The impact of auditory presentation procedures on behavioural measures of emotion lateralisation

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Statement of Access

Statement of Sources Declaration

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education.

Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

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Declaration of Ethics

The research presented and reported in this thesis was conducted within the guidelines for research ethics outlined in the *National Statement on Ethical Conduct in Research Involving Humans* (2007), the *Australian Code for the Responsible Conduct of Research* (2007), and the *James Cook University Code for the Responsible Conduct of Research* (2009). The proposed research methodology received clearance from the James Cook University Experimentation Ethics Review Committee (approval numbers H3678).

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Abstract

Given the importance of human emotion for survival, emotion is a fundamental topic within neuroscience. Two major theories of emotional processing forwarded over the last century are the right hemisphere hypothesis and the valence effect. The former is that all emotions are processed in the right hemisphere of the human brain while the latter is that positive emotions are processed in the left hemisphere and negative emotions in the right. A contemporary account of human emotion reveals complex and bilateral processing. Despite this, distinct effects supporting both hypotheses are robustly observed. While divided visual field research is consistent with both hypotheses, dichotic presentation is almost always consistent with the right hemisphere hypothesis. In both visual and auditory studies, when individuals process one discrete emotion per trial, evidence is consistent with the valence effect while processing two competing emotions elicits results consistent with the right hemisphere hypothesis. Overall, auditory studies have employed monaural, distractor noise, and dichotic presentation without considering whether these procedures adequately measure emotional processing. This makes it unclear whether the right hemisphere superiority reported from dichotic presentation reflects a true emotion effect or competing stimuli masking contributions from the left hemisphere. In the experiments reported in this thesis, participants classified the emotional aspect of speech and music during monaural, distractor noise, and dichotic presentation. All competing stimuli were neutral in emotional valence to ensure participants only processed one target emotion per trial. A right ear effect occurred in the time it took participants to classify each aspect of words from dichotic presentation: non-emotional, emotional content, and emotional prosody. These ear effects were attributed to left hemisphere superiority in language processing. When participants classified the non-emotional or emotional content of words with monaural presentation, unpleasant words were classified least correctly when presented to the right ear. When participants classified music, ear advantages only occurred from dichotic presentation and depended on the duration of the melodies and behaviour measured. A left ear effect emerged in response times to emotional classifications of longer duration melodies, and no ear difference occurred in the control task confirming that this left ear effect was consistent with the right hemisphere hypothesis. However, with affective classifications of brief versions of the same melodies, sensitivity to pleasantness elicited a right ear effect consistent with the valence effect, while sensitivity to a non-emotional classification revealed a left ear advantage consistent with the right hemisphere's role in processing music. Response bias also showed a bias to respond "pleasant" with brief melodies presented to the right ear consistent with the valence effect, and no ear effect occurred in the control condition. In the experiments reported in this thesis, only dichotic presentation consistently produced ear effects associated with language and music processing and the right hemisphere hypothesis and the valence effect. The valence effect can occur with dichotic presentation with melodies when the duration of the melodies is brief and sensitivity and response bias is measured, a finding consistent with divided visual field research. However, the validity of using any visual field or ear advantage to explore which emotion laterality theory best explains emotional processing is questioned. This thesis forms the basis from which a more systematic study of the behavioural consequences of emotional processing with auditory information might proceed.

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Chapter 1. Introduction

From left-brain right-brain mythology to the neural organisation of emotion

A popular topic regarding the human brain is whether an individual is left-brained or right-brained. A Google search, “Are you left-brained or right-brained?” reveals approximately twenty-four million hits. Left-brainers are thought of as analytical, orderly, and skilled in language and mathematics; right brainers creative, disorganised, artistic and emotional. This folk psychology has evolved from neuroscience research into hemispheric asymmetry. One of the main questions in affective neuroscience over the last century is which hemisphere is responsible for emotional processing, with the major theories including the right hemisphere hypothesis and the valence effect. The right hemisphere hypothesis is that all emotions are processed in the right hemisphere of the human brain (Borod, Koff, & Caron, 1983; Ross, 1985). The valence effect is that positive (or approach related) responses are processed in the left hemisphere while negative (or withdrawal related) responses are processed in the right (Reuter-Lorenz & Davidson 1981; Reuter-Lorenz, Givis, & Moscovitch, 1983). Each share the premise that one hemisphere is superior to the other in processing emotion however they differ in which hemisphere is dominant for all or specific emotions. Traditional methods to test each theory began with observations of individuals with brain lesion, followed by behavioural and neuroimaging approaches typically focusing on how individuals process the perception of facial affect, the emotional prosody of speech and the emotional appraisal of music. Both theories were proposed prior to the advent of neuroimaging and contemporary reviews of this research (Phan, Wager, Taylor & Liberzon, 2002) reveal complex bilateral emotional processing indicating that any left-brain, right-brain theory is too coarse an account of the neural organisation of emotional processing. Notwithstanding this, distinct behavioural differences in response to emotional stimuli presented to one hemisphere or the other continue to be reported (e.g. Marzoli & Tommasi, 2009; Reuter-Lorenz, Givis, & Moscovitch, 1983). Moreover, these behavioural differences generally comply with one of the two major theories of emotion. Consequently, hemispheric asymmetry has become a somewhat frustrating and controversial topic within affective neuroscience. This thesis presents a critical review of the lateralisation of emotional processing and proposes a more systematic investigation to understand the behavioural consequences of the neural organisation of emotion.

Processing the emotional content of information

How we process the emotional aspects of our social world is integral to understanding the human experience. Emotions such as happiness, sadness, fear, anger and disgust are known as core affective states and are universal to humans (Ekman, 1992; Russell, 2003; Russell & Barrett, 1999). These emotions facilitate choice and action and thus are critical for human survival. Given the importance of human emotion, emotional processing has become a central topic within neuroscience. One of the most salient emotional stimuli is the human face since it can portray both the emotional state of a person as well as influence the emotions of an observer. Neurologically healthy individuals can almost instantly judge whether someone's facial expression is happy or sad. Similarly, processing the emotional aspects of auditory information serves several important social functions. Affective prosody is a non-linguistic feature of language that conveys the emotional state of the speaker. Individuals can quickly recognise whether someone is calm or distressed just by listening to their voice and respond accordingly. Individuals can also easily judge whether a song is happy or sad. While individuals have an incredible capacity to process human emotion, how they do so is complex and not fully understood. Despite the vast literature on hemispheric specialisation of emotional processing, there are still many apparent contradictory findings. In the following review evidence for hemispheric specialisation of emotional processing will be examined while also drawing upon some of the strengths from the facial affect literature to form the basis from which a more systematic study of processing the emotional aspects of auditory information might proceed.

