compared to extracts that conflict with grouped structure. Discussion of Seashore Measures of Music Talents subtests performance is presented in Section 7.1.1, and discussion of probe recognition task responses are presented in Section 7.1.2. Relationships between musical perceptual skills and probe recognition task scores are discussed in Section 7.1.3; discussion of the use of grouping scores to determine groups for electrophysiological examination is presented in Section 7.1.4, and conclusions of behavioural findings are discussed in Section 7.1.5.

7.1.1 Seashore Measures of Music Talents Sub-test Performance

Inclusion of the Seashore Measures of Music Talents sub-tests in the current research was adopted to ensure participants were capable of perceiving aspects of the auditory information necessary for adequate performance of the experimental tasks, particularly the probe recognition task. Adequate performance of the probe recognition task requires ability to distinguish differences in diatonic pitch and demands the ability to retain pitch series in working memory for a sufficient time period that would support comparison to a subsequently presented pitch series. To this end, the Seashore Tonal Memory sub-test was presented in order to identify those participants who may be incapable of either detecting variations in diatonic pitch series, or retaining pitch series in memory for a sufficient period of time to support comparison of pitch series. All participants completed the Tonal Memory sub-test without difficulty, indicating that all participants possessed the necessary skills to process and retain auditory information presented in the probe recognition task in working memory.

The degree that probe recognition task responses would reflect the impact of variations in rhythmic structure is additionally dependent on the listeners' ability to process rhythmic information. To this end, the Seashore Rhythm sub-test was provided to identify those participants who may be incapable of perceiving differences in rhythmic aspects of the task. No participants demonstrated any difficulty completing the Rhythm sub-test. Seashore Time and Pitch sub-tests were also included in the testing regime in order to provide additional information for subsequent post-hoc analysis but were not used as a basis for exclusion from further participation in the research.

7.1.2 Probe Recognition Task Performance

This section presents discussion of behavioural responses from the probe recognition task. Overall scores are discussed in Section 7.1.2.1; scores associated with within-group and across-group probes are discussed in Section 7.1.2.2, and responses times associated with within-group and across-group probes are discussed in Section 7.1.2.3.

7.1.2.1 Overall scores

Correct performance of the probe recognition task required participants to identify whether a 3- to 5-note extract of a 10-note diatonic pitch series was identical to the original series or alternatively, that one pitch in the series was altered from the original. Post-hoc questionnaire responses suggested that performance of the task was difficult, and this observation was supported by behavioural data demonstrating mean correct recognition of 62.6% of extracted probes.

With a duration of 7.2 s for the 10 note presentation of the pattern in each probe recognition task trial, and a further duration of 6 s before listeners had heard the entire probe extract and were able to respond, recency effects typically evident in serial working memory tasks may have been expected to impact on correct recognition of probes extracted from the first and second halves of the pattern and result in greater accuracy and reduced reaction times for pattern second half probes (McElree & Dosher, 1989; Monsell, 1978). Recency effects were not evident in recognition performance, however, as no significant recognition difference was observed for probes extracted from the first or second halves of the pattern. However, mean response times were significantly greater for probes extracted from the first half of the pattern. This finding indicates that while access to working memory trace representations of the first and second pattern halves was equally successful, correct recognition of information presented in the first pattern half required a significantly longer reaction time. Previous serial working memory task research has observed progressively greater probe reaction times for list items presented earlier in patterns (McElree & Dosher, 1989; Monsell, 1978), and have suggested that the process underlying recognition reflects parallel comparison between probe and pattern and stems from weaker working memory trace strength for earlier presented list items (Golob & Starr, 2004). Weaker strength memory traces for earlier presented list items may thus underlie the observed data and support a speed/accuracy trade-off explanation of the observed recognition and reaction time responses. Additionally, the rhythmic structure of each pattern was designed to cue the division of each pattern into two or more segments. Grouping of sequential information has been demonstrated to elicit primacy and recency effects within each grouped segment (e.g. Hitch, Burgess, Towse, & Culpin, 1996). In view of this finding, division of the patterns based on rhythmic cues may have acted to reduce the recency effect of the sequence as a whole.

7.1.2.2 Within-group/ across-group scores

Probe recognition task performance was significantly influenced by the extent that probe extracts matched grouped structure determined by longer-duration notes. Significantly better recognition of probes that matched the pattern rhythmic structure (within-group probes) was evident for extracts probing both the first and second pattern halves. These data indicate that the structure of working memory representations of patterns were influenced by increases in note duration in accordance with the Gestalt Proximity principle, and support the first experimental hypothesis that recognition of tone sequence extracts presented in accordance with rhyhmic grouped structure would be significantly better than in response to extracts presented in conflict with rhyhmically grouped structure.

Probe recognition task research has previously demonstrated better recognition of within-group probes compared to across-group probes (Dowling, 1973b; Frankland & Cohen, 2004; Peretz, 1989; Peretz & Babai, 1992; Tan et al., 1981) and specifically, better probe recognition of within-group musical extracts probing duration-based grouped structure (Dowling, 1973b; Frankland & Cohen, 2004; Peretz, 1989). Although recognition of probes that matched the pattern rhythmic structure (within-group probes) was significantly better than recognition of extracts that conflicted with the rhythmic structure overall and for both first and second pattern halves probes, better recognition of within-group probes than across-group probes was more clearly demonstrated for extracts probing the second pattern half than extracts probing the first pattern half, which demonstrated only a weak advantage for within-group probes. These data suggest that note duration influences working memory for grouped structure, yet the extent of this influence on subsequent recognition is sensitive to recency effects. The current data suggests that grouping based on note duration impacts less on recognition of note extracts presented earlier in patterns.

Peretz (1989) discussed the extent that grouping cues were retained in memory representations of musical structure. Whereas grouping effects on recognition were evident in response to presentation of extracted probe patterns *prior* to presentation of the original melody, grouping effects were not evident for probe patterns presented *after* the original pattern. Peretz suggested that grouping cues elicited only a temporary influence on working memory representations of musical structure, which were not sufficiently durable to impact on probes presented after the pattern. While this view may support a recency-based view on the strength of grouped representation and provide a basis to interpret the current results, other findings demonstrating grouped working memory representations in response to probes following sequences containing up to 25 items (Dowling, 1973b) suggest that grouped working memory traces are sufficiently durable to impact on both pattern halves in the current research.

7.1.2.3 Within-group/ across-group response times

Analysed over all valid trials (including both correct and incorrect responses), probe recognition task response times were significantly influenced by the extent that probe extracts matched grouped structure determined by longer-duration tones. Overall, across-group probes were associated with significantly longer response times than within-group probes, although analysis of the separate pattern halves indicated that this effect was limited to the first pattern half only. No significant difference was observed between within- and across-group trials in the second half of the pattern. Two potential processes underlie these data: longer response times for across-group probes may indicate an increase in processing time due to greater difficulty matching probe extracts with working memory representations of the probe extract, or may reflect slower response time due to greater uncertainty underlying the recognition decision. In both cases, longer response times to across-group probes indicate that longer-duration tones were used as a key structural component in the generation of the pattern memory trace, and reflect an influence of the Gestalt Proximity Principle on structuring of working memory representations of patterns.

Notably, longer response times for first half across-group probes were associated with marginally better recognition performance for within-group probes, whereas similar duration response times for within- and across-group probes in response to second half probes were associated with better performance for within-group probes.

Together, these data indicate that responses to across-group probes in both halves of the pattern were associated with greater difficulty in providing accurate responses, although the behavioural mechanisms differed for each half. As first half probes were associated with longer response times overall, particularly for across-group probes, participants' confidence in responding accurately is likely to have been lower for the less recent information presented in these trials, and slower responses resulted. By contrast, second half probes reflected more recently presented information. Response times to these trials were faster than first half trials and did not differ between probe types suggesting better access to memory representations or confidence in responding to these trials.

Analysis of probe recognition task response times specifically for correct trials provides further support for this contention. Response times for correct trials were reduced as compared to response times analysed across all trials, further supporting the link between greater processing difficulty or uncertainty and slower response times. Correct across-group probes demonstrated response times that were longer than within-group trials overall, and for both the first and second pattern halves. However, these differences were not statistically significant.

As across-group trials were associated with significantly less correct responses, these data indicate that a trade-off in response time processing was not adopted in order to support greater accuracy in responses to across-group trials. Instead, participants appear to have adopted a processing strategy that resulted in more equivalent speed responses for more recently presented information at the cost of reduced accuracy for across-group trials.

7.1.2.4 Summary of scores and response times

Together, probe recognition task scores and response times indicate that longer-duration tones significantly impacted on the structural organisation of working memory representations of the sequences. Whereas the impact of longer-duration tones on the more recently presented sequence information in the second half of the pattern was demonstrated in significantly better recognition performance for within-group probes, less recently presented sequence information extracted from the first half of the pattern elicited a weaker recognition advantage for within-group probes, which was associated with a significantly faster response time. This response may indicate that the effect of longer-duration tones on the grouped working memory representation is sensitive to temporal delay, so that information may be recoded into representations other than the initial grouped code. This proposal accords with those of Peretz (1989) and may suggest that in order to examine grouping effects prior to any recoding process, electrophysiological examination of grouping processes need assess processes occurring at the time of presentation of the stimulus eliciting the grouped structure. This approach was adopted for electrophysiological analysis of grouping-related processes in the current research.

7.1.3 Musical Perceptual Skills and Probe Recognition Task Scores

Correct recognition scores in the probe recognition task were weakly correlated with the Seashore Pitch, Rhythm and Tonal Memory subtests and was also weakly correlated with number of years involved in musical instrument performance training. Separate analysis of within-group and across group performance indicated that within-group performance was the predominant basis of these relationships, and that relationships with Seashore sub-test performance were predominantly linked with recognition of extracts probing the second pattern half, whereas relationships with years musical training were linked with recognition of extracts probing the pattern first half. Seashore Rhythm subtest performance, on the other hand, correlated with greatest strength to the pattern second half across-group performance. These data demonstrate that within-group trials weakly tapped aspects of processes used to complete the Seashore Pitch, and Tonal Memory subtests, and also processes associated with musical training, whereas across-group trial performance did not reflect an association with these processes. As such, across-group trial performance indicates that extracts that straddle longer duration notes interfere with the use of music perceptual processes associated with musical training and performance of Seashore Pitch and Tonal Memory sub-tests. Only rhythmic perceptual skills reflected in performance of the Seashore rhythm subtest are reflected in performance of across-group trials. This result indicates that higher performance on trials featuring a rhythmic structure that did not match the structure cued by longer-duration tones was more strongly associated with individuals' ability to compare and match rhythmic patterns as cued by the Seashore Rhythm subtest. By contrast, within-group trials that matched the rhyhmic structure cued by the longer-duration tones did not draw on rhythmic pattern matching processes, and were not significantly associated with performance on the Seashore Rhythm subtest. When examined by pattern halves, relationships between Probe Recognition Task performance and the Seashore Rhythm subtest were significant only for the pattern second half. This finding may reflect differences in lengths of the tasks. Whereas all Probe Recognition Task trials consisted of 10-tone patterns, Seashore Rhythm subtest pattern trials consist of either five, six or seven tone patterns. Notably, Probe Recognition Task across-group trials in the second half of the pattern consist of the last five to seven tones of the pattern, and in view of this, significant relationships between the rhythm subtest and only these components of the patterns suggests that similar processes are tapped at this point in the pattern, whereas pattern matching involving longer stimulus lengths does not as strongly draw on processes reflected by performance on the shorter Seashore Rhythm subtest. Notably, no significant relationships were found between Seashore time subtest performance and performance on any aspect of the probe recognition task. This result indicates that these two tests tap different aspects of temporal processing - the Seashore Time subtest examines an individual's temporal processing acuity on a millisecond scale, whereas the Probe Recognition Task assesses an individual's sensitivity to rhythmic information as a cue for segmentational grouping. These results indicate that the different aspects of temporal processing tapped by the two tests are not significantly related.

Behavioural research examining use of grouping preference rules to determine boundary locations in musical segments has indicated that musical training does not generally result in significant differences in the application of grouping rules (Deliège, 1987; Peretz, 1989). This was reflected in the current research by the non-significant relationship between years of musical instrument training and the tendency to correctly recognise within-group probes better than across-group probes as assessed by grouping scores. Musical training significantly correlated with within-group recognition, demonstrated a weak non-significant relationship with across-group scores, and no significant relationship with difference in performance between within-group and across-group trials. Musical training would be expected to result in high performance levels of working memory recognition for pitch series information (Krumhansl, 1991) and as indicated by analysis examining the relationship between musical training and probe recognition task performance, musically trained individuals tended to perform better on the task overall, but only for those probes that matched the rhythmic groups presented in the initial patterns. Probes that conflicted with the rhythmic grouping in the initial pattern were only weakly associated with enhanced recognition performance for musical trained participants. This data indicates that musical perceptual skills enhanced by music training are better tapped by those probe recognition task trials that present information in a format that enables those mental schema that have been developed through musical training to be applied. Across-group trials presented information in a format that did not provide an opportunity to apply these training-enhanced processes.

7.1.4 Use of Grouping Scores

Use of grouping scores to delineate those participants who had tended to recognise musical fragments better when the fragment matched the rhythmic structure of the original pattern versus fragments that did not match the rhythmic structure resulted in the identification of strong-grouping, weak-grouping and non-grouping participants, with each participant group demonstrating strong significant differentiation of mean grouping scores from those of other participant groups. A strong advantage for recognition of within-group probes was demonstrated by strong-grouping participants, whereas non-grouping participants demonstrated either no advantage for within-group trials over across-group trials, or even better recognition performance for across-group trials as compared to within-group trials – a result which was not predicted in the experimental hypotheses.

Potential strategies adopted by participants to perform the probe recognition task which may have impacted on grouping scores were explored in responses provided in post-hoc questionnaires. Questionnaire responses indicated that participants demonstrating better recognition of across-group trials strongly differed in the strategy adopted for the performance of the task, and in particular, while individuals demonstrating better across-group performance often noted the relative salience of the longer-duration note within the initial pattern, use of longer tones as a basis for dividing patterns into segments was less prominent in this group. Typically, these participants claimed to hear the patterns as comprised of separate notes and attempted to hold the patterns in memory on a note-by-note basis. However, as the total pattern length made storage of the entire pattern on a note-by-note basis difficult, better recognition of across-group probes by these participants may reflect a tendency to include the longer-duration note as a salient feature of working memory representations of note subsets as a central cue rather than as a group ending. By contrast, individuals demonstrating the strongest recognition performance advantage for within-group trials noted the salience of the longer-duration note as a cue that delineated segments of the pattern. The majority of strong-grouping participants reported hearing and explicitly attempting to store the pattern in segments bounded by the longer-duration note. Although questionnaire responses reflecting use of longer tones were not significantly different between the two participant groups, trends in responses suggest that the strategies adopted by participants to perform the probe recognition task may have influenced the degree that participants used grouping cues as a basis to encode the pattern structure and as a result the degree that rhythmic structure impacted on recognition of within- and across-group probes.

7.1.5 Conclusions on Behavioural Findings

Consistent with previous findings, the rhythmic structure of pattern extracts significantly influenced participants’ recognition performance for pitch changes within the patterns. Participants were significantly less likely to correctly recognise pattern extracts that conflicted with the rhythmic grouping of the original pattern, providing strong support for the proposal that longer-duration notes are used as a basis for structuring working memory representation of pitch series. Furthermore, participants’ reaction times were significantly influenced by grouping structure – reaction times were significantly longer in response to pattern extracts that conflicted with the rhythmic grouping of the original pattern. Rhythmic grouping effects were evident in both pattern halves, although the effects of grouping on recognition scores was most strongly evident in the second half of patterns, whereas participants' reaction times were impacted by grouping effects in the first half of the pattern. These differences in performance across the two pattern halves indicate that while grouping effects did impact on each pattern half, more recently encoded grouped structure impacted more strongly on the accuracy of participants' access to the working memory code, whereas less recently encoded grouped structure impacted on the reaction time associated with access to the working memory code. The differential responses across the pattern halves indicate that while grouping impacts on working memory representations of both halves of the patterns, recency effects impact on the nature of the working memory trace and the nature of the grouped code may alter with time. This finding concurs with Peretz (1989), who suggested that grouped representations may be a limited duration format for the encoding of pitch series. Instead, other coding structures may be subsequently used as a basis for the formation of more durable memory codes. This proposal provides implications for research that seeks to examine the durability of grouped representations within structural representations of music.

Although behavioural data demonstrated in this study and other research examining rhythmic grouping indicate that grouped codes may be subject to the impact of durability factors, in the current research, electrophysiological responses were captured at the time of exposure to grouping cues, and as a result, durability factors were not considered a potential confounding factor impacting on examination of responses at the time of exposure. Furthermore, the incorporation of all trials associated with grouping cues provides a key benefit of enhancing the signal-noise ratio of electrophysiological responses associated with the grouping process, and as a result, maximises the opportunity to identify those electrophysiological responses associated with the grouping process. In view of these factors, examination of electrophysiological responses in response to both halves of the pattern at the time of initial hearing was employed to provide insights into the processes underlying grouping phenomena.

The following sections discuss the neurophysiological findings presented in Chapter 6. This discussion will be presented in four broad sections. Section 7.2 will discuss task-related differences in neurophysiological responses associated with performance of the probe recognition task and the reference task, whereas Sections 7.3, 7.4 and 7.5 will discuss SSVEP responses associated with grouping scores in the probe recognition task. Section 7.3 will present discussion associated with sustained responses, Section 7.4 will discuss dynamic SSVEP responses associated with presentation of the lengthened-duration tone, and Section 7.5 will discuss dynamic SSVEP responses associated with presentation of the initial tone.

7.2 Task-Related SSVEP Differences

This section of the discussion examines differences in SSVEP responses between the probe recognition task and the reference task. Section 7.2.1 discusses sustained differences in SSVEP responses between the two tasks, and Section 7.2.2 discusses dynamic differences in SSVEP responses between the tasks. A summary of this discussion is presented in Section 7.2.3.

7.2.1 Sustained Task-Related Differences

Use of a reference task in neurophysiological protocols provides a baseline against which the effects of activation tasks may be measured. In the current research, a reference task was presented that consisted of identical physical stimulus properties as those used in the activation task – the probe recognition task. Both the reference task and the probe recognition task presented tone sequences consisting of standard tone durations and IOIs with a semi-random lengthening of tone duration occurring at equal probability in each task. This task design ensured that physical stimulus properties of each task were equivalent and would result in activation of neural regions associated with processing of identical stimulus properties. By contrast, task *demands* associated with performance of each task varied strongly. Whereas the reference task required the participant to detect the occurrence of two simultaneous tones in the ongoing sequence of single tones, and was presented as a low demand task; the probe recognition task required participants to temporarily hold a sequence of tones in working memory for comparison to a subsequently presented subset of the sequence and detection of any altered tone pitches. As such, the probe recognition task placed demands on participants’ processing of pitch-related information in the sequence and retention of this information for subsequent comparison to the probe patterns.