Hemispheric asymmetry

Hemispheric asymmetries have been widely observed in humans (see Brancucci, Lucci, Mazzatenta, and Tommasi, 2009) and several other vertebrate species (e.g. Rogers & Andrew, 2002). Early observations of patients with brain injuries to one of the two cerebral hemispheres noted specific behavioural changes in these individuals. For example, Wernicke (1874) observed that patients with damage to the left posterior, superior temporal gyrus displayed deficits in language comprehension, which led him to conclude that the left hemisphere was important for language comprehension. Procedures for studying hemispheric asymmetries in neurologically healthy individuals took some time to evolve of which the divided visual field technique and dichotic listening are the best known.

Divided visual field tasks

The divided visual field technique was initially introduced by Mishkin and Forgays (1952). This technique involves the tachistoscopic presentation of a visual stimulus (e.g. a picture of a smiley face for less than 180 ms) to the left or right visual field. This method is based on the anatomic properties of the visual system; the neural pathways from the left visual field project first to the right visual cortex, whereas those from the right visual field project to the left visual cortex. Thus, in a divided visual field task, an image presented to one visual field is processed, at least initially, by the opposite cerebral hemisphere (Beaumont, 1983). In a typical divided visual field experiment, a series of stimuli are presented to one or the other visual field while the participant's task is to detect, categorise or later recall these target stimuli. In such tasks, shorter reaction times and fewer errors in the detection of stimuli presented to one visual field relative to the other is attributed to superior processing in the contralateral cerebral hemisphere.

Monaural, distractor noise, and dichotic presentation

Listening studies require participants to respond to auditory stimuli presented to one ear versus the other. Listening methods to measure hemispheric asymmetry are more varied, with monaural, distractor noise and dichotic presentations all featuring in the literature. In a monaural listening task, participants respond to auditory stimuli presented to only one ear. During distractor noise presentation, the target stimulus is presented to one ear while an unrelated sound, such as white noise, is simultaneously presented to the unattended ear. In the dichotic listening procedure, the target stimulus is presented to one ear while a similar competing auditory stimulus is simultaneously presented to the unattended ear. Unlike vision where neural projections travel directly to the opposite cerebral hemisphere, in the human auditory system, projections from each cochlear are sent to both cerebral hemispheres bilaterally. Although auditory input travels bilaterally, contralateral neural connections are thought to be stronger and more efficient than ipsilateral connections (Kimura, 1961). In addition, the presence of a competing stimulus to the opposite ear results in inhibition of the ipsilateral pathway further enhancing processing in the contralateral pathway (Brancucci et al., 2004). Shorter reaction times and fewer errors from stimuli presented to one ear compared to the other are thus taken as evidence of superior processing in the opposite cerebral hemisphere. The best known hemispheric asymmetry is the right ear advantage for verbal stimuli indicative of left hemisphere superiority for processing verbal information (e.g. Kimura, 1961; Bryden, 1988).

Hemispheric asymmetries for emotional processing

A meta-analysis of 55 functional brain scan studies demonstrates that happiness, sadness, disgust, fear and anger are associated with activity in both cerebral hemispheres (Phan, Wager, Taylor & Liberzon, 2002) suggesting that the right hemisphere hypothesis and the valence effect may be too simplistic. Nonetheless, distinct behavioural differences have been observed with emotionally valanced images to a single visual field (Reuter-Lorenz, Givis, & Moscovitch, 1983) and with auditory messages presented to each ear (Marzoli & Tommasi, 2009). For example, in a widely publicised study, Marzoli and Tommasi (2009) had a female confederate approach 160 individuals in three nightclubs and request a cigarette. Those approached met the request twice as often when it was addressed to the right ear compared to the left. Marzoli and Tommasi attributed this right ear advantage to the cigarette request being appraised most positively by the left hemisphere. Thus, while neuroimaging studies suggest widespread bilateral processing of affective stimuli, distinct behavioural effects between one hemisphere and the other still occur. Reconciling these behavioural observations consistent with hemispheric specialisation with the underlying bilateral neurological substrates is the central aim of the current thesis. In this light, a brief review of the lateralisation of emotion follows to highlight behavioural laterality effects consistent with each major theory of hemispheric specialisation of emotion. Following this, key meta-analyses are presented to acknowledge a contemporary account of the neural organisation of emotion. Finally, a critical review of behavioural research is presented to determine what methodological factors might contribute to the behavioural observations that have been reported.

Early observations of brain lesions to the neural organisation of emotion

Early observations of patients with lesions to the right hemisphere revealed a decrease in emotional expression (Mills, 1912). Similarly, Babinski (1914) observed that individuals with right hemisphere lesions behaved inappropriately, indifferently or manically. More systematic comparisons between patients with damage to the left and right hemisphere by Buck and Duffy (1980) indicated that patients with right hemisphere damage expressed fewer emotions compared to individuals with left hemisphere damage to pictures designed to elicit emotional expressions. These observations led to the right hemisphere hypothesis that the right hemisphere alone is responsible for the perception, expression and experience of all emotion (e.g. Borod, Koff, & Caron, 1983; Heliman & Bowers, 1990; Ross, 1985). However, different patterns of emotion responding depending on the hemisphere that was damaged have also been observed. For instance, patients with damage to the right hemisphere often show signs of inappropriate cheerfulness and mania (Starkstein et al., 1989), whereas patients with damage to the left hemisphere often exhibit symptoms of depression (e.g. Morris et al., 1996; Paradiso, Chemerinski, Yazici, Tartaro & Robinson, 1999). It was in part these observations that led to the belief that positive and negative emotions are predominately processed within the left and right hemispheres respectively: the valence hypothesis. Hence, lesion research provides contradictory evidence with some studies consistent with the right hemisphere hypothesis and others the valence effect. However, it should be noted that each human brain differs anatomically and the location of lesion, extent of damage and time between damage and testing inevitably vary among participants. Thus, heterogeneity associated with lesion studies may partly account for these conflicting results.

Concerning neurologically healthy individuals, for simplicity, this review introduces research on the perception of facial expressions of affect and the emotional prosody of speech, however the emotional appraisal of music will be discussed with the critical review of behavioural research. Some divided visual field experiments investigating neurologically healthy individuals have demonstrated a left visual field advantage in recognising emotional facial expressions (Ley & Bryden, 1979; McKeever & Dixson, 1981; Suberi & McKeever, 1977). For example, Ley and Bryden (1979) presented cartoon line drawings of five faces, each with different emotional expressions ranging from extremely positive to extremely negative. The participants' task was to indicate if a centrally presented face had the same emotional expression as a face presented in the left or right visual field. Response accuracy was better for left visual field items relative to right visual field items indicating right hemisphere superiority for facial affect perception consistent with the right hemisphere hypothesis. However, other divided visual field studies have reported a valence effect for the recognition of facial affect (e.g. Harrison & Gorelczenko, 1990; Reuter-Lorenz, Givis, & Moscovitch, 1983). For instance, Rueter-Lorenz and Davidson (1981) presented pairs of images of the same face so that one image was in the participants' left visual field and the other the right. One image displayed either a positive or negative emotion while the other was neutral. The participants were informed that one face was expressing an emotion whereas the other was neutral and that the task was to indicate as rapidly as possible which side contained the emotional face. Overall, reaction times were quicker for sad faces presented to the left visual field and happy faces presented to the right visual field, suggesting that recognition of positive facial affect is processed in the left cerebral hemisphere while negative affect is processed in the right. Thus, like lesion observations, studies using the divided visual field approach to investigate the perception of facial affect in neurologically healthy individuals are also contradictory with some studies consistent with the right hemisphere hypothesis and others the valence effect. However, these studies have employed widely different methods, such as pairing target faces with either a neutral or competing emotional face. The impact of varying such methods on observed emotion laterality effects is further discussed in the critical review of behavioural research.

In contrast to lesion research and divided visual field studies investigating facial affect, dichotic listening studies using emotional prosody seem to only support the right hemisphere hypothesis. In neurologically healthy individuals, studies using the dichotic listening procedure have consistently observed a left ear advantage in the processing of emotional prosody (Haggard & Parkinson, 1971; Hatta & Ayetani, 1985; Ley & Bryden, 1982; Safer & Leventhal, 1977; Saxby & Bryden, 1984; Voyer, Bowes, & Soraggi, 2009). For instance, Ley and Bryden (1982) presented sentences spoken in happy, sad, angry and neutral voices to one ear while monotone sentences were presented to the other ear. Participants were instructed to attend to one ear to which the valanced sentence was presented and to ignore the monotone sentence presented to the other ear. They were asked to judge both the content of the sentences they heard as well as the emotional prosody. Recognition of the verbal content was superior for target sentences presented to the right ear and a left ear advantage occurred for the recognition of emotional prosody. This result is consistent with left hemisphere superiority for verbal processing and right hemisphere superiority for emotional prosody.

While dichotic listening studies investigating emotional prosody rarely demonstrate the valence effect, one study does provide partial evidence. In a dichotic listening task, Bryden and MacRae (1989), simultaneously presented the words, ‘power’, ‘tower’, ‘bower’, ‘dower’, spoken with happy, sad, angry or neutral prosody to participants’ left and right ears. The participants’ task in one block of trials was to indicate when a specific target word (e.g. ‘power’) occurred, and, in a second block, to indicate when a specific emotional prosody (e.g. ‘happy’) occurred. Again, the result was a right ear advantage for recognising words and a left ear advantage for emotions. However, the authors observed a larger left ear advantage for angry and sad targets than for happy targets. The authors interpreted this finding as partial evidence for the valence hypothesis since it indicates that negative emotions are primarily processed in the right hemisphere. However, this result is only one exception and it is weak evidence at best, as a full valence effect would also predict a right ear advantage when participants recognised happy targets. Altogether, while early lesion research and divided visual field studies investigating facial affect are consistent with either the right hemisphere hypothesis or the valence effect, dichotic listening studies investigating emotional prosody generally comply with the right hemisphere hypothesis.

Inconsistent laterality effects from visual and auditory research led to several meta-analyses being conducted on the lateralisation of emotion. The first meta-analysis to investigate the neural organisation of emotion was conducted by Phan, Wager, Taylor and Liberzon (2002) briefly mentioned before. This meta-analysis included 55 positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) studies of neurological healthy individuals. Overall, fear, sadness, happiness and disgust was associated with activity in both cerebral hemispheres. There was no evidence to support either the right hemisphere hypothesis or the valence effect. The medial prefrontal cortex was shown to play a central role in all emotions irrespective of emotional valence. In addition, rather than emotional valence being mediated by one hemisphere compared to the other, fear was associated with activity in the amygdala, sadness the subcallosal cingulate cortex, and happiness and disgust the basal ganglia. This was the first meta-analysis to demonstrate emotional processing is widespread and bilateral and that separate brain regions were involved with different aspects of emotion. However, there is substantial difficulty in interpreting results from non-uniform experiments. This meta-analysis used 35 visual and nine auditory experiments, including several stimuli, such as faces and emotional prosody, various tasks, such as discrimination and identification, and the number of emotions also varied among studies. Thus, study heterogeneity could also partly account for the bilateral and widespread activation observed. Nonetheless, this was the first meta-analysis to demonstrate a more sophisticated account of the neural organisation of emotional processing than the current major theories provide.

Subsequent meta-analytic studies have focused on more specific aspects of emotional processing thus reducing study heterogeneity. For example, Fusar-Poli et al., (2009) conducted a meta-analysis of 105 fMRI studies of emotional face perception in neurologically healthy individuals. The study contrasted happy, sad, angry and disgusted facial expressions against neutral faces. The inclusion criteria were that each study was an original paper published in a peer-reviewed journal, employed the emotional face paradigm and was an fMRI study that used the image subtraction method to determine activation/deactivation foci. Like Phan et al. (2002), processing of emotional faces was associated with bilateral activation in several brain regions. However, the activation was not identical to the former meta-analysis. For example, fearful faces were associated with activation in the bilateral amygdala and the fusiform and medial frontal gyri. Happy faces were associated with activation in the bilateral amygdala, left fusiform gyrus and right anterior cingulate cortex. Sad faces were associated with the right amygdala and left lingual gyrus. Angry faces were associated with activation in the left insula and right inferior occipital gyrus. Finally, disgust was associated with activation in the insula and in the fusiform gyrus bilaterally. It is possible that the differences between the apparent areas of activation is due to the difference in the selection criteria for inclusion in the meta-analysis, however this does not change the observation that in both studies activation in response to emotionally valanced stimuli was generally bilateral with specific regions showing greater activation to specific emotional stimuli in contrast to one hemisphere than the other.

A similar pattern of results is evident in meta-analyses of emotional prosody perception. Witteman, Van Heuven and Schiller (2012) examined 27 fMRI studies of emotional prosody perception conducted in neurologically healthy individuals. Studies using stimulus driven tasks had participants focus on emotional compared to neutral prosody. Studies that were task dependent had participants direct attention to emotional prosody compared to a non-emotional prosodic aspect of the same stimulus, such as its linguistic features. This meta-analysis included both types of these studies in which the comparison conditions differed. The former is useful for understanding early processing and the latter for later processing of emotional prosody perception. Overall, a bilateral temporofrontal network was observed for emotional prosody perception. In addition, right hemisphere superiority was observed in early processing in the primary auditory cortex. It was concluded that this hemispheric specialisation is more likely driven by non-emotional prosodic factors such as acoustical processing. If this right hemisphere advantage is from acoustic processing rather than emotional prosody perception then this may explain why the overall finding of this meta-analysis is consistent with the previous large-scale fMRI meta-analysis of facial affect perception in neurologically healthy individuals (Fusar-Poli et al., 2007) that did not observe right hemisphere superiority in facial affect perception. Overall, this study demonstrates bilateral activation of emotional prosodic perception consistent with the large-scale fMRI meta-analysis on the perception of facial affect.