Comparison of mean neurophysiological responses to the reference and probe recognition tasks demonstrated that performance of the probe recognition task resulted in generalised SSVEP amplitude reductions across all electrode sites compared to the reference task. Research examining SSVEP responses in a range of cognitive tasks has demonstrated an association between amplitude reductions and increased task demands. Regional activation and SSVEP amplitude reductions have been linked (Silberstein et al., 1995; Silberstein et al., 2000; Silberstein et al., 1990) in a similar fashion as regional activation has been linked with alpha band amplitude reductions and interpreted within the context of event-related desynchronisation (e.g. Pfurtscheller, Neuper, & Berger, 1994). In view of this research, the sustained SSVEP amplitude reductions observed in the probe recognition task compared to the reference task support the proposal that the probe recognition task placed greater demands on a broad range of neural regions than processing associated with the reference task.

Comparison of mean SSVEP latency responses demonstrated that probe recognition task latency responses were typically equivalent or increased compared to reference task responses. SSVEP latency increases were most strongly evident at right frontal regions, whereas equivalent latency responses were evident in left frontal, right temporal and right parietal regions. Sustained reductions in SSVEP latency responses associated with the probe recognition task were evident in the left temporal and temporoparietal regions. SSVEP latency changes have been proposed to index changes in transmission times in cortico-cortico and thalamo-cortical loops resulting from excitation or inhibition of post-synaptic cells (Silberstein, 1995b; Silberstein et al., 2001). Silberstein et al. have interpreted SSVEP amplitude and latency reductions as transient increases in regional activity at the timing when neural resources are specifically required for task-related processing (Silberstein, Cadusch et al., 1996; Silberstein et al., 1998; Silberstein et al., 2000). In view of this research, mean differences in SSVEP amplitude and latency responses between the reference and probe recognition tasks suggest that the left temporal and temporoparietal regions are activated more strongly by task demands associated with performance of the probe recognition task. By contrast, SSVEP latency increases associated with SSVEP amplitude reductions in right frontal regions suggest that neural transmission times are increased in these regions in association with processing of the probe recognition task. These issues will be further explored in discussion of dynamic task responses in the following section.

7.2.2 Dynamic Task-Related Differences

Examination of dynamic responses associated with performance of the reference and probe recognition tasks demonstrated that probe recognition task SSVEP amplitude responses throughout the lengthened tone and the following tone were attenuated compared to mean reference task responses at a broad range of neural regions in each of the timings examined. SSVEP amplitude responses suggest that performance of the probe recognition task required consistently greater participation of a broad range of neural regions than performance of the reference task. In particular, late responses during both the lengthened tone and the following tone demonstrated strongly divergent responses between the reference task and probe recognition task. At 480 ms following the missing onset, and at the same timing following the initial tone, SSVEP amplitude responses were strongly attenuated compared to the mean reference task level at left temporal and temporoparietal regions in the probe recognition task, and by contrast, were increased compared to the mean level in dynamic reference task responses. In accordance with interpretation of SSVEP amplitude reductions as regional activation, these two points in time evoke greater contributions by left temporal and temporoparietal neural regions in the probe recognition task, whereas the same timings are associated with a decrease in contributions by the same regions in the reference task.

Dynamic SSVEP latency responses demonstrated that performance of the probe recognition task was associated with SSVEP latency increases compared to the mean reference task level at right posterior frontal, right temporal and right parietal regions during the lengthened tone. SSVEP latency increases associated with performance of the probe recognition task may be associated with the manipulation of information in working memory. Silberstein et al (Silberstein, Song et al., 2003; Silberstein et al., 1997) have reported SSVEP latency increases associated with working memory tasks when the task involves the manipulation of information, as opposed to simply holding it on-line. In view of this research, the observed latency increases during the lengthened tone may reflect the manipulation of information for use within the working memory code. As Reference task processing placed no demands on the retention of information for the task, this manipulation of information would not have been required in the reference task. This issue will be explored in greater detail in the discussion of data associated with grouping performance in Sections 7.3, 7.4 and 7.5.

Dynamic SSVEP latency responses in frontal regions of both the probe recognition task and reference task reflected event onsets/offsets in each of the tasks, so that tone onsets/offsets were associated with transient latency decreases in a broad range of frontal regions at 200-250 ms post-onset in both tasks. Notably, the onset/offset response during the initial tone demonstrated strong frontal latency reductions compared to the reference task. Given that frontal regions were generally associated with a tonic SSVEP latency increase during the probe recognition task, this enhanced latency reduction associated with the first tone in the probe recognition task suggests that this initial tone was associated with different status in the probe recognition task than the reference task and resulted in enhanced coupling strength of local cortical networks in the frontal regions (Silberstein, 1995a). This issue will be explored in greater detail in the discussion of data associated with grouping performance in Sections 7.3, 7.4 and 7.5.

7.2.3 Summary of Task-Related Processing

Together, SSVEP responses associated with the probe recognition task and reference task demonstrate that processing of similar physical stimuli in accordance with different task demands modulates the relative contributions of neural regions to the task. As task strategy modulates the contributions of neural regions to task processing, these findings suggest that examination of electrophysiological responses associated with the probe recognition task in accordance with variations in participants' strategies and behavioural scores may provide information regarding the neural regions associated with these variations in processing. This approach was adopted for within-task analysis of participants' responses to the probe recognition task in order to examine variations in neural regions associated with greater tendencies to organise tone sequences using rhythmic cues. The following sections discuss this analysis.

7.3 Sustained SSVEP Grouping Responses

The third and fourth research hypotheses examined in this study propose dynamic activation of frontal, temporal and parietal regions linked with underlying grouping-related processes. While these research hypotheses focus on transient responses linked with the grouping process, examination of sustained SSVEP responses provides an indication of neural regions that may tonically bias processing modes to influence grouping processes in a sustained way. This examination of sustained processes provides a basis for addressing the second research hypothesis, which proposes that participants who demonstrate use of lengthened tones as a cue to rhythmically group the tone sequences will demonstrate tendency towards use of left hemisphere frontal and temporal neural regions in encoding tone sequences, whereas participants who do not rhythmically group the tone sequences will demonstrate a tendency towards use of right hemisphere frontal and temporal neural regions in encoding sequence material. Findings associated with this hypothesis will be discussed in this section. Section 7.3.1 will discuss SSVEP responses associated with task-related processing, whereas Sections 7.3.2 – 7.3.6 will discuss factors underlying the observed SSVEP findings, and Section 7.3.7 will summarise the discussion regarding sustained SSVEP responses.

7.3.1 Task-Related Comparisons

Comparison of sustained SSVEP responses to the probe recognition task and the reference task for strong-grouping and non-grouping participants demonstrated substantial differences in neural regions associated with performance of the probe recognition task and lateralisation of neural regions participating in an ongoing way to the task. Whereas regions associated with statistically significant Hotelling's T responses for strong-grouping participants were focussed in left temporal and post-central regions, regions associated with significant Hotelling's T responses for non-grouping participants were prominent in broadly distributed right frontal regions. Both groups demonstrated significant Hotelling's T responses in left posterior temporal regions, although these were linked with strongly contrasting SSVEP latency responses across the two groups, with strong-grouping participants demonstrating SSVEP latency decreases suggesting excitatory responses, and non-grouping participants demonstrating SSVEP latency increases, suggesting inhibition of the region. By contrast, neural regions associated with reductions in non-grouping latency responses were instead strongly lateralised to right temporal lobe regions. SSVEP amplitude responses further emphasise these lateralised differences. Whereas strong-grouping participants demonstrated strong left temporal and temporoparietal amplitude attenuation, non-grouping participants demonstrated more uniformly attenuated amplitude reductions over bilateral temporal and parietal regions.

As discussed in Section 4.3.3, Silberstein et al. have demonstrated an association between amplitude reductions and increased task demands (Silberstein, Cadusch et al., 1996; Silberstein et al., 1995; Silberstein et al., 2000; Silberstein et al., 1990), suggesting a link between regional activation and SSVEP amplitude reductions. Furthermore, SSVEP amplitude and latency reductions have been interpreted as transient increases in regional excitatory activity at the timing when neural resources are specifically required for task-related processing (Silberstein, Cadusch et al., 1996; Silberstein et al., 1998; Silberstein et al., 2000). In the current research, the topography of sustained SSVEP responses is consistent with predominant temporal lobe contributions that typically support performance of auditory tasks, and indicate that variations in grouping behaviour are linked with sustained variations in lateralisation of temporal and temporoparietal contributions during task performance. These findings strongly support aspects of the second research hypothesis proposing greater use of left-sided temporal neural regions by participants who rhythmically grouped the tone sequences and greater use of right-sided temporal neural regions by participants who do not rhythmically group the tone sequences. Lateralisation of frontal neural regions in strong-grouping and non-grouping responses was weakly demonstrated in sustained responses, suggesting that the impact of temporal organisation of the tone sequences on neural lateralisation is more prevalent in the temporal lobes than in frontal regions.

The following discussion examines various factors understood to impact on relative hemispheric contributions to musical task performance which may have impacted on the observed differences between groups in the current research. Factors discussed in these sections are stimulus complexity (7.3.2); musical training (7.3.3); use of analytic/holistic processing strategies (7.3.4); use of local/global pitch processing strategies (7.3.5); and use of local/global temporal processing strategies (7.3.6).

7.3.2 Complexity

Greater use of left hemisphere networks have been observed in association with increases in task complexity or difficulty in dichotic listening tests, which have demonstrated an increasing right ear advantage (suggesting greater application of left hemisphere networks) as a function of greater task difficulty (Gordon, 1978; Halperin, Nachson, & Carmon, 1973; Messerli, Pegna, & Sordet, 1995; Natale, 1977; Shanon, 1980). Peretz and Morais (1988) noted right ear advantages associated with difficult recognition tasks where performance levels were at around 60% correct responses. Notably, probe recognition task scores in the current research indicated that this task was also difficult, with an overall mean score of 62.6%. However, overall performance on the probe recognition task was similar between the groups, with differences between groups only evident when differential performance on the recognition of within-group and across-group probes is examined. These differences emerge only as a function of the probe type presented at the recognition phase of the task, and any processing differences resulting from differences in perceived task difficulty would only emerge at this later phase of the task. As such, performance scores provide no basis to suggest task difficulty impacted differently on laterality differences observed for strong-grouping and non-grouping participants during the encoding phase of the task.

7.3.3 Musical Training

A range of respondent and task-related factors have been linked with differences in relative hemispheric contributions in response to performance of musical tasks. Musical training has been proposed to influence the relative contribution of left hemisphere regions to musical task performance (e.g. Bever & Chiarello, 1974; Bhattacharya & Petsche, 2005; Evers, Dannert, Rodding, Rotter, & Ringelstein, 1999; P. R. Johnson, 1977; Kellar & Bever, 1980; Marinoni, Grassi, Latorraca, Caruso, & Sorbi, 2000), although this effect has been linked to some extent with greater use of analytic processing strategies (further discussed in Section 7.3.4). In the current research, and as presented in Section 6.1.4, examination of potential relationships between musical training and grouping performance indicated no significant relationship between the tendency to group and number of years musical training, and revealed no significant differences in the degree of musical training between strong-grouping and non-grouping respondents. In view of these findings, musical training would not appear to be a key factor underlying the observed hemispheric differences in temporal lobe activation.

7.3.4 Analytic/Holistic Strategies

While musicianship has been associated with greater activation of left hemisphere structures in performance of musical tasks, musical training, per se, may not be the sole basis of these responses. As musical training develops skills that enable use of analytic strategies to perform musical tasks, early research focussing on lateralisation effects resulting from musical training suggested that the use of analytic strategies enabled by musical training results in aspects of the observed increases in left hemisphere activation (e.g. Bever & Chiarello, 1974). Early research in the area suggested that musicians alone possess the necessary resources to adopt a structural conceptual framework in performing complex musical tasks, resulting in increased left hemisphere contributions, whereas non-musicians do not have access to these resources (Shanon, 1980). However, tasks which promote greater use of analytic strategies by non-musicians in performance of melodic recognition tasks have been demonstrated to result in greater left hemisphere contributions to melodic recognition task performance in dichotic listening tests (Gaede, Parson, & Bertera, 1978; Gates & Bradshaw, 1977, Experiment 1; Peretz & Morais, 1980, 1983, 1987; Peretz, Morais, & Bertelson, 1987) and in PET research (Mazziotta et al., 1982) which demonstrated that greater adoption of analytic strategies by both musically trained and untrained participants resulted in greater activation within left posterior superior temporal cortex in performance of the Seashore Tonal Memory subtest. In the current research, responses to a post-hoc question that queried the extent that participants adopted specific strategies when listening to the probe recognition task patterns indicated that strong-grouping participants were not significantly more likely to adopt specific strategies when listening to the initial patterns than non-grouping participants. Notably, non-grouping respondents were significantly more likely to process patterns 'as separate notes', potentially suggesting use of a more analytic strategy than respondents who did not indicate use of this strategy. Whilst this strategy may have impacted on processing in terms of the analytic/holistic dimension, adoption of this strategy impacts strongly on the degree that temporal information is incorporated in the working memory code, and as a result, the degree that regional activation is impacted on by the temporal processing strategy adopted. The impact of the strategy in terms of temporal processing is discussed in more detail in Section 7.3.6.2, and Section 7.4.2.5.

7.3.5 Pitch Factors

Specific strategies applied to the processing of pitch and rhythm patterns in musical tasks have been demonstrated to vary on a local/global dimension and impact on relative hemispheric contributions to task processing. In the pitch dimension, respondent strategies or tasks that induce listeners to process melodies as separate pitch events (local pitch processing) have been associated with increasing use of left hemisphere resources in dichotic listening research (Gaede et al., 1978; Gates & Bradshaw, 1977, Experiment 1; Peretz et al., 1987), and in research examining brain damaged populations (Ayotte, Peretz, Rousseau, Bard, & Bojanowski, 2000; Liegeois-Chauvel et al., 1998; Peretz, 1990; Vignolo, 2003), although notably, lesion research indicates that processing of local pitch information depends on *both* the left and right superior temporal lobes. By contrast, strategies or tasks that promote use of pitch contour information (global pitch processing) have been associated with use of right hemisphere resources in dichotic listening designs (Peretz & Morais, 1987), in recognition tasks using monaural presentation (Mazzucchi, Parma, & Cattelani, 1981; McKinnon & Schellenberg, 1997; Peretz & Babai, 1992) and in brain damaged populations (Liegeois-Chauvel et al., 1998; Peretz, 1990; Zatorre, 1985).

In the current research, probe recognition task stimuli provided limited availability of contour-based cues that may have been used as an alternative basis to group notes. To minimise contour-based cues, a maximum of 2 pitch changes in a given direction were presented prior to a change in pitch movement. In this way, 10-note patterns contained a minimum of 4 pitch contour changes, and as a result, pitch contours were not strongly cued by the pitch sequence, and less likely to provide a basis for processing pitch content of patterns. Despite this design, post-hoc questionnaire responses indicated that non-grouping participants attempted to use pitch contour-based strategies for encoding pitch patterns more often than strong-grouping participants, although this difference was not significant. Stronger left temporal and temporoparietal responses in strong-grouping participants and stronger right temporal responses in non-grouping participants accord with this tendency in behavioural responses, and in view of this, neurophysiological differences between the groups may partially reflect difference in application of contour-based strategies. However, differences in the degree that contour-based strategies were applied by the two groups were not significant, and as indicated by lesion research, use of local pitch processing strategies typically draws on processing in both left and right hemispheres, whereas in the current research, use of local information pitch cues was associated with only left hemisphere activation. As such, while use of pitch interval or contour cues may play into the observed neurophysiological responses, these factors are unlikely to be the key factor underlying the observed differences in lateralisation between the two groups.

7.3.6 Temporal Factors

This section discusses temporal factors that may underlie sustained SSVEP task-related responses. Areas of discussion covered in this section are metric/rhythmic hemispheric processing distinctions (7.3.6.1); incorporating temporal information in sequence processing (7.3.6.2), and the role of left hemisphere processing in temporal organisation (7.3.6.3).

7.3.6.1 Metric/rhythmic hemispheric processing distinctions

In the temporal dimension, local/global distinctions have also been applied with regard to rhythm processing (local) and processing of metre (global) (Peretz, 1990; Schuppert, Munte, Wieringa, & Altenmuller, 2000). Metre and rhythm have been conceived as being composed of distinct processing components (Drake, 1998; Lerdahl & Jackendoff, 1983), and have also been distinguished by neuropsychological evidence showing functional dissociations between the dimensions, which may feature differences in relative left and right hemisphere processing contributions, although less consistently than local/global differences observed in the pitch dimension. Functional dissociations between rhythm and metre processing have been indicated by lesion research demonstrating deficits in processing of one temporal aspect in brain damaged individuals while the other aspect remains intact (Liegeois-Chauvel et al., 1998; Peretz, 1990). Deficits in rhythm discrimination alone have been observed following left temporal or temporoparietal damage (Di Pietro, Laganaro, Leeman, & Schnider, 2004; Mavlov, 1980), whereas right superior temporal lobe damage has been demonstrated to impact on metre processing but not rhythm (Fries & Swihart, 1990; Wilson, Pressing, & Wales, 2002). Further support for a hemispheric distinction between rhythm and metre processing is provided by behavioural evidence showing that individuals more easily tap rhythmic patterns with the right hand and beat with the left hand than the other way round (Ibbotson & Morton, 1981), and that damage to the right superior temporal lobe interferes with beat tapping but not production or discrimination of irregular temporal sequences (Fries & Swihart, 1990; Wilson et al., 2002).

In the current research, probe recognition task stimuli provided limited availability of metric cues that may have been used as an alternative basis to organise the rhythmic content of patterns. To minimise availability of cues that may have been used to establish a regular pulse, longer-duration notes were positioned at irregular timings within patterns, so that no predictable or regular pattern of accented beats could be extracted from the duration information. As such, use of a metric approach to processing patterns was prevented by the pattern content, and as a result, is unlikely to play a role in participants' processing strategies or observed differences in neurophysiological responses associated with strong- and non-grouping participants.