A final meta-analysis in this review was conducted by Lindquist, Wager, Kober, Bliss-Moreau, and Barrett (2012) who examined 91 PET and fMRI studies from 1990 to 2007 extending on the original meta-analysis conducted by Phan et al. (2002). Studies included used the induction method of emotion perception and experience of fear, sadness, anger, disgust and happiness. The intent was to determine whether the neural organisation of emotion is primarily localised or constructed. A locationist perspective predicts a distinct emotional category (e.g. fear) is consistently associated with a local area of the brain (e.g. amygdala). The constructionist approach predicts multiple operations, some of which are not emotion specific, are associated with many brain regions and multiple emotional categories. In this meta-analysis, specific emotion categories did not consistently localise to distinct brain regions. Many regions of the brain were activated in the experience of an emotion category versus all other emotion categories. The authors proposed different roles for brain regions that have traditionally been associated with one emotion category. The amygdala, anterior insula and orbitofrontal cortex seemed to all be associated with core affect. The amygdala is involved in determining whether sensory information is motivationally salient. Integral to core affect, the orbitofrontal cortex seems to be associated with integrating sensory information from the body and the world to guide human behaviour. Similarly, the anterior cingulate and dorsolateral prefrontal cortex are associated with attention while the dorsomedial prefrontal cortex and hippocampus are associated with conceptualising and accessing previous experience. Finally, language plays a vital role in conceptualising and regions such as the ventrolateral prefrontal cortex support language functions. This meta-analysis demonstrates that many processes, of which not all are emotion specific and multiple regions of the brain are associated with the perception and experience of emotion.

Altogether, investigations into the neural organisation of emotion began with lesion studies followed by behavioural methods with each major theory of emotion proposed prior to the advent of neuroimaging. Individual lesion studies and divided visual field experiments investigating the perception of facial affect provide evidence consistent with both the right hemisphere hypothesis and the valence effect. In contrast, dichotic listening studies investigating emotional prosody tend to only be consistent with the right hemisphere hypothesis. A contemporary meta-analytical review on neuroimaging studies demonstrate both hemispheres are involved in the perception of facial affect and emotional prosody perception revealing that any “left-brained / right-brained” theory is too coarse an explanation of the neural organisation of emotional processing. A strength of the meta-analytic approach is that is can pool together a large body of research providing high statistical power. However, limitations also come with this approach. One limitation is the “file drawer” problem, where most studies that fail to reject the null hypothesis are not published and therefore are not included in these meta-analyses. This raises the possibility that results from meta-analyses are an over estimation. Given that they did not support either theory of emotion the file drawer problem makes no hemispheric specialisation even more likely. In addition, the file draw problem did not prevent each meta-analysis from demonstrating both hemispheres are significantly involved in emotional processing. However, an alternative explanation for this bilateral processing is study heterogeneity that comes with measuring something as complex as emotional processing. Behavioural and neuroimaging methods ranging from facial affect to emotional prosody, varying in the demands of the task, number of emotions and sample characteristics, are all examples of moderating factors combined in a meta-analysis. Without minimising the complex neural organisation of emotion itself, one cannot ignore these factors partly contributing to widespread bilateral activation patterns. This thesis is not concerned with testing the right hemisphere hypothesis against the valence effect because affective neuroscience has advanced beyond the point where this question makes sense. The intent of this review was to demonstrate that emotion laterality literature is vast and that the contemporary consensus is that emotional processing is more sophisticated than left-brain, right-brain folk psychology. However, this thesis is concerned with why there are distinct behavioural consequences of this complex neural organisation that appear to be hemisphere specific. Despite bilateral processing of affective stimuli, real behavioural differences between stimuli presented to one hemisphere or the other appear to occur for both visual and auditory stimuli. Consequently, hemispheric asymmetry on affective processing is a frustrating and controversial topic within neuroscience. Overall, most behavioural research is consistent with the right hemisphere hypothesis however the valence effect is also observed under specific conditions. While meta-analyses provide valuable insight into the neural organisation of emotion, they do not explain why these behavioural differences are robustly observed. To this end a critical review of behavioural experiments is required with a focus on the methods used to measure hemispheric asymmetries, as this would appear to be the most likely explanation for the observed inconsistencies. The following critical review will draw on the strengths of the facial affect literature to highlight issues in auditory research, which is the focus of the current thesis. However, before beginning this critique it is necessary to revise some of the anatomical differences between visual and auditory perceptual pathways that will become relevant to issues related to understanding how auditory stimuli presented to one ear are processed in the brain.

Anatomical differences between visual and auditory processing streams

As mentioned, the dominant method for studying hemispheric asymmetry in visual processing is the divided visual field technique. The clear advantage of this approach is that projections from each visual field in the retina are sent directly to the contralateral hemisphere without immediate interference from the ipsilateral hemisphere. To ensure that the image is initially only processed by the contralateral hemisphere two conditions are required. Firstly, the stimuli must be presented to the left or the right of a central fixation point and secondly the stimulus presentation time must be relatively brief to prevent participants' eye movements from exposing the visual stimulus to both hemiretinas (Sergent, 1997). If these conditions are met it is possible to measure a direct contralateral hemispheric effect without interferences from the ipsilateral hemisphere. In contrast, the auditory perceptual system is far more complex. Projections from each cochlear are sent bilaterally to both cerebral hemispheres. Thus, unlike vision, auditory stimuli will always be processed to some extent bilaterally. This makes research into auditory hemispheric processing more complicated because it is not possible with any listening method to restrict even early processing to only one cerebral hemisphere.

In addition to auditory processing being more complex than visual processing, the stimulus presentation procedures that have been employed are more varied. Marzoli and Tommasi’s (2009) right ear advantage for a cigarette request could be considered a surprising effect because Kimura (1967) strongly argued that; “*normal auditory asymmetries could be demonstrated only with dichotic presentations, that is, with different stimuli presented to the ears simultaneously”* (p. 169). Kimura concluded that, “*when stimuli are presented strictly to one ear, as in monaural presentation.... there is no difference whatever between the ears”* (p. 169). Kimura assertion is based on the theory that dichotic stimulation results in inhibition of the ipsilateral pathway, which consequently enhances processing in the contralateral pathway. Thus, while it is not possible to restrict processing to one hemisphere compared to the other, ipsilateral suppression was thought to at least enhance the contralateral pathway, thus superior processing in one cerebral hemisphere can still be determined by an ear advantage from the contralateral ear. Kimura’s argument has been widely accepted and led to dichotic presentations being the norm in studies designed to detect hemispheric advantages in auditory processing despite the evidence for ipsilateral suppression being rather circular. That is, ipsilateral suppression was assumed to occur because dichotic procedures were the most likely to detect hemispheric differences, which were in turn validated by dichotic presentation studies. It was nearly 40 years before methods to directly test ipsilateral suppression were developed.