7.3.6.2 Incorporating temporal information in sequence processing

While use of metric cues is unlikely to have been a contributing factor in the observed responses, an alternative factor that may account for the neurophysiological differences between strong-grouping and non-grouping participants was the extent that participants incorporated temporal information in the listening process. Different authors place different degrees of emphasis on the extent that temporal information is used within the music listening experience. Jones and colleagues have proposed that music listening is inherently rhythmical, so that temporal and pitch information are necessarily coded as unitary processes (e.g. Jones, 1992; Jones & Boltz, 1989; Jones et al., 1981). Other authors argue for separate processing of pitch and temporal information, at least in early processing stages of music sequences (Justus & Bharucha, 2002; Krumhansl, 2000; Palmer & Krumhansl, 1987), and this proposal is most strongly supported by neuropsychological evidence which demonstrates that pitch and rhythm information processing may be dissociated by brain damage (Ayotte et al., 2000; Liegeois-Chauvel et al., 1998; Peretz, 1990; Peretz & Morais, 1993; Vignolo, 2003). Attentional strategies may also impact on the degree that processing of one specific dimension is emphasised. For example, directing attention to pitch-based aspects of the musical stimulus has been demonstrated to emphasise activation of neural regions associated with pitch processing, whereas directing attention to more rhythmic aspects of the stimulus may activate regions associated with rhythm processing (Janata, 2005; Parsons, 2001; Platel et al., 1997). As such, different processing modes and neural regions are activated during musical tasks in accordance with the attended dimension.

In the current research, listeners' attention was directed to pitch-based aspects of the stimulus and successful performance of the task required no explicit demand for processing of rhythmic aspects of the stimulus. Comparison of post-hoc questionnaire responses by grouping performance indicated that although strong-grouping participants demonstrated a trend towards greater salience and use of longer-duration notes as a basis for establishing the memory trace for the pitch sequence, differences in explicit use of the longer tones were not significantly greater than non-grouping participants. This finding suggests that explicit use of pattern temporal content did not significantly differ between the groups. Notably however, post-experiment responses indicated that non-grouping participants processed the patterns 'as separate notes' significantly more often than strong-grouping participants. These results indicate that although participants appeared to differ only marginally in explicit use of temporal cues within the pattern, strong-grouping participants demonstrated a significantly greater tendency to process tones as related events within the patterns. Together with responses indicating a tendency towards use of longer tones as a basis for remembering the patterns, these findings indicate use of a processing strategy involving temporal organisation of the sequence information on a local time-scale by strong-grouping participants. By contrast, non-grouping participants were less likely to incorporate longer-duration cues in pattern memory, and did not incorporate this local temporal organisation strategy within the processing of the sequence information. These differences between temporally-based strategies may underlie the observed neurophysiological differences in hemispheric contributions by the two participant groups.

7.3.6.3 Left hemisphere role in temporal organisation

Evidence supporting a hemispheric distinction between rhythm and metre processing suggests a relative left hemisphere dominance for temporal organisation of time intervals. Further support for a predominant left hemisphere role in temporal organisation is provided by dichotic listening (Halperin et al., 1973; Robinson & Solomon, 1974) and lesion research (Di Pietro et al., 2004; Efron, 1963; Mavlov, 1980; Prior, Kinsella, & Giese, 1990; Robin, Tranel, & Damasio, 1990; Swisher & Hirsh, 1972; Vignolo, 2003) which support the proposal that the left hemisphere, particularly left posterior temporal, temporoparietal, inferior parietal cortex (Di Pietro et al., 2004; Mavlov, 1980; Swisher & Hirsh, 1972; Wertheim & Botez, 1961) is involved in the perceptual integration of events in time (Efron, 1963; Swisher & Hirsh, 1972), and plays a key role in rhythmical aspects of music temporal processing. This issue will be discussed in greater detail in Section 7.4.2.5.

7.3.7 Summary of Sustained Responses Associated with Grouping

In the current research, strong-grouping participants, who were less likely to process the patterns as separate notes, display excitatory activity in left temporal (predominantly posterior) and left temporoparietal regions. These sustained responses reflect aspects of a rhythmic processing approach adopted by the strong-grouping participants that was not implemented by the non-grouping participants, who instead implemented a more note-by-note approach to the rhythmic content of the patterns and demonstrated greater sustained excitatory activity in the right temporal region. Furthermore, non-grouping participants demonstrate responses suggested of sustained inhibitory processing at the left temporoparietal region. These responses point to a strong association between grouping-related processing and responses of left temporal and temporoparietal regions.

7.4 Dynamic SSVEP Responses Associated With Lengthened Tones

The previous section discussed sustained responses to the probe recognition task by examining the averaged SSVEP response obtained during the encoding phase of the task. While this approach provides a useful indication of neural regions consistently activated by task-related processing, this approach blurs any dynamic responses associated with processing of an inherently dynamic stimulus e.g. a sequence of tones. To examine dynamic and potentially transient responses evoked by performance of the probe recognition task, SSVEP amplitude and latency responses were calculated using an averaging period sufficiently brief to enable examination of these dynamic responses. The following section discusses these transient responses to the probe recognition task.

Research hypotheses proposed in this study propose sustained and dynamic activation of neurophysiological regions linked with underlying grouping-related processes. The third of these hypotheses proposes that presentation of relatively longer tones in a tone sequence will evoke dynamic responses in brain regions that are sensitive to deviations of temporal structure in frontal, temporal and parietal regions, and that activity in these regions will be greater for participants who demonstrate use of lengthened tones as a cue to rhythmically group the tone sequences. SSVEP changes associated with deviations in task temporal structure were hypothesised to reflect attention-orienting processes initiated when the event structure in the task violated temporal expectations established by the event sequence. The timing of this violation of expectation was proposed to be linked with the timing of when a regularly presented tone onset was replaced by the sustained portion of a lengthened-duration tone. At this timing, it was anticipated that the non-presentation of a note onset would initiate a process that updates the temporal model established by the context prior to the event. These cognitive processes have been reflected in ERP research by the appearance of OEP or P300 responses (Janata, 2001; Jongsma et al., 2005; Jongsma et al., 2004; Joutsiniemi & Hari, 1989; Karamürsel & Bullock, 2000; Picton et al., 1978a; Raij et al., 1997; Sutton et al., 1967).

Discussion of SSVEP responses associated with this issue is presented in two broad sections. Section 7.4.1 discusses early onset responses associated with processing of the lengthened tone, whereas Section 7.4.2 discusses late onset responses associated with processing of the lengthened tone.

7.4.1 Early Onset Responses to the Lengthened Tone

In this section, SSVEP responses associated with frontal and central responses to the lengthened tone are discussed. Issues discussed in this section are MMN-related responses (7.4.1.1), N2b-related responses (7.4.1.2), and links between SSVEP responses and N2b-related responses (7.4.1.3).

7.4.1.1 MMN-related responses

ERP responses that reflect cognitive events related to temporal change detection processes have been demonstrated at a range of time-scales. Mismatch negativity ERP responses occurring approximately 100-200 ms after the onset of a stimulus that differs from the recent history of stimulation have been demonstrated over frontocentral scalp regions in response to IOI increases relative to the standard IOI (Alain et al., 1994; Gomes et al., 1995; Näätänen & Alho, 1995; Russeler et al., 2001; Tervaniemi et al., 1994; Yabe et al., 1997; Yabe et al., 1998; Yabe et al., 2001).

In the current study, significant SSVEP changes evident in the 100-250 ms range following the timing of the stimulus omission differed widely between strong-grouping and non-grouping participants. Strong-grouping participants demonstrated significant responses at the vertex and in left hemisphere posterior frontal, central, and parietal regions associated with SSVEP amplitude and latency reductions. Non-grouping participants demonstrated significant responses in tightly localised right posterior frontal, left temporoparietal and mid-parietal regions associated with SSVEP amplitude reductions and latency *increases*. SSVEP latency reductions have been interpreted in terms of excitatory activity (Silberstein, Cadusch et al., 1996; Silberstein et al., 1995; Silberstein et al., 1998; Silberstein et al., 2000), whereas SSVEP latency increases have been interpreted in terms of inhibitory responses (Silberstein, Song et al., 2003; Silberstein et al., 1997). Responses of strong-grouping participants demonstrate dynamic activation of left hemisphere posterior frontal, central, and parietal regions following the missing onset, whereas responses of non-grouping participants demonstrate inhibitory processing carried out by right posterior frontal, left temporoparietal and mid-parietal regions in response to the missing onset.

Notably, neither strong-grouping nor non-grouping participants demonstrated significant frontocentral responses following the missing onset in the time-scale associated with MMN responses. The lack of significant frontocentral responses in both groups suggests that the omitted onset did not evoke an MMN response and was not associated with an SSVEP response reflecting this process. MMN responses to stimulus omissions have been demonstrated to occur only within a period reflecting the temporal window of integration, understood to be in the range of 200-400 ms, so that tone omissions with IOIs greater than 250 ms do not typically elicit MMN responses. (Tervaniemi et al., 1994; Winkler et al., 1998; Yabe et al., 1997; Yabe et al., 1998; Yabe et al., 2001). As an IOI of 600 ms was used in the current research, responses to the lengthened tone occurred more than 600 ms after the most recent event onset and as a result may not have evoked an MMN response associated with the lengthened-duration tone.

7.4.1.2 N2b-related responses

Although no strongly significant SSVEP changes were observed in frontocentral regions following the missing onset, strong-grouping participants demonstrate significant changes at central electrode sites. In view of the timing, task demands and topography of this response, this response may reflect processes associated with the ERP N2b potential observed in omitted stimulus paradigms (Besson & Faita, 1995; Nittono et al., 2000; Raij et al., 1997; Simson et al., 1976) and typically elicited by detection of oddball deviants with target status (Potts, Dien, Hartry-Speiser, McDougal, & Tucker, 1998; Ritter & Ruchkin, 1992). Importantly, the N2b has also been associated with discrimination of deviant stimuli independently of actual target status (Loveless, 1986; Näätänen, Paavilainen et al., 1993; Nordby et al., 1988). The response has been proposed to represent categorical mismatch (Ritter & Ruchkin, 1992) or deviation from a mentally-stored expectation of the standard stimulus (Sams, Alho, & Näätänen, 1983).

The N2 has been demonstrated to correlate significantly with SSVEP responses (Muller & Hillyard, 2000). Although the correlation between N2 and SSVEP responses may reflect processes inherent to the gamma band, and may be less strongly reflected in relationships between 13 Hz SSVEP responses evoked by a diffuse flicker stimulus and N2 responses, the SSVEP vertex response evoked in the current research demonstrates similar topography and timing and was evoked in task conditions associated with N2b responses. As such, the SSVEP vertex response may reflect the action of processes in common with those underlying the N2b response, and in view of this, the generators underlying the N2b component will be discussed in the next section.

The generators of the N2b component are not well established. Using a dense electrode array, Potts et al. (1998) linked the auditory N2b scalp distribution with sources in frontal and superior temporal cortex, and more generally, linked N2b sources with neural regions involved in processing perceptual representations of stimuli (Potts, 2004). The N2b component of the N2 wave differs from the MMN (or N2a component) in that the N2b occurs only in attentive conditions (Näätänen, Paavilainen et al., 1993). N2b-like waves observed in omitted stimulus paradigms occur as part of wave complex consisting of a negative component peaking at approximately 200 ms located at the vertex, followed by a positive component with a parietal location peaking between 300 – 700 ms (Besson & Faita, 1995; Nittono et al., 2000; Raij et al., 1997; Simson et al., 1976). As the N2b component is typically elicited by deviant stimuli in oddball paradigms, the component is typically followed by P3 component, and in view of this, appearance of these wave complexes in omitted stimuli paradigms have been discussed in terms of an N2-P3 complex (Besson & Faita, 1995).

Strong significant SSVEP amplitude reductions over left temporal, central and mid-parietal regions demonstrated by strong-grouping participants suggests that processing associated with the deviant status of a tone omission was initiated in these participants, and that this response flags an early neurophysiological reaction to the tone omission in this group. As N2b components are typically elicited in response to detection of deviant targets, elicitation of a related response in the current research would suggest that strong-grouping participants were using similar processes to those that underlie N2b responses, indicating that lengthened notes were processed as targets by these participants. However, analysis of post-hoc questionnaire response indicated that strong-grouping participants were only marginally more likely to explicitly use longer-duration notes as a basis to store patterns than non-grouping participants, and as a number of studies demonstrate N2b elicitation in response to non-target deviants (Loveless, 1986; Näätänen, Paavilainen et al., 1993; Nordby et al., 1988), this response may reflect the discriminability of the tone omission (Loveless, 1986) for strong-grouping participants, and its deviation from the mentally-stored expectation of the standard stimulus (Sams et al., 1983), rather than its target status.

Deviance itself does not appear to be a necessary factor in order to evoke the N2b, as the response may also be elicited by isolated standard stimuli presented at irregular intervals, suggesting that temporal uncertainty is also an important factor (Loveless, 1986; Näätänen & Gaillard, 1983). Therefore, the observance of a response reflecting activation of areas supporting N2b processing may suggest that the temporal irregularity associated with the missing onset was sufficiently discriminated by strong-grouping participants to evoke the deviance detection mechanism.

Responses of non-grouping participants at this timing contrast with those of strong-grouping participants. SSVEP changes at the vertex approached significance, but did not demonstrate the strong significant responses demonstrated by strong-grouping participants. Instead, non-grouping participants showed weak SSVEP amplitude reduction at left temporal, vertex and mid-parietal regions associated with generalised SSVEP latency *increases*. These responses suggest that SSVEP vertex responses that may reflect the N2b ERP response were only weakly activated in non-grouping participants.

7.4.1.3 Summarising SSVEP links with the N2b response

Differences in SSVEP responses between strong-grouping and non-grouping participants at 170-250 ms after the non-presentation of a tone in a regular series suggest that this tone omission cued a response in strong-grouping participants associated with detection of the deviant status of the event sequence. This response was less apparent in responses of non-grouping participants, suggesting that the non-presentation of the tone was not as strongly associated with deviant status in this group. Together, these findings provide initial support for the third research hypothesis proposal that presentation of relatively longer tones in a tone sequence would evoke dynamic responses in brain regions that are sensitive to deviations of temporal structure in frontal, temporal and parietal regions, and that activity in these regions would be greater for participants who demonstrate use of lengthened tones as a cue to rhythmically group the tone sequences.

7.4.2 Late Onset Responses to the Lengthened Tone

Early electrophysiological responses which reflect detection of deviance within event sequences (eg MMN, N2b) represent the first component of a series of wave components associated with change detection. N2 responses are typically followed by P300 components (Näätänen & Gaillard, 1983; N. K. Squires et al., 1975), and this has been demonstrated specifically with regard to the N2b components (Loveless, 1986; Näätänen, 1992; Näätänen, Simpson, & Loveless, 1982). In view of this, early indications of change detection indicated by SSVEP responses suggesting activation of processes associated with detection of the deviant status of an event, and may also be linked with subsequent SSVEP responses that reflect activation of processes underlying P300 responses. This issue will be explored in the following section. Late onset SSVEP responses are discussed in Section 7.4.2.1, whereas factors underlying elicitation of ERP OEP responses are discussed in Section 7.4.2.2. A discussion of task-related factors that may have impacted on elicitation of OEP-like responses in the current research is discussed in Section 7.4.2.3, and potential links between SSVEP parietal lobe responses and OEP responses are discussed in Section 7.4.2.4. Following discussion concerning links between SSVEP responses and ERP OEP responses, Section 7.4.2.5 discusses the role of temporal lobe regions in supporting temporal organisation. This section concludes by summarising the discussion of SSVEP responses to the lengthened tone in Section 7.4.3.

7.4.2.1 Late SSVEP responses to omission

Significant SSVEP responses evoked in the 250-500 ms range following the timing of the stimulus omission demonstrated involvement of parietal and temporal lobe regions in responses of both strong-grouping and non-grouping participants. However, the pattern of responses evoked in these ‘late’ responses differs between the two groups, and features strong hemispheric differences in participating neural regions of each group, particularly within the temporal lobes. The following discussion examines SSVEP responses associated with each group.

Significant SSVEP responses of strong-grouping participants evoked in the 250-500 ms range following the timing of the stimulus omission demonstrate progressively greater participation of the left temporal region. Early significant responses which may be associated with detection of the deviant status of an event were localised over left central and vertex regions, and following this, left temporal and temporoparietal regions demonstrate strong significant SSVEP amplitude and latency reductions at approximately 300 ms following the timing of the stimulus omission. SSVEP latency responses evoked at approximately 500 ms following the timing of the stimulus omission shift from left temporoparietal regions to strong localisation at the left temporal lobe, and are accompanied by significant bilateral parietal responses associated with SSVEP amplitude reductions and latency increases.

Two clear patterns emerge in responses of strong grouping participants. Firstly, SSVEP latency reductions shift from the earlier central and parietal localisation through left temporoparietal regions around 300 ms post-omission to left temporal localisation at around 500 ms following the timing of the stimulus omission. These responses are associated with a progressive increase in strength of SSVEP amplitude reductions at the left temporal lobe. Together these responses indicate enhanced excitatory activity in left-lateralised temporal and temporoparietal regions. Secondly, parietal regions demonstrate strong bilateral amplitude reductions associated with the later component.

As these responses are associated with an SSVEP latency increase, these responses indicate inhibitory activity at this timing.

Whereas strong-grouping participants show left-lateralised temporal and temporoparietal activation from 300–500 ms post-omission, non-grouping participants show *right*-lateralised and temporoparietal activation at a similar timing. As demonstrated in responses of strong-grouping participants, these right temporal and temporoparietal responses are accompanied by mid- and right parietal inhibitory activity at this timing. Notably, significant parietal region responses occur earlier than in responses of strong-grouping participants and are less strongly engaged by the task achieving statistical significance only in mid and right parietal regions.

Both strong-grouping and non-grouping participants demonstrate activation of temporal and temporoparietal regions (left hemisphere for strong-grouping, right hemisphere for non-grouping) and bilateral parietal lobe regions at 250-500 ms following the timing of the stimulus omission indicating that this pattern of responses is a common feature to participants' reactions to the stimulus omission. Parietal lobe SSVEP amplitude and latency changes demonstrate similar features between the two groups and indicate similar shared aspects of participation by these regions, although strong-grouping participants demonstrate strong significant bilateral parietal lobe participation in task performance, whereas parietal lobe responses of non-grouping participants are restricted to mid-right parietal regions and are less strongly activated than those of strong-grouping participants. The following discussion examines the task factors, regional topography and timing of these responses that provide a basis for interpretation of these responses within the context of temporal organisation of the sequence structure.

7.4.2.2 Omitted event potential (OEP)-related responses

In the probe recognition task, the temporal structure of the patterns was constructed with longer-duration tones presented at irregular time intervals in order to prevent the development of metric time frames. With this factor in mind, longer duration tones were not presented in a predictable sequence, and provided a break in expectation established by the regular presentation of the preceding notes in the pattern. As such, responses of both strong-grouping and non-grouping participants' evoked during the lengthened-duration note may reflect the impact of the probe recognition task design on processing of tone omissions by breaking the expectation for regular presentation of tone onsets.

Temporal breaks in expectation, particularly those evoked when expected tones are not presented have been well-examined in ERP paradigms under the general heading of omitted event potentials (OEPs). Typically, omitted event potentials are evoked where expectation for event presentation at a particular point in time is developed by regular stimulus presentations and then violated via non-presentation. In tasks probing rhythmic expectations using musical stimuli, OEPs have been observed when a rhythmic violation was inconsistent with the musical expectancy. (Besson & Faita, 1995; Besson et al., 1994; Janata, 2001; Jongsma et al., 2005).

ERP responses to rhythmic violations are generally associated with two components in the ERP response - a negative ERP potential with latency of approximately 150 to 200 ms observed over frontal or vertex regions, followed by a late positive potential with latency of approximately 350 - 700 ms reported over a range of frontal, vertex and parietal regions (Baudena et al., 1995; Besson & Faita, 1995; Besson et al., 1997; Joutsiniemi & Hari, 1989; Nittono et al., 2000; Paller et al., 1992; Raij et al., 1997; Tarkka & Stokic, 1998). For tasks that employee SOAs greater the 200 ms, the early negative potential has been linked with the N2b potential (Jongsma et al., 2005), whereas the later positive potential has been linked with P300 responses (Besson et al., 1997; Jongsma et al., 2005; Ruchkin & Sutton, 1973, 1978; Sutton et al., 1967). Localisation of the later positive potential varies with task design and recording methodology. The later positive potential appears to be more localised to frontal regions in OEP designs where task instructions require no attention be directed to the omitted tone (Besson et al., 1994; Busse & Woldorff, 2003). In these scenarios, the late positive potential demonstrates characteristics of P3a responses. OEP tasks that direct attention to the omitted tone show more posterior-localised P300 responses (Besson & Faita, 1995; Busse & Woldorff, 2003; Janata, 2001; Jocoy et al., 1998; Jongsma et al., 2005; Jongsma et al., 2004; Simson et al., 1976), demonstrating characteristics more closely associated with P3b responses. The following section discussed task factors that may have impacted on SSVEP responses associated with the omission.

7.4.2.3 Influence of task design of elicitation of OEP responses

In the current study, probe recognition task instructions provided no requirement for participants to attend to rhythmic elements of the patterns. Instead, the task construction and instructions were designed to focus participants' attention on pitch-related aspects of the patterns. Research demonstrating that attention directed towards pitch, timbre or rhythmical dimensions of a musical stimulus activates neural regions associated with processing of that aspect of the stimulus (Janata, 2005; Parsons, 2001; Platel et al., 1997) might suggest that listeners' attentional focus determines the information encoded in the perceptual code. However, musical sequence processing has been proposed to be inherently rhythmical (e.g. Jones, 1992; Jones & Boltz, 1989; Jones et al., 1981), and despite indications that attention may be directed to specific musical dimensions (Janata, 2001; Palmer & Krumhansl, 1987; Parsons, 2001; Platel et al., 1997) and neuropsychological evidence which demonstrates that pitch and rhythm information processing may be dissociated by brain damage (Ayotte et al., 2000; Liegeois-Chauvel et al., 1998; Peretz, 1990; Peretz & Morais, 1993; Vignolo, 2003), questionnaire responses provided after completion of the probe recognition task indicated that while participants' attention was directed towards pitch-based aspects of the stimulus by the task instructions and design, appearance of longer-duration notes was commonly noted as an attended feature in probe recognition task patterns. As such, cognitive responses evoked by attended tone emissions in the probe recognition task would be likely to occur within the attentional focus and would be reflected in later SSVEP responses by activation of regions underlying more posterior P3 responses.

7.4.2.4 Linking parietal lobe SSVEP responses with OEPs

Both strong-grouping and non-grouping participants demonstrated significant parietal lobe activation in the probe recognition task at 300-500 ms following the timing of the stimulus omission. As these responses demonstrate similar timing and contributions of regions evoked in OEP and P300b tasks these responses may represent the activation of regions supporting omission-related processing. Two factors are particularly notable in parietal responses of strong-grouping and non-grouping participants.

Firstly, strong-grouping participants demonstrate strongly significant and broadly distributed bilateral parietal responses, whereas non-grouping participants demonstrate less strongly significant responses localised primarily within mid and right-parietal regions. These differences indicate that parietal regions were more strongly engaged in strong-grouping participants' processing of the omitted onset than parietal regions of non-group participants, and suggest that strong-grouping participants demonstrated greater use of omission-related processing than non-grouping participants. These differences in parietal responses to the omitted tone may be explained in view of research demonstrating the degree to which the amplitude of both P3b and OEP responses reflect the delivery of information by the stimulus. That is, parietal responses associated with P3 responses reflect the degree that information carried by an event is actually used (R. Johnson, Jr. & Donchin, 1978; Stuss & Picton, 1978). The absence of a stimulus has been shown to result in a P3 only when that absence delivered information to the subject. A such, omission responses are not evoked when the absence of a stimulus delivers no information (Klinke et al., 1968; Ruchkin & Sutton, 1973; Sutton et al., 1967). Differences in parietal responses of strong-grouping and non-grouping participants viewed in the context of these findings suggests that stronger and more extensive parietal responses in strong-grouping participants demonstrates greater use of the information carried by the omitted tone by these participants in incorporating the deviant status of the event in an updated model of the auditory environment.

A second notable factor in parietal responses of strong-grouping and non-grouping participants is that SSVEP amplitude reductions in both groups are associated with SSVEP latency increases linked with inhibitory responses. While a clear precedent for interpreting these parietal latency increases is not evident in the literature, a partial explanation for these responses may be evident in viewpoints that the P3b signifies the closure or completion of controlled processing (Desmedt, 1981; Hillyard & Picton, 1988; Hoffman, 1990; Posner, 1975). To this end, latency increases associated with this response may represent the inhibitory processing associated with closure of processing the series of cognitive events associated with the deviant event. This suggestion remains tentative and requires support through further research.

7.4.2.5 Temporal lobe role in supporting temporal organisation

The P3b component follows stimulus evaluation and has been proposed to occur when an updating of the mental model of the current stimulus environment is required (Donchin & Coles, 1988). The response reflects the establishment of a connection between posterior association cortex, temporal and temporoparietal regions critical for initiation of memory mechanisms (Calhoun et al., 2006; Donchin & Coles, 1988; Knight, 1994; Polich, 2003). In particular, involvment of the temporoparietal junction is indicated in findings showing that the region is the most strongly activated neural region associated with P3b responses in both fMRI (Bledowski, Prvulovic, Goebel, Zanella, & Linden, 2004; Menon, Ford, Lim, Glover, & Pfefferbaum, 1997) and intracranial electrode studies (Smith et al., 1990). A significant role for the temporoparietal junction in the P3b response is further suggested by the observation of reduced auditory P3b responses following lesions to the temporoparietal junction (Knight, Scabini, Woods, & Clayworth, 1989).

In view of evidence discussing the role of the temporal and temporoparietal regions in tone omission tasks, activation of these regions in SSVEP responses of both strong-grouping and non-grouping participants at timings associated with OEP and P3b responses, suggest that these responses reflect participation of these regions in omission-related processing. Specifically, activation of temporal and temporoparietal regions in SSVEP responses of participants at 300-500 ms post-omission suggests that these regions are involved in a process whereby detection of deviance from time-based expectations for stimulus presentation reflected in parietal regions initiates the interaction of neural regions supporting the processing of the stimulus information with those involved in maintaining the representation of the recent auditory past. This interaction would serve to update the model for future time-based expectations of stimulus presentation. Responses of both strong-grouping and non-grouping participants suggest that regions supporting this process are active in both groups at this timing. However, as activation of these regions is notably stronger in strong-grouping participants this may suggest greater contributions from these regions towards this process in strong-grouping participants. Notably, lateral and medial temporal lobe regions have also been strongly linked with encoding of both semantic and episodic information in long-term memory (e.g. Giovagnoli, Erbetta, Villani, & Avanzini, 2005).

However,behavioural responses in the current research indicate that the grouped working memory representations were subject to durability factors, and as a result, activation of these regions in the current context are more strongly related to more immediate representations of the grouped structure in working memory.

Participation of temporoparietal regions in temporal modelling has been demonstrated via demonstrations of the regions ability to form and store templates of high-probability auditory events for several seconds (Winkler, Cowan, Csepe, Czigler, & Näätänen, 1996). Deviations from this stored template evoke MMN responses in non-attentive conditions and evoke activity in a distributed neural system that includes the hippocampus, parietal, temporal, and frontal lobes. In the current attentive processing design, activation of neural regions associated with N2b responses would reflect this detection of deviance from the temporal model, initiating the involvement of the parietal, temporal and temporoparietal regions in the subsequent updating process. Activation of these regions in response to the tone omission suggests that tone omissions were used as a basis for the updating of the temporal model and future expectations of tone presentations in both participant groups. However, opposing lateralisation of these regions in responses of strong-grouping and non-grouping participants indicates that processes supported by the temporal and temporoparietal contributions differ between the groups.

As discussed in detail in Section 7.3, a range of factors have been demonstrated to impact on hemispheric contributions in musical task performance. In the current research, analysis of task performance and post-experiment responses indicated no significant differences between strong-grouping and non-grouping participants' perception of task difficulty, overall task performance, discrimination of longer-duration notes, musical training, use of analytic strategies, or use of contour-based pitch strategies. In view of these findings, these factors are unlikely to substantially support the hemispheric differences observed between the two groups.

Group differences were observed in the stated tendency to process the patterns as separate notes, with non-grouping participants showing significantly greater tendency to adopt this strategy. In view of this, an alternative factor underlying the relative differences observed in lateralisation of temporal and temporoparietal contributions by strong-grouping and non-grouping participants may be understood by considering the degree that these groups drew on processes involved in the temporal organisation of the probe recognition task pattern information. As discussed in Section 7.3.6.1, hemispheric distinctions observed between rhythm and metre processing suggest a relative left hemisphere dominance for temporal organisation of time intervals (Di Pietro et al., 2004; Fries & Swihart, 1990; Mavlov, 1980; Wilson et al., 2002), and substantial evidence from lesion research supports a key role for the left hemisphere in this process (Di Pietro et al., 2004; Efron, 1963; Mavlov, 1980; Prior et al., 1990; Robin et al., 1990; Swisher & Hirsh, 1972; Vignolo, 2003).

Further support for a predominant left hemisphere role in temporal organisation stems from dichotic research demonstrating a significant right ear advantage in tasks involving temporal ordering of stimuli (Halperin et al., 1973; Robinson & Solomon, 1974) and lesion research demonstrating that temporal ordering of auditory information is significantly poorer in aphasic participants (i.e. individuals with predominantly left hemisphere brain damage impacting on language reception or production ability) (Efron, 1963; Swisher & Hirsh, 1972), particularly those with damage in the left posterior temporal lobe (Swisher & Hirsh, 1972). This finding parallels early findings of a relationship between the impaired ability to indicate the number of tones in a series and receptive language aphasia (Horenstein, LeZak, & Pitts, 1966) and led to the proposal that the left hemisphere is involved in the perceptual integration of events in time (Efron, 1963; Swisher & Hirsh, 1972), particularly the primary projection area for the given modality (Swisher & Hirsh, 1972).

More recently, research examining the impact of brain damage on temporal processing ability has demonstrated a key role for the left hemisphere in rhythmical aspects of music temporal processing (Di Pietro et al., 2004; Mavlov, 1980; Prior et al., 1990; Robin et al., 1990; Vignolo, 2003), although less frequently, specific cases of disturbances in rhythmic processing independently of meter following right temporal lobe damage have also been identified (Penhune, Zatorre, & Feindel, 1999; Peretz, 1990). Notably, individuals who typically demonstrate highly proficient rhythmic processing - musically trained individuals – who have demonstrated deficits in rhythmic processing or structuring of notes in time as a result of brain trauma have been repeatedly linked with lesions in left posterior temporal and left inferior parietal cortex (Di Pietro et al., 2004; Mavlov, 1980; Wertheim & Botez, 1961). Further incidental support for a role of these regions in rhythmic processing has been provided by examination of the musical processing abilities of individuals with William's syndrome, a disorder which results in a disproportionate growth of the left posterior supratemporal region and lateral cerebellar regions. Individuals with William's Syndrome show deficits in global versus local processing and demonstrate *better* rhythmic performance than age-matched controls (Levitin & Bellugi, 1998)

In the current research, strong-grouping participants, who indicated in post-experiment responses that they were less likely to process the patterns as separate notes, displayed excitatory activation in left temporal and left temporoparietal regions. Activation of these regions may reflect aspects of a temporal organisation or rhythmic processing approach adopted by the strong-grouping participants that was not implemented by the non-grouping participants, who instead implemented a more note-by-note approach to the content of the patterns. This note-by-note approach adopted by non-grouping participants was associated with SSVEP amplitude reductions localised primarily within right temporal and temporoparietal regions, suggesting greater activation of this right hemisphere region for non-grouping participants.

7.4.3 Summary of Lengthened Tone Discussion

In summary, SSVEP responses associated with participants processing of the probe recognition task patterns during the task phase where expectations for a tone onset presentation were violated demonstrated clear differences between strong-grouping and non-grouping participants. Early responses of strong-grouping participants at 170-250 ms following the timing of the tone omission were associated with activation of vertex regions, and in view of the timing, topography, and task demands, this response was interpreted as being associated with detection of the deviant status of the event. This early response was not strongly apparent in responses of non-grouping participants, and was interpreted to reflect the lesser degree to which the tone omission was assigned deviant status from the expected event sequence in this group.

Later responses of both strong-grouping and non-grouping participants at 300-500 ms following the timing of the tone omission in the probe recognition task were associated with significant parietal lobe amplitude reductions. These responses were interpreted to represent the activation of regions supporting omission-related processing in a similar way to those represented by posterior late positive OEP responses. Strong-grouping participants demonstrated a broader distribution and greater amplitude reduction of these responses, which were interpreted to reflect the greater use of the information carried by the omitted tone in incorporating the deviant status of the event in an updated model of the auditory environment.

Finally, strong significant temporal and temporoparietal activation was associated with responses at 300-500 ms following the timing of the tone omission, lateralised to the left hemisphere in strong-grouping participants, and to the right hemisphere in non-grouping participants. Activation of these regions was interpreted to reflect the role of these regions in supporting the current representation and model of the auditory environment used to generate expectations for future events. Laterality differences observed in activation of these regions were interpreted to reflect greater application of temporal organisation processes in strong-grouping participants than non-grouping participants, which impacted on the degree that left hemisphere resources were adopted for the task.

Together, these findings support the third research hypothesis proposal that presentation of relatively longer tones in a tone sequence would evoke dynamic responses in brain regions that are sensitive to deviations of temporal structure in frontal, temporal and parietal regions, and that activity in these regions would be greater for participants who demonstrate use of lengthened tones as a cue to rhythmically group the tone sequences.

7.5 Initial Tones - Dynamic SSVEP Responses

The previous section discussed dynamic responses associated with presentation of a relatively longer-duration tone in the probe recognition task. This analysis demonstrated that individuals who show greater tendencies to rhythmically group working memory representations of tone sequences show electrophysiological responses in response to rhythmic grouping cues that are characteristic of the detection of deviant events and the updating of internal representations used to predict future events. Demonstration of these processes in response to presentation of a cue used to generate working memory representations of the patterns suggests that these processes may be linked with the establishment of the grouped memory trace.

A secondary component of the grouping process involves information presented at or immediately after the group boundary being associated with the onset of a group. Although a group boundary may define the end of one group *and* the commencement of a subsequent group, a range of behavioural and electrophysiological responses have been associated specifically with group *beginnings*. These findings indicate the operation of processes that occur subsequently to the identification of a grouping cue, and are associated with events that are perceived as group beginnings. The following section will discuss these processes in association with responses evoked in the probe recognition task by notes that immediately follow relatively longer duration notes.

Research hypotheses proposed in this study propose dynamic activation of neurophysiological regions linked with underlying grouping-related processes. The fourth of these hypotheses proposes that the presentation of tones *immediately after* relatively longer-duration tones in a to-be-remembered pitch sequence will evoke SSVEP responses associated with the closure of grouping-related processing in temporal and parietal regions. Specifically, this hypothesis proposes that these responses will reflect contribution of neural regions supporting CPS-related closure processes following detection of group boundaries. These responses were hypothesised to be evident in late central or parietal responses. The following sections discuss findings associated with the tone immediately following the lengthened tone – the *initial* tone. Section 7.5.1 discusses early onset SSVEP responses associated with presentation of the initial tone in the probe recognition task, whereas Section 7.5.2 discusses late onset SSVEP responses associated with presentation of the initial tone in the probe recognition task, and incorporates discussion associated with the fourth research hypothesis. Following this discussion, Section 7.5.3 summarises the discussion presented in this section.

7.5.1 Early Onset Responses to the Initial Tone

This section discusses early onset SSVEP responses occurring in association with presentation of the initial tone in the probe recognition task. Section 7.5.1.1 discusses similarities between ERP N1-P2 responses and frontal SSVEP responses; Section 7.5.1.2 discusses evidence suggesting additional processes underlying enhancement of frontal responses for intial tones; Section 7.5.1.3 discusses relationships between frontal SSVEP latency reductions and grouping scores, and Section 7.5.1.4 discusses links between frontal SSVEP latency responses and early onset ERP enhancement. Section 7.5.1.5 discusses evidence for attention-related enhancement of the initial tone; Section 7.5.1.6 discusses links with attention-related enhancement of early frontal SSVEP latency responses, and finally, Section 7.5.1.7 discusses the role of enhanced frontal SSVEP responses in working memory representations.

7.5.1.1 Links between ERP N1-P2 responses and SSVEP responses

Analysis of responses to tones immediately following relatively longer-duration tones - here referred to as ‘initial tones’ - indicated that SSVEP responses evoked by these tones differed between strong-grouping and non-grouping participants. Responses evoked in the initial 150-250 ms post-onset period by strong-grouping participants demonstrated significant SSVEP amplitude attenuation and latency decreases at left and mid-posterior frontal and left anterior temporal regions, with broadly distributed left frontal responses generally approaching significance. These early responses reflect significant activation of the left posterior frontal and anterior temporal regions in response to the initial tones.

ERP research indicates several common early ERP responses associated with presentation of standard tones in auditory sequences perception tasks. Typically, standard tones evoke a large wave complex, N1-P2, with peak latencies at about 100 ms and 200 ms respectively with maximal amplitudes at or anterior to the vertex (Picton, Hillyard, Krausz, & Galambos, 1974). The N1 component is elicited by tone onsets and also for offsets of tones with duration greater than 500 ms (Hillyard & Picton, 1978) and is generated by cerebral mechanisms sensitive to change from an immediately preceding stable level (For review refer to Näätänen & Picton, 1987). Three distinct generators have been suggested to underly components of the N1 wave: primary auditory cortex activity evident in ERP fronto-central scalp responses; auditory association cortex activity observed in mid-temporal scalp locations, and a third component evident in central scalp responses reflecting a diffuse non-specific generator system (Näätänen & Picton, 1987). This third component was proposed to be linked with initiation of widespread transient arousal that facilitates stimulus detection, analysis and response generation. The N1 is enhanced by attention (Ford & Hillyard, 1981; Hillyard, Hink, Schwent, & Picton, 1973; Picton & Hillyard, 1974), although this enhancement may be linked with overlaying of the endogenous attention-related 'processing negativity' (Näätänen, Gaillard, & Mantysalo, 1978; Näätänen & Michie, 1979) or 'negativity difference' (Hansen & Hillyard, 1980) superimposed on the N1 waveform.