In 2004 Brancucci, et al. directly tested ipsilateral suppression from dichotic presentation measuring auditory evoked magnetic fields in response to complex tones.

In their study, ten healthy subjects listened to a randomised series of three complex tones that varied in intensity. Auditory evoked activity over the right auditory cortex progressively increased as tones of increasing intensity were presented to the right ear. However, this auditory evoked activity was abolished when a concurrent tone was presented to the contralateral (left) ear. However, auditory evoked activity was only abolished in the ipsilateral hemisphere when the two competing tones shared a similar fundamental frequency. This result is what would be predicted based on Kimura’s (1967) theory of dichotic ipsilateral suppression, although the dependence on a shared fundamental frequency is problematic for the application of ipsilateral suppression in many dichotic listening experiments. When the stimulus presented is speech and music they consist of many overlapping frequencies and in many experiments, it is unlikely that the competing stimuli are similar in fundamental frequency.

The issue of ipsilateral suppression is further complicated by evidence that it is not symmetrical during dichotic presentations. Fujiki, Jousmaki and Riitta (2002) reported significantly greater ipsilateral suppression in the left auditory cortex than the right during dichotic stimulation. In their study, auditory evoked magnetic fields in response to tones were observed during monaural and dichotic stimulation. When tones were presented monaurally to each ear, sharp peaks were observed in both hemispheres and these peaks were significantly larger in the contralateral than the ipsilateral hemispheres. However, when the same tones were presented dichotically, right ear inputs had significantly stronger projections to the left hemisphere than left ear inputs to the right hemisphere. The authors concluded that beyond hemispheric asymmetry, there is also an asymmetry within the auditory system mediated by a competition mechanism during dichotic stimulation. This complicates the interpretation of ear advantages from dichotic presentations because it is difficult to distinguish the relative contribution of hemispheric asymmetry from asymmetrical ipsilateral suppression effects.

Other effects of the unattended stimulus

Prete, Laeng and Tommasi (2014) recognised that the unilateral presentation of a single emotional face versus bilateral presentation of two competing emotional faces led to different results, with the former demonstrating a valence effect and the latter right hemisphere dominance. To verify whether this was a consequence of the number of faces or emotional units processed Prete, Laeng, Fabri, Foschi and Tommasi (2015) conducted four experiments in which participants rated the friendliness of happy, angry faces and chimeric faces. A chimeric face consists of two different emotional hemifaces presented to the centre of the screen so that each hemiface is presented to a different hemifield. In the first experiment, participants were required to rate the friendliness of a series of unilaterally presented emotional faces. In the second experiment, participants rated the friendliness of a series of chimeric faces presented bilaterally. Experiment three and four were identical to experiments one and two except that only a single anterior callosotmised patient was tested. Experiment one and three revealed happy faces were rated as friendlier when presented to the right visual field than the left, and angry faces as less friendly when presented to the left visual field than the right. In addition, there was no hemispheric asymmetry for neutral faces indicating that this valence effect was a consequence of emotional processing. In contrast, experiment two and four led to significantly higher friendliness ratings when chimeric faces were presented to the left than the right visual field consistent with right hemisphere dominance in emotional appraisal. This study demonstrates that conflicting laterality effects emerge from the presentation of a target alone versus a target and competing emotional stimulus. Importantly, when two competing emotional units are processed simultaneously the left hemisphere seems to lose its superiority in processing positive emotions and the right hemisphere dominates in processing all emotions.

This finding has important implications for auditory laterality research. In contrast to lesion and divided visual field studies that provide evidence consistent with both hypotheses, dichotic listening studies investigating emotional prosody are almost always consistent with the right hemisphere hypothesis. In the dichotic listening method, a target stimulus is presented to one ear while a competing auditory stimulus is simultaneously presented to the unattended ear. If the emotion laterality effects observed by Prete et al. (2015) apply to auditory laterality effects then the affect of the unattended stimulus might change the ear advantage observed. Specifically, if the affect of the target and competing stimulus are congruent, hence comprising a single emotional unit, the ear advantage should be consistent with the valence effect. In contrast, if the affect of the target and competing stimulus are incongruent and hence two discrete emotional units, the ear advantage should be consistent with the right hemisphere hypothesis. Thus, one explanation why the valence effect is almost entirely absent from dichotic listening studies may be that affect incongruency from dichotic stimulation is eliciting results consistent with the right hemisphere hypothesis. In light of this, it is necessary to review the few dichotic listening studies in which affect congruency was manipulated.

Grimshaw, Seguin and Godfrey (2009) initially replicated Bryden and MacRae’s (1989) study to ensure that their stimuli produced a right ear advantage when participants were required to indicate the target word (power, bower, tower, or dower) and a left ear advantage when they detected a target prosody (happy, angry, or sad). In this first experiment, the words presented to each ear differed and emotional prosody was also incongruent, thus two competing emotional prosodies were presented per trial. In the second experiment, participants only monitored for a target word spoken in either an emotional or neutral prosody. In this experiment, the words presented to each ear differed (as in Experiment 1), however they were spoken in the same emotional prosody, thus only one emotional prosody was presented per trial. Experiment 1 demonstrated a right ear advantage when participants focused on the words and a left ear advantage when they attended to emotional prosody. Experiment 2 also demonstrated the typical right ear advantage to target words, however it was attenuated (i.e. shifted toward the left ear) when the emotional prosody was sad. The authors suggest this effect could be due to positive (or approach) emotions such as happiness (and anger) being associated with the left hemisphere and negative (or withdrawal) emotions such as sadness and fear being associated with the right hemisphere. However, this valence effect only occurred when the affect of the target and the unattended prosody was congruent. This suggests that affect congruency might contribute to the ear advantage observed.

Godfrey and Grimshaw (2016) replicated Grimshaw, Seguin and Godfrey's (2009) study with a larger sample and a within subjects design to increase power. Participants detected a target word during dichotic presentation and the competing words were spoken in the same emotional prosody (neutral, angry, happy, sad or fearful). A right ear advantage in sensitivity and response time occurred when the target words were spoken in a neutral prosody. However, unlike the attenuation of the right ear advantage observed in the earlier study, it was attenuated for all emotional prosodies presented (angry, happy, sad and fearful) consistent with the right hemisphere hypothesis. The authors suggest the power from using a larger sample and a within subjects design accounts for the difference in results between the two studies. However, in both studies, emotional prosody was task irrelevant, meaning that participants were not explicitly required to process emotional prosody. Valence specific effects are more likely to occur during emotional experience (Schepman, 2007; Schepman et al. 2012). Therefore, it remains unclear whether the valence effect occurs in dichotic presentations when the emotional content of the stimulus is task relevant and individuals explicitly process one target emotion per trial.