The P2 component, traditionally discussed as an adjunct of the N1 component, has more recently been viewed as a functionally different process to that resulting in the N1 component. This is grounded in a number of functional and source localisation differences observed between the two components. In particular, attention-related 'processing negativity' enhances the amplitude of the N1 waveform (Näätänen et al., 1978; Näätänen & Michie, 1979), whereas this attention-related negative offset acts to attenuate the amplitude of the P2. ERP and MEG source localisation of P2 responses suggest that different generator mechanisms underlie N1 sources and multiple P2 generators located in the planum temporale and auditory association cortex (area 22) (Godey, Schwartz, de Graaf, Chauvel, & Liegeois-Chauvel, 2001; Hari et al., 1987; Knösche, Neuhaus, Haueisen, & Alter, 2003).

The N1-P2 complex is sensitive to stimulus repetition. Typically, N1-P2 responses to the first stimulus in a train are largest in amplitude and diminish with stimulus repetitions to reach amplitude levels as low as half the amplitude of the initial stimulus response after only a few repetitions (Davis, Mast, Yoshie, & Zerlin, 1966; Fruhstorfer, 1971; Ritter et al., 1968). This effect is particularly pronounced for the first stimulus in a train compared to others; it is enhanced for more rapid rates of stimulus presentation and intensity (Roth & Kopell, 1969), and is more pronounced for regular than irregular ISIs (Öhman & Lader, 1977). The effect is strongly correlated with ISI so that longer

ISIs produce less decrement of amplitude (Davis et al., 1966). Even so, repetition effects on N1-P2 amplitude are evident in ISIs of up to 10 s or more (Davis et al., 1966; Ritter et al., 1968).

Frontal SSVEP latency responses of both strong-grouping and non-grouping participants to standard tones in the probe recognition task demonstrate features in common with N1-P2 responses. Specifically, both respondent groups demonstrate broadly distributed frontal SSVEP latency minima at 150-250 ms following the onset of each tone in both tasks. These responses are not present at a similar timing associated with the tone omission, suggesting that these frontal responses reflect an early response to the onset of each tone, as in ERP N1-P2 responses. These early SSVEP latency responses to tone onsets demonstrate enhanced latency minima at frontal regions for initial tones compared to other standard tones, whereas subsequent tones evoke substantially smaller latency reductions. ERP research demonstrates that enhanced amplitude responses to tones initiating stimulus trains occurs specifically within N1-P2 responses, whereas earlier (Picton, Stapells, & Campbell, 1981) and later (Woods, Hillyard, Courchesne, & Galambos, 1980) ERP responses are not similarly enhanced in response to the initial stimulus onset. In view of this, SSVEP frontal latency responses evoked at 150-250 ms following standard tone onsets may be associated with processes underlying the ERP N1-P2 response.

7.5.1.2 Additional processing underlying enhancement for initial tones

Mechanisms underlying enhanced N1-P2 responses to initial tones in series have been proposed to result from refractory processes involving the recovery cycle of the neural generators (Budd, Barry, Gordon, Rennie, & Michie, 1998; Ritter et al., 1968). However, recent data suggest that modulation of N1 responses is not due to refractory mechanisms, but instead suggests that top-down processes modulate the amplitude of this early onset response (Fuentemilla, Marco-Pallare´s, & Grau, 2006; Sable, Low, Maclin, Fabiani, & Gratton, 2004). In particular, data demonstrating the action of an additional neural process supporting enhanced N1 responses to initial stimuli (Fuentemilla et al., 2006), and the observation of P3a responses associated with attention-switching following the initial tone (Alho *et al.*, 1998;Escera *et al.*, in press;

Snyder and Hillyard, 1976; Squires *et al*., 1975), supported by the proposal that N1 could trigger an attention-capturing signal for conscious perception of the stimulus (Näätänen, 1990, 1992) which could be performed by frontal sources (Giard et al., 1994), Fuentemilla et al. (2006) proposed that enhanced N1 responses may be attributed to contributions of frontal lobe structures that support attention switching in addition to contributions of supratemporal generators that support the standard N1 response. Sable et al. (2004) suggest that as the first of a series of repeating sounds is the most informative, this is enhanced by the auditory system.

In view of these findings, SSVEP latency response topographic differences observed between initial tones and other tone onsets indicates that processing of the initial tone involves different or additional processing to that underlying responses to standard tones, and may represent the additional frontal processing which has been suggested to underlie enhancement of early ERP responses to initial tones. Notably however, both strong-grouping and non-grouping participants demonstrate contributions of bilateral anterior prefrontal regions towards additional latency enhancements and as such, contributions of these anterior prefrontal regions are not likely to represent processing related to the role of the initial tone within the grouped memory structure, as these regions were activated independently of grouping performance. By contrast, activation associated with excitatory responses in posterior frontal regions indicates a unique contribution of left posterior frontal regions to the processing of the initial tone in strong-grouping participants.

A relationship between the excitatory responses in the left posterior frontal region and grouping-related processing is further supported by the comparison of task-related differences in processing of the initial tone exlusively for strong-grouping participants. Whereas the initial tone evokes a strong excitatory response in strong-grouping participants in the probe recognition task, SSVEP latency responses of strong-grouping participants to the initial tone in the reference task demonstrate that no enhancement of excitatory processing was associated with this tone in response to the more passive listening demands of the reference task. This data indicates that excitatory responses to the initial tone were linked with processing evoked specifically in response to the demands of the Probe Recognition Task, and in response to greater use of temporal information as an organisational cue.

7.5.1.3 Relationship between latency reductions and grouping scores

Examination of the relationship between SSVEP peak latency responses in the 100-300 ms following presentation of each tone and behavioural grouping scores provided further basis to suggest that individual differences in the tendency to organise patterns based on longer-duration tones is a contributing factor to the degree of enhancement of early SSVEP latency responses. Pearson's correlation analysis between early SSVEP latency peak responses at the left posterior frontal location and behavioural grouping differences scores demonstrated a weakly significant relationship between initial tones latency responses and grouping scores. Notably, correlation responses between each tone in the series and grouping scores demonstrated a pattern of relationships such that each successive tone in a group of tones was associated with a progressive reduction in correlation strength with grouping scores. This pattern of reducing strength correlation values mimicked the progressive reduction of average peak latency values for each note, suggesting a strong similarity between the strength of latency reductions for each tone and its relationship with grouping scores. As such, greater latency reductions were observed for initial tones, and these responses were more strongly associated with grouping scores than other tones showing less enhanced latency responses. Together with findings demonstrating significantly greater SSVEP latency enhancement of initial tones compared to other tones uniquely for strong-grouping participants, these data suggest that enhancements of initial tone responses are related to overall grouping scores and as such should be interpreted with regard to the influence of top-down processes acting on individuals' organisation of tone sequences and subsequent grouping behaviour. Furthermore, this data suggests that the left posterior frontal region processes are associated with the rhythmic organisation of working memory of tone sequences

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7.5.1.4 Frontal SSVEP links with early onset ERP enhancement

Top-down processes have previously been proposed to impact on N1-P2 amplitude enhancement for events initiating rhythmic groups (Fraisse & Lavit, 1986; Klinke et al., 1968), and a range of authors have noted enhancement of P2 amplitude, in particular, following stimulus omission (Jongsma et al., 2005; Klinke et al., 1968; Knösche et al., 2005). Enhancement of P2 responses following omission may be particularly relevant to grouping processes as it has been suggested that this component of the N1-P2 does not habituate in repetitive sequences leading to a reduction in P2 amplitude (Kenemans, Verbaten, Roelofs, & Slangen, 1989; Megela & Teyler, 1979). In view of this, enhanced P2 responses in rhythmic patterns may be less strongly linked with the recovery cycle of the neural generators underlying the response, and instead may reflect processes related to the use of temporal information cuing temporal structure.

An association between enhanced P2 responses and the perception of rhythmic phrase structure in music is strongly supported by demonstrations of significantly enhanced P2 responses for rhythmically phrased musical sequences compared to P2 responses associated with unphrased sequences (Knösche et al., 2005; Nan, Knösche, & Friederici, 2006; Neuhaus, Knösche, & Friederici, 2006). In these studies, pauses and lengthened tones were used to create musical phrase boundaries. Whereas P2 amplitude was significantly enhanced for the initial note following the rhythmic cue in each of these studies, amplitude of N1 responses did not significantly differ between rhythmically phrased and unphrased musical sequences in two of the three studies, and appeared to be attenuated in phrased sequences in one study.

These findings provide further support for a process other than neural recovery acting as a basis for enhanced P2 amplitude responses observed in notes initiating rhythmic phrases. Notably, however, whereas N1 responses have shown refractory effects that were sensitive to the length of a rhythmic pause (Neuhaus et al., 2006), P2 responses demonstrate less sensitivity to pause length. Additionally, P2 responses demonstrate variations in topography in response to different harmonic resolutions used at phrase boundary points, suggesting impact of higher order processing as a factor modulating the P2 response topography. In view of these findings, Neuhaus et al. (2006) suggested that variations after the phrase boundary might not only reflect simple recovery of neuronal populations after the pause, but also “some higher bottom-up order feature extraction processes necessary for the recognition a boundary between two phrases” (p. 488-489). Application of higher-order processing impacting on P2 responses to phrase boundary cues is further supported by demonstrations of an impact of culture-specific knowledge on P2 amplitude for tones initiating rhythmic phrases (Nan et al., 2006). Together, these findings demonstrate that while early ERP N1 and to a lesser extent P2 components occurring in response to lengthened IOIs in musical sequences exhibit amplitude effects that reflect physiologically-based refractive mechanisms (Budd et al., 1998), P2 responses demonstrate sensitivity to additional factors that suggest an impact of additional processes related to boundary detection.

In the current study, enhanced posterior frontal SSVEP latency reduction for initial tones in strong-grouping participants demonstrated similar latency and topography as ERP P2 responses evoked in response to rhythmic phrase boundaries. Enhancement of this frontal SSVEP latency reduction for tones initiating rhythmic sequences was demonstrated generally for both strong-grouping and non-grouping participants in anterior prefrontal regions, and uniquely for strong-grouping participants at the left posterior frontal region, suggesting a relationship between the degree of latency enhancement and implementation of the rhythmic cue in subsequent rhythmic grouping processes. In view of findings demonstrating enhanced frontal P2 responses for tones initiating rhythmic phrases, and the suggested relationship between the P2 response and phrase boundary identification, these similarities in latency, topography and task-related evocation suggest that similar processes may drive the enhanced frontal latency response in strong-grouping participants for initial tones as those driving enhanced P2 responses for tones initiating rhythmic groups. As such, these findings point to a role for enhanced frontal SSVEP latency responses in the process of identification of a rhythmic boundary cue and establishing the basis for further processing of this information.

7.5.1.5 Attention-related modulation of the initial tone

Although enhancement of early N1 and P2 ERP responses have been repeatedly demonstrated in response to cues establishing phrase boundaries, detailed discussion of cognitive processes underlying the enhanced ERP responses is not evident in the literature. The following discussion examines enhanced initial tone responses in the context of a sequence of processes evoked by a change in the temporal structure. This discussion examines the extent that early responses to the initial tone may reflect the impact of attention-related processes sensitive to variations in sequence temporal structure.

Temporal expectations provide a basis for temporally-guided attention. Research demonstrating superior reaction times to auditory stimuli presented at expected timings indicate that auditory attention may be directed to specific moments in time (Lange et al., 2006; Lange & Roder, 2006; Lange et al., 2003). Temporal allocation of auditory attention results in enhanced early and late ERP responses for events occurring at the attended timing. Lange and colleagues have demonstrated that auditory events presented at an expected and attended point in time are associated with an early enhanced negativity of frontal or central ERP responses impacting on the N1 and N2 responses (Lange et al., 2006; Lange & Roder, 2006; Lange et al., 2003). Scalp topography of these responses was proposed to reflect an increase of excitability of neural networks coding the attended timing or location resulting in the enhanced ERP negativity (e.g. Hillyard et al., 1973).

Music theoretic approaches to rhythmic processing have suggested a role for rhythmic guiding of attention. Boltz (1991) proposed that rhythm is psychologically important because prolonged tonal duration and pauses give rise to temporal accents that stand out and capture listeners' attention. Dynamic Attending Theory (Drake et al., 2000; Jones & Boltz, 1989) proposes that temporal relationships between events affects the perception of subsequent events in the sequence. By this approach, listeners are able to shift attention flexibly in accordance with different hierarchical levels of temporal structure. This proposal features the concept of future-oriented attending (Jones & Boltz, 1989; Jones et al., 1982; Jones et al., 1981) whereby expectations of temporal event structure may be used to guide expectations for future events to particular points in time. As such, this music theoretical approach parallels cognitive research demonstrating temporal allocation of attention and provides support within a music processing context for the role of attention in modulating processing of the initial tones in the current research.

7.5.1.6 Attention effects on SSPT responses

Variations in SSVEP responses as a function of attentional modulation has been demonstrated in performance of visual vigilance and continuous performance tasks (Silberstein, Cadusch et al., 1996; Silberstein et al., 1990). Using the A-X continuous performance task, Silberstein, Cadusch et al. (1996) that that faster correct response times to A-X targets were associated with greater reduction in frontal SSVEP latency, reflecting similar effects to the enhanced early ERP responses and reaction times demonstrated in temporally-guided attention research (Lange et al., 2006; Lange & Roder, 2006; Lange et al., 2003).

In the current research, enhanced early SSVEP latency reductions for initial tones may reflect the impact of temporally-guided attention on processing of the tones and reflect dedication of additional processing resources toward the point in time at which the initial tone would be expected. Whereas presentation of relatively longer duration notes was not predictable in each trial, the duration of longer notes was constant throughout all trials, and always followed by presentation of at least one tone. As such, upon detection of the lengthened tone, the temporal structure of the probe recognition task at this point in each trial was 100% predictable. Following presentation of a lengthened tone, the temporal predictability of this phase of each trial would have enabled participants to allocate attention towards this point in time. SSVEP responses of strong-grouping participants during the lengthened tone demonstrated a greater impact of the deviant temporal structure on processing which was proposed to be associated with updating of the temporal model of the sequence structure. As a result, strong-grouping participants' expectations for future tone presentations may be based more strongly on information provided by the lengthened tone than those of non-grouping participants, resulting in a more accurate temporal model underlying expectations for the presentation timing of the following tone. As a result, strong-grouping participants may have been better able to accurately allocate attention towards the timing of the initial tone predicted by presentation of the longer tone. This more accurate temporal allocation of attention may have been responsible for the enhancement of the frontal SSVEP responses observed predominantly in strong-grouping participants.

An analysis of the topographical differences between early SSVEP responses to standard tones and initial tones provides further support for this proposal of a temporally-guided attention enhancement. Whereas both strong-grouping and non-grouping participants demonstrated bilateral anterior prefrontal latency reductions specifically for initial tones, strong-grouping participants demonstrated an additional significant left posterior frontal latency reduction of the early SSVEP response. Coull and Nobre (1998) used PET and fMRI imaging to examine brain regions involved in directing attention toward a particular time point once the time interval has been estimated. Left hemisphere regions demonstrated stronger activation in response to temporal orienting than right hemisphere regions. Notably, the left ventral premotor cortex in the general region of Broca's area (BA 6/44) was activated uniquely in response to temporal orienting, suggesting an exclusive relationship with this region and aspects of temporal orienting of attention.

SSVEP latency responses observed exclusively in strong-grouping participants in response to the initial tone demonstrates strong parallels with topography of the regional activation associated uniquely with temporal orienting of attention observed by Coull and Nobre (1998), and provide further support for a proposal that early SSVEP responses of strong-grouping participants in this region are associated with temporal allocation of attention to the processing of the initial tone. In view of these findings, enhanced latency reductions observed in early responses of strong-grouping participants over left posterior frontal regions may reflect the temporal allocation of attention towards the timing of tone presentation resulting from the initial detection of deviance on the event structure. This response may be associated with similar processing to that underlying enhancement of the N1 and P2 components of ERP responses components which have previously been demonstrated to be sensitive to the phrase boundary cues.

7.5.1.7 Relationship of enhanced frontal response and working memory

The functional role of the reduction of early SSVEP latency responses to the initial tone in the sequence on the process of grouping of working memory representation may be via the modulation of the strength of the working memory representation of the initial tone. Näätänen (1982) argued that the accuracy of the short-term memory trace was related to the generation of the N1. Linear relationships between early ERP amplitudes and accuracy of short-term recall have been demonstrated for tonal sequences (Stanny & Elfner, 1980) and for visual and verbal content (Mittenberg, Skerchock, & Ryan, 1985) for N1 responses. Of particular relevance to this research, P2 amplitude at encoding of word lists has been linked with recall at the primacy portion of the serial position curve (Rushby et al., 2002). Rushby et al. suggested that the early positive components of the ERP (i.e. P1 and P2) are useful indices of the differential stimulus processing during elaborative learning which predicts later recall.

In view of these findings, enhancement of early SSVEP responses to the initial tone may have resulted in a stronger representation of physical features of the initial tone in the working memory code, providing a functional method of emphasising the role of the initial tone in the structure of the working memory representation. This proposal remains tentative as the experimental design used in this research did not allow examination of relationships between serial position curve effects in memory and SSVEP responses. Furthermore, it is understood that processing occurring after those processes linked with early ERP responses may reflect updating of stimulus representations in the working memory code (e.g. Donchin & Coles, 1988), and in view of this, early ERP responses would provide only an initial representation that may be subsequently modified. As such, the relationship between early SSVEP responses and strength of encoding in working memory requires further examination in subsequent research.

7.5.2 Late Onset Responses to the Initial Tone

The previous section discussed SSVEP responses associated with tones immediately following relatively longer-duration tones in sequences and identified an association between enhanced frontal SSVEP latency responses and the process of identification of a rhythmic boundary cue. This process was proposed to reflect the action of processes in common with those resulting in enhanced early ERP responses for tones following rhythmic phrase boundaries (Knösche et al., 2005; Nan et al., 2006; Neuhaus et al., 2006), and may result from the temporal allocation of attention as a result of processing initiated by the detection of deviance on the temporal structure (Lange et al., 2006;

Lange & Roder, 2006; Lange et al., 2003). Previous research examining electrophysiological responses to rhythmic phrase boundaries have identified two characteristic ERP responses in response to tones that follow rhythmic boundary cues. Early ERP responses reflecting rhythmic phrase boundaries were discussed in terms of enhanced N1 and P2 amplitude responses, and demonstrated similarities in topography, latency and functional aspects to SSVEP latency responses in the current study. A second, later characteristic ERP response was also identified and proposed to be related to the transition of one phrase to the next (Knösche et al., 2005) and the role of phrase boundaries as structuring elements of the entire musical piece (Nan et al., 2006).

In view of evidence for the evocation of characteristic late ERP responses to tones following rhythmic phrase boundaries, the following section discusses the extent that the use of rhythmic cues by strong-grouping participants was associated with SSVEP responses that may reflect a later use of rhythmic cues in the grouping process. Discussion presented in this section reviews evidence associated with the fourth research hypothesis, which proposes that presentation of tones *immediately after* relatively longer-duration tones in a to-be-remembered pitch sequence will evoke SSVEP responses associated with the closure of grouping-related processing in temporal, and parietal regions. Specifically, these responses will reflect contributions of neural regions supporting closure processes following detection of group boundaries. These responses are hypothesised to be evident in late central or parietal responses. Discussion examining findings relevant to this hypothesis are presented in four sections. Section 7.5.2.1 reviews late onset SSVEP responses to the initial tone, Section 7.5.2.2 notes ERP evidence for closure-related processes following boundary detection; Section 7.5.2.3 discusses links between the observed SSVEP responses and closure-related processes, and Section 7.5.2.4 discusses late-onset SSVEP responses of non-grouping participants.

7.5.2.1 Late onset SSVEP responses

In the current research, analysis of responses to initial tones in a 300-550 ms post-onset period indicated that SSVEP responses of strong-grouping and non-grouping participants demonstrated strong differences in hemispheric contributions towards processing of these initial tones, particularly in a window focused on responses in a 400-550 ms post-onset period

An initial analysis examined responses evoked in the 300-400 ms post-onset period. Notably, both strong-grouping and non-grouping participants demonstrated continued activation of excitatory SSVEP responses evident in the left temporal region during early onset responses to the initial tone. Non-grouping participants demonstrated additional left anterior frontal and right temporoparietal activation. These *sustained* responses suggest ongoing activation of this region in support of processing the initial tone. In view of the key role for temporal lobe regions role in supporting pitch representations of tones (Liegeois-Chauvel et al., 1998; Milner, 1962; Zatorre & Samson, 1991), in supporting representations of pitch sequences (J. D. Warren & Griffiths, 2003; Zatorre, 1985), and strong evidence suggesting a key role for the left hemisphere in supporting processing of temporal structure (Di Pietro et al., 2004; Efron, 1963; Halperin et al., 1973; Mavlov, 1980; Patel, Peretz, Tramo, & Labreque, 1998; Prior et al., 1990; Robin et al., 1990; Robinson & Solomon, 1974; Swisher & Hirsh, 1972; Vignolo, 2003), and in particular, temporal lobe regions (Di Pietro et al., 2004; Mavlov, 1980; Wertheim & Botez, 1961), sustained activation of the left temporal lobe suggests this region is actively maintaining the representation of sequence information throughout this initial 350 ms period of the initial tone.

Contrasting with these changes evoked in the 300-400 ms period post-onset, SSVEP responses evoked in the 400-550 ms post-onset period showed strongly lateralised differences between responses of strong-grouping and non-grouping participants. In particular, strong-grouping participants showed strong significant Hotelling's T responses associated with SSVEP amplitude reductions and latency increases indicating activation of inhibitory processes in left temporal, temporoparietal, central and superior parietal regions. By contrast, non-grouping participants demonstrated significant Hotelling's T responses at *right* hemisphere temporoparietal, parietal, and frontal regions associated with activation of inhibitory processing. These responses suggest strong hemispheric differences in processing of initial tones with regard to their subsequent use in the temporal structuring of sequences in working memory, and can be interpreted with respect to research demonstrating several characteristic responses to tones following phrase boundary cues. A discussion of the basis for this interpretation appears in the following section.

7.5.2.2 Late onset ERP responses reflecting closure

Knösche and colleagues have identified characteristic ERP responses associated with processing of a tone immediately following rhythmic phrase boundaries. The characteristic responses occur as adjuncts to enhanced N1 and P2 responses that follow these rhythmic boundary cues. A music closure positive shift response (music CPS) was demonstrated in ERP and MEG responses of musicians, and in MEG responses of non-musicians over centroparietal regions between 400 and 600 ms after the onset of a tone following a rhythmic phrase boundary (Knösche et al., 2005; Nan et al., 2006; Neuhaus et al., 2006). Non-musicians also demonstrated an 'early negative' ERP component between 300 and 500 ms after the onset of a tone following a rhythmic phrase boundary with a broadly distributed left lateralised frontocentral topography (Neuhaus et al., 2006). These responses were interpreted to reflect different processing strategies applied by musically trained and untrained groups in response to rhythmic phrase boundary cues. In particular, early negativity responses of non-musicians were proposed to reflect bottom-up processing of the rhythmic cue as a violation in the continuity and build up of a melodic context. This process was proposed to reflect a rhythmic equivalent of the early right anterior negativity (ERAN) response generated in non-musicians in response to a harmonic violation (Koelsch et al., 2000; Koelsch, Gunter, Schroeger, & Friederici, 2003). Responses of both musicians and non-musicians were proposed to reflect top-down activation of a general schema for phrasing retrieved from long-term memory (Neuhaus et al., 2006).

Memory-related processes are particularly relevant to processes underlying the CPS response. Source localisation of the CPS response has identified anterior and posterior cingulate and posterior hippocampus as likely generators of the response, leading to the suggestion that the CPS reflects chunking and attention redirection processes occurring in response to perception and closure of language and music phrases (Knösche et al., 2005). By this approach, the CPS response reflects the activation of general cognitive principles which draw on musical phrasing schema stored in long-term memory.

Activation of these generalised phrasing schema would result in the encoding of musical phrase units in a similar way to the encoding of phrase units in language. Similarities between these language and music-based processes is based on research demonstrating a similar CPS response in language tasks featuring processing of phrase closure (Hruska & Alter, 2004; Steinhauer, 2003; Steinhauer et al., 1999; Steinhauer & Friederici, 2001) to those obtained in music phrase boundary processing. Music schema stored in memory that would activate the CPS would include generalised representations of rhythmic structures commonly encountered within the musical idiom. In Western musical cultures, pauses and lengthened final notes have been demonstrated to act as the primary rhythmic cues for grouped musical structure (Frankland & Cohen, 2004), and as such would act a primary cues for evocation of rhythmic schema.

7.5.2.3 Links between SSVEP responses and closure

Silberstein et al. have linked SSVEP amplitude and latency reductions with the dedication of resources for holding information on-line in working memory (Silberstein et al., 2001; Silberstein, Stough et al., 1996). However, SSVEP latency *increases* have been associated with working memory tasks when the task involves the manipulation of information, as opposed to simply holding it on-line (Silberstein, Song et al., 2003; Silberstein et al., 1997). In a mental rotation task, Silberstein et al. (2003) observed that progressive increases in degree of manipulation required to successfully perform the task were associated with progressive latency increases during the manipulation phase of the task. These latency increases were interpreted as indicating increased activation of inhibitory synaptic processes required to support manipulation of the information.

In the current research, inhibitory SSVEP changes at left temporal and temporoparietal regions occur at the timing demonstrated in music phrase processing tasks to be associated with the CPS-related chunking of the prior phrase (Knösche et al., 2005). As SSVEP amplitude attenuation in combination with latency increases has previously been associated with working memory tasks when the task involves the manipulation of information, as opposed to simply holding it on-line (Silberstein, Song et al., 2003; Silberstein et al., 1997), the left temporal and temporoparietal lobe responses may be interpreted to reflect the role of these regions in supporting the active manipulation of sequence information at this timing. The manipulation process would serve to support a process whereby the information presented in the prior sequence is integrated within the structure of the entire musical sequence (Nan et al., 2006), and would form the basis of the working memory representation of this section of the musical sequence. By establishing a cognitive mode which supports the reticulation of information within local neural regions, inhibitory processing at the temporal lobe would also provide the basis by which the closure of processing of the previously presented sequence information is achieved. Notably, left posterior frontal regions also demonstrate latency decreases at this timing which approach significance, providing further demonstration of the action of inhibitory responses in key regions involved in supporting the ongoing representation of sequence information at a timing when a structural boundary may cue the organisation and integration of this information within a larger cognitive structure.

In discussing ERP responses associated with processing of phrase boundaries cued by rhythmic information, Neuhaus et al. (2006) proposed that an early negative ERP component between 300 and 500 ms after the onset of a tone following a rhythmic phrase boundary with a broadly distributed left lateralised frontocentral topography represented use of a bottom-up processing approach to the rhythmic cue, whereas the more posteriorly distributed CPS response reflected the use of processing which drew on representations of rhythmic schema stored in long-term memory supported by hippocampal regions. In the current research, significant activation of left temporal and temporoparietal regions in late onset SSVEP responses suggest that strong-grouping participants may have drawn on schema-based representations of rhythmic groups supported by these regions to organise working memory representations.

A notable difference between responses observed in the current research and those of Neuhaus et al. (2006) concerns the influence of musical training on topography of CPS responses. Whereas Neuhaus et al. observed posterior CPS responses in both ERP and MEG responses of musicians, only MEG responses of non-musicians demonstrated the posteriorly distributed CPS responses. By contrast, in the current research, the predominantly musically untrained participant group demonstrated temporal and posterior CPS-like responses, suggesting activation of similar processes to the musician group observed by Neuhaus et al. Notably, left posterior frontal responses of strong-grouping participants demonstrate strong latency increases which do not achieve statistical significance in association with weak amplitude attenuation. While not significant, strong latency increases in left posterior frontal regions may indicate that bottom-up processing of the rhythmic cue was also weakly activated in processing of strong-grouping participants, although this processing was not sufficiently activated to result in statistically significant responses. Activation of temporal processing in the current research would be likely to reflect the greater demands on memory-related processing in the current study compared to the passive listening approach adopted by Neuhaus et al.

7.5.2.4 Comparison with responses of non-grouping participants

Responses of non-grouping participants suggest that a different sequence of processing occurred through the tone following the rhythmic grouping cue. Late onset SSVEP responses were associated with significant left frontal and temporal Hotelling's T responses, which were accompanied by broadly distributed right frontal and right temporoparietal Hotelling's T responses which bordered on significance. As evident in responses of strong-grouping participants, left frontal and temporal SSVEP amplitude reductions and latency increases at this timing suggests that this region actively maintained the representation of sequence information throughout this early period of the initial tone processing. In contrast to strong-grouping participants, this early processing incorporates additional activation of right frontal and posterior temporal/temporoparietal regions. Right posterior frontal and right temporal regions have previously been demonstrated to support working memory for melodic information (Zatorre et al., 1994), supporting a suggestion that activation of these regions provides additional resources for the active retention of the sequence information.

SSVEP responses of non-grouping participants in the 400-550 ms post-onset period demonstrate a strong divergence in regional activation from those regions supporting processing of the initial tone by strong-grouping participants. Whereas strong-grouping participants exhibited significant inhibitory activation at the left temporal and temporoparietal regions, non-grouping participants demonstrate significant inhibitory activation in the right frontal region, accompanied by excitatory activation in the temporoparietal region. Together, these responses suggest that non-grouping participants' processing at this timing features ongoing activation of temporoparietal regions accompanied by inhibitory processing in the right frontal region. In view of the role of right frontal areas in the active maintenance of melodic information (Zatorre et al., 1994), a latency increase at this region may represent the manipulation of sequence information. However, weak amplitude responses associated with this response suggest that this region is only minimally activated in support of this process.

A further notable feature of responses of non-grouping participants was the observation of significant Hotelling's T responses at bilateral parietal regions. SSVEP amplitude reductions and SSVEP latency increases indicating inhibitory activation occur at the timing and topography previously associated with the CPS response. In view of the task design used to evoked these responses, it may be that these parietal responses observed in non-grouping participants represent the action of phrase closure processing responding to the detection of the phrase boundary. This interpretation of the parietal responses is further supported by the observation of earlier responses to the initial tone in this group which appear similar in timing and topography to the enhanced P2 response observed in music phrase boundary processing (Knösche et al., 2005). This interpretation may seem at odds with the demonstrated behaviour of non-grouping participants, as this group demonstrated a relative *lack* of use of phrase boundary cues in delineating working memory representations of the sequence information. However, a distinction can be made between task designs used to evoke the CPS response and the current research. In particular, tasks used to evoked the CPS response have been designed as perceptual tasks, with either detection (Knösche et al., 2005) or counting (Nan et al., 2006) of dissonant notes prescribed as the participants' task. With these task directions, no demands were placed on participants' working memory for the sequences. Instead, processing modes adopted by participants would reflect more closely the reference task design used in the current research.

By contrast, the probe recognition task was designed to place demands on participants' working memory representations of the sequence information, and it was these representations that were probed by the subsequent probe pattern in each trial. With this design, results obtained in the probe recognition task reflected the extent that a grouped representation of the sequence material was used as a basis for comparison to the probe pattern. As such, participants who demonstrated an effect of grouping on recognition performance, must not only have perceived the grouped structure, but also incorporated and retained this grouped structure in the ongoing working memory representation. Peretz (1989) demonstrated that grouped sequence representations may be initially formed but not necessarily be used as an ongoing structural representation of sequence information, and in view of this finding, it is plausible that non-grouping participants did actually perceive the rhythmic grouping cue and react with a process that used the cue as a basis for establishment of a perceptual boundary, but did not incorporate this information within the ongoing representation of the sequence structure used to perform the probe recognition task. This proposal is further supported by the left temporal and temporoparietal lobe responses of strong-grouping participants that suggest manipulation or recoding of the auditory information at the timing when chunking and sequence closure is proposed for CPS responses, and the lack of this response in non-grouping participants.

7.5.3 Summary of Initial Tone Discussion

In summary of results examining processing of the initial tone, listeners that made greater use of the rhythmic cue in organisation of working memory representations of the sequences demonstrated a sequence of neurophysiological responses associated with processing of the initial tone that differed strongly to those of listeners who did not use the rhythmic cue to structure memory for the sequences. These responses follow processing associated with the lengthened tone that were initiated in response to detection of deviation in the predicted temporal structure of the sequence, and which reflected the significance of the change in the temporal structure of the sequence. These responses were suggested to be involved in a process which acted to incorporate this detected change in an updated temporal model of the stimulus sequence used to direct attention to future events.

Responses associated with the initial tone represent a continuation of the sequence of processes evoked by a change in the temporal structure. In particular, strong-grouping participants demonstrated left posterior frontal SSVEP latency changes with topography, timing and function that resemble enhancement of early ERP N1 and P2 responses. These responses were interpreted as reflecting the impact of attention-related processes (Drake et al., 2000; Jones & Boltz, 1989; Lange et al., 2006; Lange & Roder, 2006; Lange et al., 2003; Näätänen, 1990, 1992) sensitive to variations in sequence temporal structure which acted to enhance the processing and identification of this tone in association with the boundary, and establish the basis for further processing of this information (Knösche et al., 2005). Greater enhancement of initial tone left frontal responses in strong-grouping participants was proposed to result from the deviation detection process initiated during the lengthened tone and the updating of the temporal model which has been proposed to result from this process.

SSVEP changes that followed these responses were proposed to indicate left temporal lobe processing in support of stimulus representations in the working memory trace by both strong-grouping and non-grouping participants. This sustained processing was followed by divergent responses in strong-grouping and non-grouping participants which were proposed to reflect manipulation of the working memory trace and closure of temporal organisation processes in strong-grouping participants, which contrasted with the ongoing right temporoparietal region activation in non-grouping respondents suggestive of continued representation of sequence information. Taken together, these findings support the fourth experimental hypothesis which proposed that presentation of tones immediately after relatively longer-duration tones in a to-be-remembered pitch sequence will evoke an SSVEP response in strong-grouping respondents associated with the closure of grouping-related processing in temporal and parietal regions.

The following section examines the relationship of the processes presented in this discussion with literature discussing the role of frontal regions in structural processing of musical stimuli.

7.5.3.1 Structural processing

When considering the role of various brain regions in supporting the processing of musical structure, Levitin and Menon (2003) proposed that theories of structure in music and language are “in fact theories of temporal coherence and how elements are grouped over time" (p. 2142). Temporal coherence as used in this musical sense refers to the sense that a sequence of tones is connected or musically coherent (Deutsch, 1999). A prominent role of the grouping of elements in the determination of temporal coherence is affirmed by numerous authors (e.g. Deutsch, 1999; Levitin & Menon, 2003, 2005). Additionally, Levitin and Menon propose that generation of structure results in informational redundancy, a proposal that accords well with other musical theoretical positions which see grouping as the initial stage in the building of a hierarchical musical structure that relies progressively less on surface structure and more on a reduced or simplified representation of the surface features (Deliège, 1996; Deliège & Mélen, 1997; Michon, 1987).

In the current research, strong-grouping participants demonstrated regional activation of left frontal, temporal and temporoparietal regions in support of the temporal organisation of tone sequences. Activation of these regions in support of structural processing is supported by research examining various forms of musical structural processes, both temporal and non-temporal. The P600, a late positive ERP component with a parietal maxima occurring approximately 600 ms after a harmonic or melodic violation of expectation, has been linked with integration of structural information (Besson & Faita, 1995; Besson et al., 1994; Koelsch et al., 2000; Patel, Gibson et al., 1998; Regnault et al., 2001). Earlier, negative ERP responses occurring around 150- to 350-ms after an unexpected harmonic event have been taken to reflect the application of music syntactic rules. These right anterior temporal negativity (RATN) (Patel, Gibson et al., 1998) and early right anterior negativity responses (ERAN) have been typically observed predominantly over right anterior temporal or frontal regions, although magnetic equivalents of the response have been shown to result from bilateral frontal lobe generators in Broca's area and its right hemisphere homologue (Maess et al., 2001).

Findings of Broca's activation in music syntactic processing provides impetus for suggestions of a broader role for Broca's area beyond merely processing of syntax in language. This suggestion is particularly well supported by findings demonstrating activation of Broca's area in fMRI responses to both harmonic and timbral changes (Koelsch et al., 2002), and other research demonstrating that these regions are not only sensitive to harmonic violations reflecting syntactical processing, but also to other types of violations such as violations of sensory consonance (Regnault et al., 2001; Tillmann et al., 2003). Koelsch (2002) discusses activation of Broca's and also Wernicke's area in oddball musical contexts as processing of a deviant event within a rule-based musical context, and this interpretation is supported by data suggesting that early inferior frontal activation reflects integration of deviant acoustical events within a temporal structure whereas later frontal and posterior responses reflect rule-based structural processing (Regnault et al., 2001; Tillmann et al., 2003).