A similar pattern of results has been observed in listening studies using musical stimuli. Like emotional prosody, dichotic listening studies using musical stimuli also show a left ear advantage for affective appraisals (Bryden, Ley & Sugarman, 1982; Leichner & Broscher, 1998)**.** For example, Bryden, Ley and Sugarman (1982) presented pleasant, neutral and unpleasant melodies to participants in a dichotic listening task. Emotional judgments were more accurate for presentations to the left ear than the right. The authors concluded that the right hemisphere is superior to the left hemisphere in processing affective features of music. However, a closer examination of this study reveals that this ear advantage differed depending on the affect of the melody presented to the unattended ear. The authors note the only support of the valence effect came from a comparison of the conditions in which the affect of the target and unattended stimuli were the same. Under these conditions the largest left ear advantage was observed with the negative stimuli, while the positive stimuli elicited a slight right ear advantage. Thus, congruency between the affect of the target and the unattended stimulus elicits results consistent with valence effect, while incongruency produces a left ear advantage consistent with the right hemisphere hypothesis. However, a review of the literature indicates that this is the only dichotic listening study that has demonstrated evidence for the valence effect with musical stimuli. Thus, it is possible that this finding is no more than a type one error.

Interestingly, when no stimulus is presented to the unattended ear, a monaural presentation, the valence effect has been observed using musical stimuli. Gagnon and Peretz (2000) presented melodies monaurally to participants in either an affective or non-affective classification task. Western listeners usually describe tonal melodies as pleasant and atonal melodies as unpleasant. In making these classifications listeners were quickest for tonal melodies presented to the right ear and atonal melodies presented to the left ear, a valence effect. In the non-affective control task, participants judged whether the same melodies sounded in key or out of key and no ear advantage was observed for this cognitive classification, indicating that the observed valence effect was specific to the emotional judgment. However, as noted, dichotic listening studies using similar approaches that include two discrete emotional units tend to support the right hemisphere hypothesis (Bryden et al., 1982; Leichner & Broscher, 1998). This study also challenges Kimura’s (1961) claim that dichotic listening is the only presentation procedure able to detect an ear advantage.

The difficulty in replicating the valence effect with auditory stimuli has become obvious in this review of the research. Gagnon and Peretz (2000) are the only researchers to demonstrate a valence effect with monaural presentation of melodies, and with only 16 participants in their affective judgment task. In a body of literature with so few reports of a significant effect despite a large number of studies, one must be careful not to place too great an importance on a single result. A lack of power in individual studies and publication bias favouring significant results, might mean that the few valence effects reported in the literature are simply type one errors (Open Source Collaboration, 2015). The general failure to replicate the valence effect reduces confidence in those studies reporting an effect. One must be skeptical of the existence of a valence effect until the effect can be reliably replicated.

Direction of attention

In addition to the features of the stimulus, the participants' direction of attention also affects ear advantages. Hugdahl and Andersson (1986) investigated the impact of attention on the right ear advantage for verbal stimuli. Participants listened to pairs of competing CV syllables presented dichotically under three conditions: a non-forced, free recall condition (i.e. focus on any ear); a forced-right ear condition (i.e. focus on the right ear); and a forced-left ear condition (i.e. focus on the left ear). In the non-forced condition, participants recalled more CV syllables presented to the right ear than the left. However, in the forced-right ear condition, significantly more CV syllables were recalled from the right ear than the left ear and the opposite effect occurred from the forced-left ear condition. The authors concluded that in addition to linguistic processing these ear advantages were due to the participants' direction of attention. Similarly, Jancke, Buchanan, Lutz, and Shah (2001) investigated the impact of attention on hemispheric activation from linguistic and prosodic features of words. One dichotic listening condition involved word detection while the other required emotional prosody detection. Irrespective of the task, fMRI indicated focusing attention to the left ear increased activation in the right auditory cortex, whereas focusing attention to the right ear increased activation in the left auditory cortex. Thus, hemispheric activity was enhanced in the opposite auditory cortex to the ear which participants directed attention and this activity did not depend on the feature of the stimulus being processed. Hugdahl et al. (2009) argue that the three forced attention conditions with dichotic presentation tap different cognitive processes: unforced attention results in lateralised perceptual processes, forced right attention taps attentional processes, and forced left attention taps executive cognitive control processes and not processing asymmetries. Altogether, these findings suggest that ear advantages and hemispheric activation depend on the direction of attention.

Importantly, a major difference between monaural, distractor noise, and dichotic listening is how an individual's attention is directed. In a monaural presentation, attention is solely directed to one ear with little conscious effect. In contrast, distractor noise and dichotic presentations involve focusing attention on the stimuli presented to one ear while ignoring the stimuli presented to the opposite ear. Thus, in these latter presentation conditions, individuals might be more inclined to switch attention from one ear to the other, particularly if explicit instruction is not given. One could argue that individuals are most likely to switch attention during dichotic presentation because of the difficulty of having to ignore a similar competing stimulus presented to the opposite ear. In contrast, individuals are more likely to automatically attend to the target stimulus with monaural and distractor noise presentations since only silence or an unrelated competing stimulus occurs at the opposite ear. Thus, one possibility for the discrepancies in findings in emotion laterality research, is that ear advantages observed from dichotic presentations might be an artefact of the direction of attention rather than hemispheric asymmetry. Thus, if ear advantages from dichotic presentation are used to measure emotion laterality effects, it is critical what instructions are given to participants so that any observed ear advantages can be attributed to hemispheric asymmetry rather than the direction of attention.

Monaural, distractor noise versus dichotic listening

The studies mentioned above led to the question of whether the presentation procedure leads to systematic emotion laterality effects. A thorough review of the literature suggests there has been no direct comparison of listening methods in emotion laterality research. However, some researchers have asked whether dichotic listening is the best method to measure laterality effects outside affective neuroscience. For instance, Hammond (2010) compared word recognition for monaural, distractor noise and dichotic listening. The monaural condition required participants to recognise words presented to each ear with no stimulus presented to the unattended ear. The distractor noise condition required participants repeat words presented to each target ear while a recording of babble from six human voices was presented to the unattended ear. Finally, the dichotic listening presentation consisted of competing words presented to both ears with three response procedures: free recall (of both words in any order), focused right ear recall (repeat the word heard in the right ear first) and focused left ear recall (repeat the word heard in the left ear first). In this study, there were no significant ear advantages in response accuracy in the monaural and distractor noise conditions. However, an overall right ear advantage occurred from dichotic presentation. Thus, when comparing monaural, distractor noise, and dichotic listening for word recognition, only dichotic listening elicited a significant ear advantage consistent with language processing in the left hemisphere.