Tillman, Janata and Bharucha's (2003) fMRI data, in particular, points strongly towards involvement of bilateral inferior frontal regions in the integration of harmonic and sensory information over time. According to these authors, inferior frontal regions (and insula) are proposed to participate in an integration process that supports the linking of incoming events with those stored in working memory. When listening to sequential auditory information, listeners draw on knowledge stored in long-term memory to develop expectations for typical future events. Incoming events are compared with these expectations via integrative processes that allow the detection of deviant events which would require the dedication of additional neural resources.

Activation of the left frontal region in support of strong-grouping participants' initial tone processing may reflect the action of this frontal region in the integration process discussed by Tillmann et al (2003) and in accordance with the temporal guiding of attention as demonstrated by Lange and colleagues (Lange et al., 2006; Lange & Roder, 2006; Lange et al., 2003). In accordance with this proposal, detection of violation in temporal structure from that predicted in accordance with temporal expectations would result in the updating of the temporal model and the temporal directing of attention towards the revised timing. An event presented in accordance with this updated temporal model at the expected timing would evoke enhanced responses reflecting the identification of the event and the impact of the attentional focus and would initiate processes associated with the integration of the group boundary within the working memory representation of the ongoing event sequence.

The ‘shared syntactic integration resource hypothesis’ (SSIRH) proposes that frontal regions provide the required resources to support the structural integration of syntactic representations residing in temporal or parietal regions (Patel, 2003; Patel et al., 2004). This hypothesis accords with regional activation observed in late onset responses to the initial tone in the current research, and provides further support for the suggestion that the grouping process involves a network of frontal, temporal and parietal regions that coordinate the maintenance of stimulus representations in temporal regions with schema-based respresentations of rhythmic structures in temporo-parietal regions and the application of temporal expectations subserved by left posterior frontal regions to integrate updated temporal models in the structural organisation of ongoing working memory representations.

This role of the posterior frontal regions in supporting processing of temporal structure is further supported by the demonstration of significant frontal activation in support of processing structured versions of musical extracts compared to scrambled versions. Levitin and Menon (2003; 2005) have demonstrated significant fMRI activation in the pars orbitalis regions of inferior frontal cortex (BA 47) (left greater than right) and adjoining anterior insula (right greater than left) compared to scrambled musical versions. In view of data obtained in this study and previous results implicating inferior frontal and insula regions in integration of musical (Koelsch et al., 2002; Maess et al., 2001; Tillmann et al., 2003) and non-musical information (Friederici et al., 2000; Meyer et al., 2000), Levitin and Menon propose that the pars orbitalis region of left inferior frontal cortex comprises a structure tracker, and in combination with the anterior insula constitutes a “modality-independent brain area that organizes structural units in the perceptual stream to create larger, meaningful representation.

ERP, MEG and fMRI research examining the processing of musical structure point to consistent involvement of frontal lobe regions, particularly the inferior frontal lobe and neighbouring insular cortex; and temporoparietal and parietal regions in supporting the processing of sequential auditory information in order to organise structural aspects into meaningful wholes. A contemporary view of the role of these regions, previously understood to participate predominantly in processing of structural aspects of only language, now encompasses structural processing of a range of auditory tasks including aspects of musical processing. Structural aspects of musical experience that appear to be processed by these frontal and parietal regions includes suprasegmental organisational processes, including those governed by rule-based knowledge, and also those which provide prosodic information (such as rhythmically determined phrase boundary cues). As such, this structural processing applies to a broad range of processes that involve the integration of incoming information with expectations developed in response to recently presented information. This integration process acts to update the ongoing model of the auditory environment in order to maintain a contextually relevant model of current experience, and optimise the basis by which expectations of future events are determined. Among other implications of this process, this updating process involves organisation of structural units into larger meaningful wholes. By this approach, key to the generation of a relevant temporal model is the ability of the processing system to generate revised temporal models, and by implication, initiate closure processing that terminates ongoing use of outdated temporal models. SSVEP responses acquired in response to rhythmic grouping processes in the current research support the proposal of such a model, whereby frontal, temporal and parietal regions coordinate in the detection of change in the environment, initiate processing to update temporal expectations, and provide closure on processing of information. The following discussion examines the role of closure in SSVEP responses presented in this research.

7.5.3.2 Closure

Significant responses at left temporal, temporoparietal and frontal regions of strong-grouping participants associated with latency increases suggest the use of inhibitory processing at a timing linked with processes used to delineate phrase boundary representations. Strong emphasis on inhibitory processing within brain regions used to maintain the ongoing sequence representation at this timing suggest that boundary cues initiate a process in the following event that dynamically shifts processing away from acquisition and representation of perceptual information to transient manipulation of the information. This suggestion parallels proposals of the function of segmentation cues in the grouping process by initiating the manipulation and integration of information in order to achieve perceptual closure (e.g. Michon, 1987). By this approach, segmentation processes use structural boundaries for the division of the ‘stream of consciousness’ into internally representable and integrated units. This process may be supported by the CPS response, which reflects "memory and attention processes necessary for the transition of one phrase to the next" (Knösche et al., 2005, p.271). Clarke (1987) discussed application of the segmentation process with regard to the organisation of perceptual experience:

> Perception does not flow in an entirely homogeneous fashion: it segments experience into a succession of units, whose relative autonomy is a function of the coherence of the perceptual information and the perceptual strategy of the observer. Each of these durational segments is a perceptual present, and has the property that until it is a complete and bounded segment, the information within it continues to be active and available (p. 229).

The application of this process by strong-grouping participants in regions supporting working memory representations would provide the mechanism by which sequence information is delineated and grouped in memory. By contrast, inhibitory processing by non-grouping participants suggests that while processing related to the closure of sequence perception may have occurred, this processing may not have acted to integrate the perceptual information in higher representations. Michon (1987) noted that information in the present remains available until it can be processed at a higher and more abstract level. Structural boundaries such as syntactic events or pauses act to cue this shift from instantaneous availability to the generation of a representation at higher levels (Michon, 1987). Prior to the generation of this higher-level representation in response to a boundary cue, information remains available at the level of the surface structure until recoding results in the irretrievable loss of this surface information. Michon proposes that as boundary cueing results in the delineation of structurally "healthy" patterns represented at higher levels, this provides an explanation of research obtained in the current research, and in both music and language contexts demonstrating that memory does not readily straddle two successive structural units (Dowling, 1973a; Peretz, 1989; Peretz & Babai, 1992; Stewart & Gough, 1967; Suci et al., 1967; Tan et al., 1981).

Michon proposes that abstract representations generated as a result of the grouping process not only reflect organisation cued by stimulus characteristics, but also integrative processes which incorporate the context and the implicit knowledge about the events. As such, this grouping and recoding process has been proposed to integrate structural representations derived via bottom-up processes cued by stimulus characteristics with top-down processes representing implicit knowledge about the events (Michon, 1987). This implicit knowledge may incorporate schemas developed through experience in the musical idiom. In this manner, the grouping process would act to determine a temporally integrated whole that encompasses information derived from both sensation and experience.

Rhythmic changes attain particular significance as structural cues when discussed with reference to segmentation of the perceptual present. Gap detection and rhythmic reproduction studies indicate that while individuals are able to accurately perceive and reproduce time intervals within rhythmically derived structures, they are impaired at perceiving or reproducing time intervals between rhythmic groups (e.g. Bolton, 1894; Fraisse, 1956; Thorpe, 1985; Thorpe & Trehub, 1989; Woodrow, 1909). Fraisse (1963), Fraisse and Lavit (1986), and Michon (1987) discuss this phenomenon in terms of processes suggested by the Gestalt psychologists. Time intervals between rhythmic groups serve to reinforce the distinction between successive perceptual units, reflecting Gestalt-like processes which act to distinguish between aspects of a sensation which provide maximal information and achieve a dominant perceptual quality, and aspects which are relatively devoid of information that take on the status of background. In essence, these authors propose that processing of groups and gaps occurs in terms of Gestalt figure-ground relationships.

7.6 Conclusions

Listeners that made greater use of the rhythmic cue in organisation of working memory representations of pitch sequences demonstrated a sequence of neurophysiological responses associated with processing of the sequences that differed strongly to those of listeners who did not use the rhythmic cue to structure memory for the sequences. Responses associated with a lengthened tone that acted as an initial cue to the delineation of grouped structure were associated with the detection of deviation in the predicted temporal structure of the sequence. The extent of this response reflected the significance of the change in the temporal structure of the sequence to those participants who used this information to structure working memory representations. These responses were suggested to be involved in a process which acted to incorporate this detected change in an updated temporal model of the stimulus sequence used to direct attention to future events.

Responses associated with the initial tone represented a continuation of the sequence of processes evoked by a change in the temporal structure. In particular, early responses to the initial tone were proposed to reflect the impact of attention-related processes sensitive to variations in sequence temporal structure which acted to enhance the processing and identification of this tone in association with the boundary. Activation associated with this process was maximal in left posterior frontal regions which have previously been associated with processing of musical structure. Sustained left temporal, frontal, and temporoparietal responses associated with the initial tone were proposed to support processing of sequence information that was used as the basis for working memory representations. These regions demonstrated a late transient inhibitory response which was linked with the manipulation of the sequence information and the closure of processing, prior to the establishment of processing for subsequent information.

Together, this series of responses indicated that participants who used temporal cues as a basis for the structuring of working memory representations of tone sequences, demonstrated a series of responses that indicated that the relatively longer tone durations were processed as a deviant event, and initiated a sequence of events that used this information to adjust the temporal model used to form expectations of future event presentations. This revised temporal model resulted in enhanced processing of a subsequent event and the closure of processing of working memory representations of the ongoing sequence at this timing.

These responses tentatively support Gestalt proposals of the use of lengthened temporal intervals in delineating grouped structure, and subsequent music theoretic proposals based on the Gestalt approach (Dalla Bella et al., 2003; Deutsch, 1999; Drake, 1998; Krumhansl, 1990; Lerdahl & Jackendoff, 1983; A Penel & Drake, 1998; Peretz, 1989). Relatively longer temporal intervals were processed as salient deviant events by those individuals who implemented this information in subsequent processing. In the musical context, these responses suggest that relatively longer temporal intervals were processed as breaks in the musical flow, and it was this processing which initiated subsequent responses that resulted in the use of this cue as a structural feature in the working memory representation. Although responses of strong-grouping participants provide strong support for the processing of a longer time interval in accordance with Gestalt-based approach, responses of non-grouping participants less strongly support this proposal. Electrophysiological responses of non-grouping participants demonstrated non-significant trends towards the processing of lengthened tones as deviant events, and as such responses to the lengthened notes in this group only weakly support Gestalt-based approaches, and as such, suggest that those individuals who did not implement the temporal cue as a basis for structuring working memory representations were less likely to perceive lengthened temporal intervals as cues for determining structural representations. This series of responses demonstrates that temporal cues do not form an obligatory basis for the structuring of musical information, instead, listeners are able to adopt flexible strategies in the organisation of musical information. This factor is acknowledged in the grouping preference rules of the influential GTTM (Lerdahl & Jackendoff, 1983), which state that grouping cues define *possible* boundaries of note groups.

7.7 Future Directions

7.7.1 Use of Lengthened Notes

This research examined the impact of lengthened tones on listeners' structuring of working memory representations. The choice of using lengthened tones to examine the impact of relatively longer IOIs, as opposed to examining the impact of relatively longer IOIs as cued by longer time intervals between notes was made for two key reasons. Firstly, music psychological investigations have demonstrated that lengthened tones act as the strongest cue for the delineation of rhythmic groups or are more often nominated as the most salient cues for the delineation of grouped structure (Frankland & Cohen, 2004). In view of these findings, lengthened tones were adopted in order to maximise the strength of the temporal cue used for this research. Secondly, as music psychology research has demonstrated that lengthened tones act as a primary cue for grouping, the use of this cue in the current research would maximise the relevance of the findings to existing music psychology findings. A potential confounder in the use of lengthened tones associated with responses to the ongoing tone presentation was addressed in the current research by focusing analysis on comparison of responses to the same stimulus across groups who demonstrated different grouping behaviour in behavioural responses. As such, any potential confounding factors associated with responses uniquely evoked by the sustained portion of the lengthened tones were balanced equally across the respondent groups, and as a result, were not considered a potential confounder of dynamic responses. However, future research can provide further information regarding the influence of the tone length on neural regions participating in the organisation process by manipulating the relative duration of tones within a given IOI.

7.7.2 Use of Deviance Detection for Processing Group Boundaries

This research aimed to examine processes involved in the use of temporal cues in structuring working memory representations of musical sequences. McAdams (1996) discusses the impact of experience within a musical culture as basis for the development of musical knowledge structures encoded in long-term memory. When activated, these schemas draw on existing representations in long-term memory to provide a top-down influence on processing and expectations of the incoming stimulus. The relative use of these top-down influences versus use of surface-driven bottom-up processing in music perception is to a large extent determined by the extent that the sequence of incoming stimuli matches with aspects of musical experience stored in long-term memory and evokes relevant schema. Sequences which do not equate with schema stored in long-term memory are more likely to be processed using bottom-up surface-based approaches. As such, familiarity of the musical stimuli is a key factor in the relative use of processing strategies. When listening to a new piece of music from a familiar musical culture, bottom-up processes such as grouping via temporal proximity may be used to determine perceptual organisation, but in addition, familiar stylistic aspects of the piece may evoke learned schemata which in turn will guide subsequent processing and expectations of the musical structure.

Stimuli used in this research were designed to prevent use of perceptual organisational processes such as metric processing and use of pitch contour cues, which may have confounded the examination of temporal information as a grouping cue. As a result, aspects of musical structure that would normally be encountered in the Western musical idiom were not featured in the stimuli used in this research. Exclusion of cues which may have prompted use of metric processing or contour cues would have reduced the extent that the stimuli used in this research evoked existing musical schema, and as a result, participants' processing of the stimuli is likely to have been heavily dependent of surface-based bottom-up processing. Furthermore, familiarity with a musical selection has also been demonstrated to impact heavily on the relative application of bottom-up processes, so that increasing familiarity enables perception of increasingly higher levels of hierarchic structure as the basis of perception (e.g. Deliège, 1989; Drake, 1998). In view of these factors, responses elicited by the stimuli used in this study reflect those most likely to be obtained in response to an unfamiliar musical stimulus, rather than those elicited in response to a familiar stimulus, or one that readily matches musical schema stored in long-term memory. Instead, these stimuli are less likely to evoke processing sensitive to surface features of the stimulus including tone duration variations, and more likely to elicit top-down processing drawing on existing musical schema. This factor may also have been a determinant of the absence of a clear CPS response in strong-grouping participants, as this response has been proposed to depend on the implementation of musical knowledge structures from long-term memory. However, the presence of a CPS-like response in non-grouping participants suggests that this process may have been applied regardless of the use of musical schemas. Further research examining the impact on electrophysiological responses of variations in the use of top-down versus bottom-up processing in organisation of music structure will be required to resolve this issue.

7.7.3 Additional Factors to Consider in Future Research

Future research examining neurophysiological processes associated with rhythmic grouping may seek to provide clarification of other factors that were controlled within the design of the current research. Factors which may influence the strength of the grouped structure or which may influence the relative involvement of neural regions participating in the grouping processes include:

- Metric factors – the current research attempted to minimise the influence of metric processing on the structural organisation of the probe recognition task patterns. Further research may seek to clarify the influence of metrical processing on structural organisation of sequential events and brain regions participating in this type of organisation;
- Group size – to control for the influence of varying group sizes, groups consisting of varying number of events were presented and examined within an overall averaged response. Future research could provide further information regarding the influence of group sizes on the organisation process by examining group length as an independent factor within the experimental design;
- Musical training – although some musically trained individuals were included as participants in the current research, none were considered to be sufficiently trained and actively involved in musical performance activities for degree of musical training to be examined as a separate factor. Furthermore, musically trained individuals were equally represented within the strong-grouping and non-grouping participants, and in view of these factors, separate examination of musical training as a factor was not undertaken in the current research. However, the influence of musical training on the neural regions participating in the grouping process may be clarified in future research by comparison of neurophysiological responses of musically untrained individuals with highly musically trained individuals within a similar experimental design as adopted in the current research.

To conclude, this thesis examined the use of rhythmic information in the organisation of listeners' representations of sequential auditory events. Findings indicated that frontal, temporal, and parietal regions, particularly within the left hemisphere, coordinate to support the use of these cues in the organisation of the listening experience. Examination of SSVEP responses in this research enabled the identification of specific aspects of sequence processing associated with dynamic activation of these regions. Future research will be required to expand on these findings to better understand the influence of the factors outlined here on neural regions participation in grouping processes. Ultimately, future research should aim to use stimuli that more closely replicate commonly encountered musical stimuli, in order to replicate processes used in listeners' every-day experience and provide a better understanding of the music listening process.

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Appendix A PARTICIPANT INFORMATION SHEET

SWINBURNE UNIVERSITY OF TECHNOLOGY

Project Title: Cortical activity associated with rhythmic grouping of pitch sequences

Researcher: Philip G. Harris

Coordinating Supervisor: Prof. Richard B. Silberstein

SUBJECT EXPLANATORY STATEMENT

I am conducting a research project to examine the relationship between musical thinking and brain electrical activity. This study will take place over two sessions. In the first session, you will be asked to complete several questionnaires which are designed to evaluate aspects of musical ability, and to assess how right- or left-handed you are. In the second session, you will be asked to perform a series of tasks involving listening to music. These tasks are designed to activate different areas of the brain. The level of activation will be gauged by recording your brain electrical activity.

In the second session, a 64-electrode cap will be placed on your head. The electrodes contained in the cap are designed to maintain a gentle pressure on your scalp. These will be used to record your brain electrical activity. A small quantity of recording gel which is water soluble will be squirted down each electrode barrel helping to make good contact between the electrode and the scalp. In addition, a set of half-mirrored glasses are mounted on the helmet which will rest comfortably in front of your eyes. You will be able to see through these glasses and at the same time you will be able to see a dim flickering red light.

There are no dangers or health risks associated with the study. The electrodes are used for recording the natural activity of your brain. They cannot give you a shock.

The total time involved in this study over the two sessions will be about 2 hours. Participation is voluntary and your initial agreement does not stop you from discontinuing the study at any time.

IF YOU PRESENTLY SUFFER OR HAVE EVER SUFFERED FROM EPILEPSY WE ASK YOU TO WITHDRAW FROM THE STUDY NOW.