In contrast to this behavioural comparison of presentation procedure, Stefanatos, Aguirre, Detre, and Wetmore (2008) investigated hemispheric activation of the human auditory cortex for speech stimuli comparing each listening method. Participants were required to distinguish between serially presented target and distractor consonant - vowel (CV) syllables presented monaurally to each ear, with a burst of distractor pink noise in the unattended ear, or in competition with CV syllables presented dichotically. Auditory regions of the left hemisphere were most activated from monaural presentations of CV syllables to the right ear. Right ear input presented monaurally resulted in twice as much activation in the left auditory cortex as right ear input during distractor noise and dichotic listening. In addition, dichotic listening produced the most variability in response accuracy and latency. The authors suggest that this variability reflects the greater demands and additional processes required for dichotic listening. It was concluded that dichotic listening is a complex task involving widely distributed neural networks and that hemispheric activation is most clearly established from monaural listening.

Thus, while dichotic listening elicits the strongest ear advantage in many situations, hemispheric activation is most clearly established from monaural listening. This reinforces the theme of this chapter that the behavioural consequences of the neural organisation of hemispheric specialisation can differ.

Summary and research focus

Overall, there is behavioural evidence consistent with the right hemisphere hypothesis and the valence effect from patients with brain damage and neurologically healthy individuals. Divided visual field studies using facial affect also demonstrate evidence for both hypotheses. In contrast, dichotic listening studies which have asked participants to classify the emotion conveyed by both spoken prosody and music have generally failed to find a valence effect and tend to support the right hemisphere hypothesis. Facial affect research demonstrates different laterality effects emerge from the presentation of single versus competing emotional stimuli consistent with the valence effect and right hemisphere hypothesis respectively. In reviewing listening research, dichotic listening studies tend to demonstrate that when one emotional unit is processed results are consistent with the valence effect, while two competing emotional units produce results consistent with the right hemisphere hypothesis. This makes it difficult to determine whether dichotic studies consistent with the right hemisphere hypothesis are the result of a true emotion effect or the unattended stimulus masking contributions from the left hemisphere. Interestingly, the clearest evidence of the valence effect in the listening literature comes from melodies presented monaurally, however this effect has never been replicated. Moreover, a valence effect has also been reported when a cigarette request was addressed to one ear and distracting background nightclub noise occurred in both ears. That these studies report evidence consistent with the valence effect and this effect is almost entirely absent from dichotic listening except for affect congruency makes it unclear whether ear advantages are consistent based on the listening method employed. Dichotic listening is the leading method to measure hemispheric asymmetry for auditory stimuli. Kimura (1961) strongly argues that dichotic listening is the only approach that ensures ipsilateral suppression to enhance the contralateral processing stream. However, ipsilateral suppression is asymmetric during dichotic stimulation with the right ear to left hemisphere route having a greater advantage than the left ear to right hemisphere route. While dichotic listening does appear to elicit the strongest ear advantage, neuroimaging research indicates that monaural listening is the best method to ensure the target hemisphere processes a stimulus. A thorough review of the literature suggests there has been no systematic comparison of listening methods to ensure they are a valid measure of emotional processing. This thesis acknowledges a complex account of the neural organisation of emotion. However, if researchers intend to use listening methods to determine the behavioural consequences of this neural organisation then a systematic study of processing the emotional aspects of auditory information is required. This thesis presents a comparison of each listening presentation procedure to determine whether consistent ear advantages arise when participants classify the non-emotional and emotional aspects of speech and music. If different ear effects emerge from each listening method, then this would demonstrate a measurement issue in listening research aimed at measuring emotional processing. If consistent ear effects emerge across each listening approach then this would validate dichotic listening as a tool to measure emotional processing.

Chapter 2. Processing emotional aspects of speech

The experiments reported in this chapter use speech stimuli to explore the best presentation procedure to measure how emotion plays a role in speech perception. Speech conveys emotion in two ways: the emotional content of speech, known as “lexical emotion”, and the emotional prosody with which it is spoken. The focus of this chapter is to determine the best presentation procedure to detect any hemispheric specialisation when individuals process these two emotional aspects of speech. To do so, the reported experiments will systematically vary the stimulus presented to the unattended ear while keeping the target stimuli the same. Importantly, the processing of any stimulus, especially speech, has both affective and non-affective components. An appropriate control task will be employed which requires processing a non-emotional aspect of speech to be confident that any observed differences are due to emotional processing. In addition, it is also necessary to equate the emotional valence and arousal of stimuli, monitor participants’ direction of attention and screen participants for differences in handedness and hearing sensitivity since these factors can moderate laterality effects. A more systematic investigation will help determine whether processing the emotional aspects of speech vary according to the methods featured in the listening literature. Since Chapter 1 reviewed hemispheric asymmetry for emotional prosody, this chapter introduces how individuals process lexical emotion.

How individuals process the emotional aspect of speech

It is well established that dichotic listening studies requiring participants to process the linguistic aspect of speech elicits a right ear advantage while processing emotional prosody elicits a left ear advantage (Bryden & MacRae, 1989; Haggard &

Parkinson, 1971; Hatta & Ayetani, 1985; Ley & Bryden, 1982; Safer & Leventhal, 1977; Saxby & Bryden, 1984; Voyer et al., 2008). However, much less research reports on how individuals process lexical emotion. Graves, Landis and Goodglass (1981) were the first to investigate hemispheric asymmetry in response to emotionally laden words using the divided visual field technique. When emotion words and non-emotion words were presented to participants in a lexical decision task, accuracy was superior for right visual field presentations than left in classifying all words. However, accuracy was greater for emotion words than non-emotion words for left visual field presentations than right. Thus, while processing all words was associated with the left hemisphere, processing lexical emotion was consistent with the right hemisphere hypothesis. However, eleven of the twelve emotion words used by Graves et al. were unpleasant in valence and only one was pleasant thus an over representation of unpleasant words may have contributed to this right hemisphere dominance.

Strauss (1983) replicated Graves, Landis and Goodglass' (1981) study with an equal number of pleasant and unpleasant words and did not observe any lexical emotion laterality effect. Instead, a right visual field advantage occurred for all words, indicating left hemisphere superiority in processing words regardless of the emotional content. However, other divided visual field studies have reported a valence effect for the recognition of emotion words. For example, Holtgraves and Felton (2011) compared participants' performance from a lexical decision task using pleasant and unpleasant words. Reaction times were faster for pleasant words presented to the right visual field and unpleasant words to the left visual field. Thus, like facial affect research, studies investigating lexical emotion perception using the divided visual field technique are also contradictory consistent with left hemisphere superiority in language processing, the right hemisphere hypothesis, and the valence effect.