The coordinating supervisor of this study is Professor Richard Silberstein. If you have any queries, please contact Professor Silberstein on 9214 8273 or Philip Harris on 9214 5541. In the event that your enquiry is not satisfied, or you have a complaint about the way you have been treated during the study, please write to:

The Chair,
Human Experimentation Ethics Committee
Swiburne University of Technology,
P O BOX 218
Hawthorn, VIC. 3122

SCAN PROTOCOL SHEET

INFORMED CONSENT FORM	
SUBJECT CODE	***NOTE _ _***

Project Title: Cortical activity associated with rhythmic grouping of pitch sequences
Researcher: Philip G. Harris
Coordinating Supervisor: Richard B. Silberstein

NOTE: ***Personal details will remain confidential***

I, the undersigned, have read and understood the information in the Explanatory Statement. Any questions I have asked have been answered to my satisfaction.

I agree to participate in this activity, realising I am free to withdraw at any time.

I agree that research data collected for the study may be published or provided to other researchers provided my name is not used.

SURNAME__________________OTHER NAMES:__________________

SIGNED:__________________________DATE:________________
participant

SIGNED__________________________DATE:________________
investigator(s)

Appendix B PERSONAL DETAILS FORM

B.S.I
SHEET

PERSONAL DETAILS - 1	
SUBJECT CODE	***NOTE*** **_ _**

NOTE: ***1.Personal details will remain confidential***

***2.** For questions requiring a YES / NO response, please **CIRCLE** the correct response*

Surname____________________________________Given Names_____________
____

Date____Time ___________________
____

Date of birth______________Age_______________Sex________________Handedness
____

Have you had any formal musical instrument or music theory training? **Yes / No**

If you answered yes to the previous question:

Was the training musical instrument (name instrument) and/or music theory?___________________

How many years of formal training have you received?__________________

What level did you attain?(eg. A.M.E.B. 2nd grade) ___________________

Have you had any non-formal musical instrument or music theory training?

(eg. self-taught) **Yes / No**

If you answered yes to the previous question:

Was the training musical instrument or music theory?____________________

How many years of non-formal training have you received?_______________

Do you have any hearing problems (tinnitus, hearing deficits, etc)? **Yes / No**

If yes, specify -

____

B.S.I SHEET	

PERSONAL DETAILS - 2	
SUBJECT CODE	***NOTE* _ _**

NOTE:

1.Personal details will remain confidential

***2.** For questions requiring a YES / NO response, please **CIRCLE** the correct response*

Surname__________________Given Names_________________________________

Date____Time ___________________

Date of birth_______________Age__________Sex__________Handedness_________

No. of years of primary education (eg. 6)___________________________________

No. of years of secondary education (eg. 6)_________________________________

No. of years of tertiary education (eg.3)____________________________________

Academic qualifications (Year 11, VCE, B.App.Sci., etc)_____________________

Do you presently suffer or have you ever suffered from epilepsy? **Y / N**

If yes, specify____

Do you have any other visual defects (short sightedness, lazy eye, etc)? **Y / N**

If yes, specify____

Do you have any hearing problems (tinnitus, hearing deficits, etc)? **Y / N**

If yes, specify____

Have you ever sustained a serious head injury? **Y / N**

If yes, specify____

Do you presently suffer from any neurological or psychiatric disorders? **Y / N**

If yes, specify____

Have you consumed tea or coffee today? **Y / N**

If yes, indicate time of last consumption____________________________

Have you had any recent illness? **Y / N**

If yes, specify____

Do you currently take any prescription drugs? **Y / N**

If yes, specify____

Are you a smoker? **Y / N**

If yes, indicate the last time you smoked____________________________

Appendix C POST-EXPERIMENTAL RESPONSE FORM

Post-experimental response form

How hard was it to decide if the probe contained a false note?

____

Did you use any particular strategy to do the task? **YES / NO**

____

____

____

Different people use different approaches to do this type of task.eg. Some people listen to the notes as though they formed a continuous line with up and down steps.

Do you think you listened in this way? **YES / NO**

____

____

____

Do you think the rhythm of the patterns was made up of notes with a similar length, or do you think that the rhythm of the patterns made up of mainly short notes with a longer note every once in a while. **SIMILAR LENGTH / DIFFERENT LENGTHS**

____

____

____

(if different lengths) Do you think the rhythm of the pattern had any influence on the way you listened to and remembered the patterns? **YES / NO**

____

____

____

An approach people may use to do this type of task is to concentrate on each note separately without joining the notes together.

Do you think you listened in this way? **YES / NO**

____

____

____

(If previous questions do not adequately determine strategy) Is there any other listening strategy you may have used to do the task? **YES / NO**

____

____

____

____

____

Do you think you repeated the patterns to yourself as they were playing? **YES / NO**

____

____

____

Did you feel like you were able to remember the whole of each pattern? **YES / NO**

____

____

____

When you were listening for the extra note in the other task that we did, do you think you used any of the listening strategies that we have discussed for the probe task? **YES / NO**

____

____

____

Reference task response

Number of times participant heard two notes at once ______

Appendix D SSVEP EYES-CLOSED PILOT STUDY

SSVEP eyes-closed pilot study

The SSVEP eyes-closed pilot study sought to determine the luminance of the steady-state stimulus necessary to obtain 13 Hz SSVEP signal strength in an eyes-closed condition analogous to that obtained in an eyes-open condition. A luminance of 3 Cd/m^2 has previously been determined to provide sufficient signal-noise ratio in the eyes-open condition to provide relative insensitivity to noise and artefact contamination (Silberstein, Burkitt, & Wood, 1993; Silberstein et al., 1990). The pilot study sought to determine the 13 Hz visual stimulus intensity necessary to evoke an SSVEP response of equivalent power as obtained in an eyes-open control condition using a stimulus of 6 Cd/m^2 – a stimulus intensity that would ensure production of a robust SSVEP response.

Method

EEG was recorded from 1 participant in response to 8 conditions of varying 13Hz stimulus luminance over 260 s duration each. EEG responses were recorded from electrodes positioned at mid-anterior frontal, vertex, left and right posterior temporal and mid-occipital regions and referenced to linked mastoid electrodes with ground as reference. The power of the 13 Hz SSVEP for each stimulus condition was calculated from the 13 Hz Fourier coefficients averaged over the entire duration of each stimulus condition separately.

Results

SSVEP magnitude associated with each stimulus condition was averaged across the five electrodes to provide a single average magnitude value for each luminance condition. Average 13 Hz SSVEP power for each stimulus condition is detailed in Table 5.1.

Table C.1 Stimulus conditions used to determine steady-state luminance

Condition Eyes open / closed	Steady-state stimulus luminance (Cd/m^2)	Averaged SSVEP magnitude (μV)
Open	No Stimulus	0.2
Open (reference condition)	6	4.0
Closed	6	2.6
Closed	12	3.8
Closed	18	4.1
Closed	24	4.9
Closed	30	5.0
Closed	36	5.2

Averaged SSVEP responses in the eyes-closed conditions demonstrated a progressive increase in magnitude with increasing luminance values and approximated the eyes-open magnitude value at a stimulus strength of 18 Cd/m^2. Another consideration in adopting the eyes-closed condition for the main study was the effect on the participants' EEG alpha power and its potential effects on the 13 Hz SSVEP response. Closing the eyes is known to produce an increase in alpha band power relative to eyes open (Berger, 1929). Small temporal shifts in alpha band centroid frequency may result in instability of the SSVEP response when the stimulus frequency of the SSVEP falls within the bandwidth of the alpha band (Regan, 1989). As enhancement of EEG power due to closing of the eyes generally occurs within the alpha range at 8 to 12 Hz (Regan, 1989), alpha band centroid frequency shifts were not considered to be a potential confounder of the 13 Hz SSVEP response. In view of results obtained in the steady-state stimulus pilot study, a stimulus luminance of 18 Cd/m^2 was adopted for subsequent use in the main study.

References

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APPENDIX E TASK INSTRUCTIONS

Probe recognition task instructions

This study examines the way people listen to music. In the study, you will be listening to short melodic patterns, that is, series of notes with different pitches and time values. Your task will be to listen to, and try and remember a pattern of notes, and then recognise whether another shorter pattern of notes comes from the original pattern or not.

Your task will go like this: at the start of a block of trials I'll ask you to close your eyes and then I will turn on the flickering light. After you've had a chance to adjust to the flicker I'll start the trials.

First you will hear 4 short notes which serve as a warning that a trial is about to begin. The warning pattern is the same for each trial, you don't have to memorise the warning pattern. After this you will hear the pattern of notes to remember. 2 - 3 seconds later you will hear a voice saying "probe", and following this you will hear a shorter pattern of notes. This shorter pattern of notes has been extracted from the original pattern, but some of these 'probe' patterns have had one note changed up or down in pitch from the original version.

The idea is for you to listen to, and try and remember the original pattern, and then recognise whether the shorter pattern of notes accurately comes from the original pattern or not. If all the notes sound identical to the original then your response would be 'true', alternatively, if you think that one note has been changed from the original pattern then your answer would be 'false'. Please remember that in false patterns only one note has been changed, so a false probe pattern will still sound very much like the original pattern.

Following the shorter probe pattern, there will be a pause of about 5 seconds for you to respond via the button box. After you have heard the probe pattern, if you believe the probe was true (that is, with no false notes) press the right button.

If you believe the probe was false (that is, one note was a different pitch to the original pattern) press the
left button. If you are not sure, please respond as best you can. This task is mainly a test of accuracy but also considers the speed of your response. In other words, the main aim is to get as many right as you can, but to answer as quickly as you reasonably can after you have heard the probe pattern. After the response pause, the warning pattern will play to warn you the next pattern is about to start. Do you have any questions at this stage?

I'll now give you some practice trials so you can get used to the format of a trial.

[PRACTISE TRIALS]

I'll ask you to close your eyes, and then I will turn on the flickering light.
If you think the probe is true, press the right button. If it's false, press the left button.

After practise

Lights off. You can open your eyes now.

Do you have any questions?

[Block 1]

This task will be exactly the same as the one you have just performed. It will last for about 5 minutes.

I'll ask you to close your eyes, and then I will turn on the flickering light.
Remember; wait until you've heard the whole probe pattern before responding. Then if you think the probe is true, press the right button. If it's false, press the left button.

[Commence data acquisition and play stimulus]

Reference task instructions

In this task, you will be played a continuous series of notes of different pitches and durations. Most of the notes will be played one at a time. Occasionally, an extra note will be added so that you will hear two notes playing at the same time. Your task is simply to relax and listen for the occurrence of two notes at the same time, and to tell me at the end of the task how many times this happened during the task. You will not be asked to remember any other details except how many times you heard two notes at once.

I'll now play you an example of the patterns you will be hearing so you can get used to the task. Listen for the extra note.

[PRACTISE TRIAL]

Did you hear when two notes played at the same time?

[REFERENCE TASK]

This task will last for about 3 minutes. Try to stay relaxed and remember how many times you heard two notes at once.

I'll ask you to close your eyes, and then I will turn on the flickering light.

[Commence data acquisition and play stimulus]

After task - How many times did you hear two notes at once?

APPENDIX F POSTER PRESENTED AT THE NEW YORK ACADEMY OF SCIENCES: THE BIOLOGICAL FOUNDATIONS OF MUSIC, NEW YORK, MAY 2000

Frontal lobe contributions to perception of rhythmic group structure: An EEG investigation

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Brain Sciences Institute, Swinburne University of Technology, 400 Burwood Road, Hawthorn, 3122, Victoria, Australia.

1 Introduction

Substantial research supports the salience of relatively longer inter-note onsets (IOIs) in determining rhythmic group structure,[1-4] yet little is understood about the neural underpinnings of the perceptual grouping process.

Gestalt-based interpretations of perceptual processes underlying rhythmic groupings have been proposed,[5] and converge with orienting response (OR) theory which proposes enhanced neural sensitivity following a change in IOI.[6]

The current study investigated cortical responses to perception of rhythmic group structure by examining changes in EEG responses associated with participants' active and passive perception of pitch/rhythm patterns.

The study used the steady-state visually evoked potential (SSVEP) to examine ongoing changes in 13 Hz EEG responses while participants listened to pitch/rhythm patterns.

2 Method - Subjects and Task

Forty-three females aged 18 - 42 (x = 23.0, SD = 5.6) with a wide range of musical training (x = 4.0, SD = 7.0, range = 0 to 32) performed two tasks while their EEG was recorded.

Pitch memory was tested with a probe recognition task, which required participants to actively memorise 10-note pitch/rhythm patterns for subsequent recognition (refer Figure 1).

A baseline task required participants to detect the rare playing of 2-note pitch pairs amongst a single-note pitch/rhythm series.

Stimuli in both tasks consisted of diatonic pitch series at 600 ms IOI with a semi-random (p=0.15) doubling of IOI to 1200 ms.

Neither task placed explicit demands on perception of rhythmic structure of the pitch series.

3 Method - EEG

Brain electrical activity was recorded from 64 scalp electrodes including all International 10-20 positions, referenced to linked ear-lobes with nose as ground.

The SSVEP was elicited by a 13 Hz flicker delivered to participants via LED arrays mounted on a set of goggles.

An across-subject SSVEP latency time series for a 5-second period centred on the occurrence of lengthened IOIs in each task was calculated at each electrode site at a temporal resolution of ~190 ms.

Figure 1. Example of probe recognition task trial. Top figure shows a pattern to be memorised. Bottom figure shows possible probe pattern played 2 seconds later. Probes end on longer-duration note, or straddle longer duration note. Participants judge whether any notes in probe pattern altered from original pattern.

4 Results

Behavioural

Longer IOIs significantly influenced participants' performance in the probe recognition task.

Pitch memory performance was significantly better when probe patterns matched rhythmic group structure established by longer IOIs (66.0%), than when probe patterns straddled over longer IOIs (59.9%), ANOVA $F(1,42) = 12.3$, $p = 0.001$.

Poorer recognition of pitch changes to patterns straddling longer IOIs suggests that longer IOIs played a significant role both in the encoding of the pitch/rhythm pattern working memory trace and its subsequent comparison to the probe pattern.

EEG

EEG responses to the pitch/rhythm patterns showed rhythmic 13 Hz SSVEP latency reductions over bilateral frontal areas in both tasks following approximately 200 ms after each note onset.

A strong enhancement of SSVEP latency reduction was apparent at left posterior frontal sites in response to a note following a longer IOI (refer Figures 2 and 3). This enhancement was not apparent at the equivalent right frontal site.

A repeated measures analysis of variance which compared latency responses in a 100-300 ms window following each note onset revealed a significant enhancement of SSVEP latency reduction at a left posterior frontal site in response to a note following a longer IOI, compared to latency reductions elicited by notes following standard IOIs in the active task, ($F(2.9, 42) = 2.9$, $p < 0.05$), but not the passive task, ($F(2.9, 42) = 1.3$, $p > 0.05$). Post-hoc T-tests comparing peak latency values appear in Figure 4.

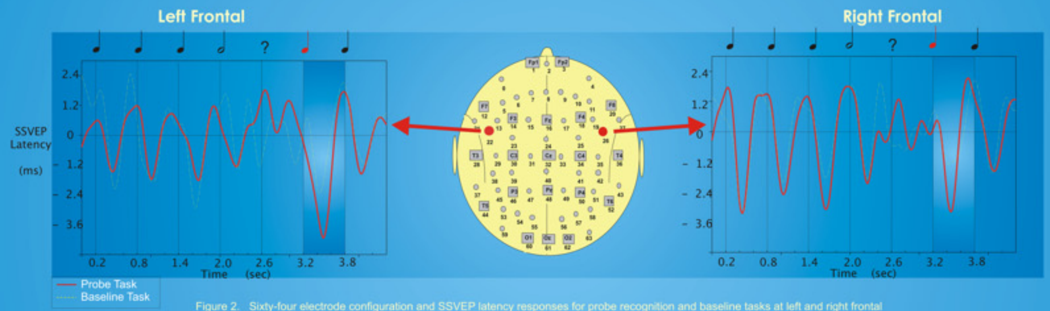

Figure 2. Sixty-four electrode configuration and SSVEP latency responses for probe recognition and baseline tasks at left and right frontal electrode sites (electrodes 22 and 26). A strong latency decrease follows longer IOI at left frontal site only in probe recognition task..

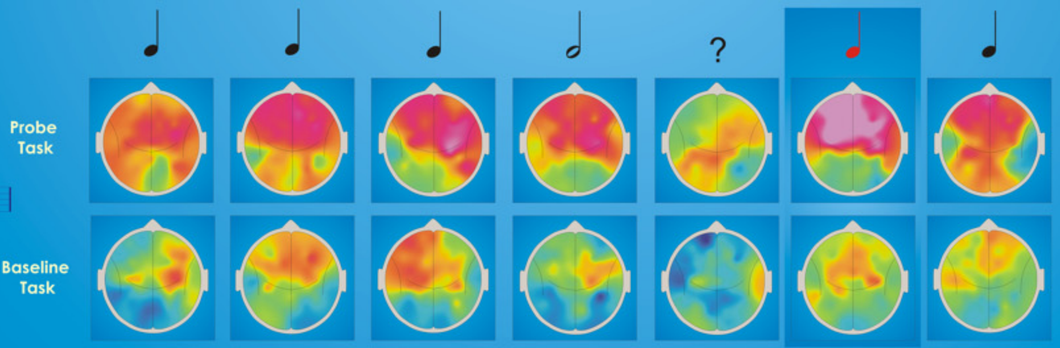

Figure 3. Topographic maps of averaged SSVEP latency responses of all 43 subjects in probe recognition and baseline tasks. Maps show latenct responses 200 ms after each note onset (including timing where note onset would have occurred during longer duration note).

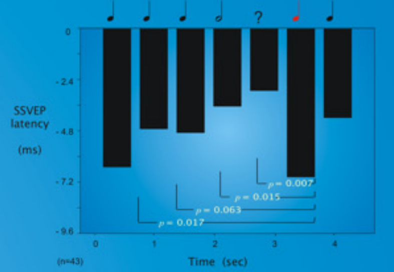

Figure 4. Peak SSVEP latency responses during 100-300 ms window following note onsets in probe recognition task at left frontal site.
P values represent one-tailed paired t-test comparisons between lengthened IOI and standard IOI peak latency responses.

5 Discussion

Steady-state latency reductions in the frontal lobes have previously been linked with increases in frontal neural processing speed,[8, 9] inferred to represent frontal excitatory processes.

In view of behavioural results indicating that longer IOIs significantly influenced internal representations of the patterns, the left frontal latency reduction following a longer IOI may index a frontal contribution to the coding of the internal representation of the pattern temporal structure.

Longer IOIs elicited transient left frontal excitation, but only in a task requiring the holding of an internal representation of the pattern.

In summary, the current study finds support for Gestalt and OR theory proposals of a special perceptual and neural status for an event following a relatively longer time interval.

Left frontal excitation in response to longer IOIs, while not a primary perceptual response, appears to be related to the coding of an internal representation of the rhythmic structure of a pitch/rhythm pattern.

6 References

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APPENDIX G PUBLICATIONS BY THE AUTHOR

Publications by the Author

Journal Articles

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