In contrast to divided visual field research, there is barely any listening research on how individuals process lexical emotion in speech. In one dichotic listening study, Sim and Martinez (2005) presented pleasant and unpleasant words to one ear paired with a non-emotion word to the opposite ear all spoken in a neutral prosody. Following a simple arithmetic distraction task, participants were required to recall the dichotic word pairs. Participants recalled more non-emotion words presented to the right ear and more emotion words presented to the left ear, indicating left hemisphere superiority in language processing and processing lexical emotion consistent with the right hemisphere hypothesis. However, a thorough search of the literature suggests that the valence effect has not been equivalently demonstrated from dichotic listening research investigating lexical emotion perception. Thus, dichotic listening studies investigating how individuals process both lexical emotion and the emotional prosody of speech are generally consistent with left hemisphere superiority when linguistic processing is required and right hemisphere dominance for emotional processing. Before exploring why visual and auditory behavioural studies produce mixed results a contemporary review of scanning studies on lexical emotion perception will be provided.

Despite behavioural hemispheric asymmetries for lexical emotion perception, like facial affect and emotional prosody perception, contemporary scanning studies indicate bilateral processing of lexical emotion. Processing word semantics appears to be associated with enhanced activation in the left hemisphere, primarily the inferior frontal gyrus, and the left temporal and occipital regions (Beauregard et al., 1997; Nakic, Smith, Busis, Vythilingam & Blair, 2006). Emotion words also trigger other aspects of the left hemisphere, such as the amygdala, orbitofrontal cortex and posterior cingulate gyrus. Activity is however not confined to the left hemisphere with heightened activity in the right anterior cingulate cortex and dorsolateral prefrontal cortex also linked to the semantic processing of emotional content (e.g. Costafreda, Brammer, David, & Fu, 2008; Kuchinke et al., 2005; Luo et al., 2004). Abbassi, Kahlaoui, Wilson, and Joanette (2000) reviewed electrophysiological and neuroimaging studies on lexical emotion perception and concluded that neither the right hemisphere hypothesis nor the valence effect are sufficient explanations of the neural organisation of lexical emotion perception and this finding is consistent with scanning studies that indicate bilateral processing for facial affect and emotional prosody perception.

This chapter is however not concerned with which theory of hemispheric specialisation best explains the emotional processing of speech since both the right hemisphere hypothesis and the valence effect are too coarse as explanations of the neural organisation of emotion. Rather, why behavioural studies produce mixed results will be explored by determining whether methodological factors are systematically related to the observation of laterality effects. One possibility, already discussed, is that different ear advantages arise from differences in the stimuli presented to the unattended ear (Bryden et al., 1982; Gagnon & Peretz, 2000; Marzoli & Tommasi, 2009). Overall, it remains unclear whether the general left ear advantage from processing lexical emotion or emotional prosody is a consequence of right hemisphere superiority in emotion perception or simply an artifact of the listening method employed. Thus, Chapter 2 explores potential ear advantages when participants are asked to classify either lexical emotion or emotional prosody using monaural, distractor noise, and dichotic presentation. Regardless of the stimulus presentation, only one emotional unit will be presented per trial. This will help to determine whether ear advantages are consistent based on the listening method employed as well as which method best detects such effects.

Processing any emotionally laden stimulus

To determine the best presentation procedure to distinguish how individuals process the emotional aspects of speech, several methodological issues must be addressed. The first and perhaps the most difficult to address is that the processing of any stimulus, especially speech, has both affective and non-affective components. When words with emotional content are used to investigate the lateralisation of emotion, ear advantages will reflect both the processing of the linguistic features of speech (such as the syntactic and semantic features of an utterance) as well as the emotional content. Similarly, words differing in emotional prosody will convey both linguistic and prosodic features. It is also possible that all three components are present in an utterance and sometimes the three sources of information can even be contradictory, as in an ironic statement. To be confident that any observed ear advantages are due to lexical emotion or the emotional prosody of speech requires measuring these distinct processes separately as well as employing an appropriate control task that is not focused on processing the emotional aspect of the stimuli.

Employing an appropriate control task

One of the first dichotic listening studies to introduce an appropriate control task was that of Bryden and MacRae (1989) who presented non-emotional words that varied in emotional prosody. They observed a right ear advantage when participants focused on the non-affective aspect of words and a left ear advantage when a separate group of participants focused on the emotional prosody of the same words. Assigning participants to focus on a different attribute of the same stimuli (i.e. linguistic versus emotional prosody) increases confidence that observed ear advantages reflect a relative estimate of linguistic versus emotional processing. In contrast, Marzoli and Tommasi (2009) who reported a valence effect in response to verbal requests for a cigarette did not incorporate any appropriate control task. In their study, no comparable control condition was employed so it is not possible to conclude whether the right ear advantage in response to cigarette requests reflect left hemisphere superiority in language processing or positive appraisal predicted by the valence effect. Both studies highlight the importance of considering the relative contribution of affective and non-affective features of speech used to measure emotional processing and employing a comparable control condition to determine processing related to the emotional aspects of speech.

Equating the arousal of emotionally laden stimuli

What makes a stimulus affective relates not only to its emotional valence but also to how arousing a stimulus is. Arousal relates to the physiological and psychological intensity of a stimulus (Lang, Bradley, & Cuthbert, 1990). Importantly, arousal is thought to be associated more with right hemisphere processing than left (Heilman, Schwartz, & Watson, 1978; Heller, Nitschke & Lindsay, 1997). Moreover, unpleasant stimuli are often rated as more arousing than pleasant stimuli (Garavan, Pendergrass, Ross, Stein & Risinger, 2001). If unpleasant stimuli are more arousing than pleasant stimuli, an imbalance in the intensity of emotional valence may contribute to the right hemisphere dominance for negative stimuli and a reversal of the left hemisphere superiority for positive stimuli. This could result in masking contributions from the left hemisphere associated with processing pleasant emotions. Importantly, arousal levels have traditionally not been equated across conditions intended to measure emotion laterality effects. This makes it unclear whether differences in arousal between pleasant and unpleasant stimuli, rather than valence per se, contribute to hemispheric asymmetry.

In behavioural research investigating how individuals process the emotional aspects of speech, in divided visual field studies, Graves and Landis (1981) and Strauss (1983) did not equate the arousal of their emotion words and demonstrated right and left hemisphere laterality effects respectively. However, Holtgraves and Felton (2011) did equate the arousal of their emotion words and did demonstrate the valence effect. In dichotic listening studies, Bryden and MacRae (1989) and Sim and Martinez (2005) did not equate the arousal of emotional prosody or emotion words respectively and both reported right hemisphere dominance in processing these emotional aspects of words. However, Grimshaw et al. (2009) did equate the arousal of emotional prosody and did demonstrate evidence consistent with the valence effect. Thus, studies consistent with the valence effect generally tend to have equated the arousal of the stimuli. In the following experiments the arousal of the stimuli employed will be equated so that if any ear advantages are consistent with the right hemisphere hypothesis the effect is unlikely to be an artifact of the arousal produced by the stimuli.

Employing a forced attention paradigm

As noted in Chapter 1, in addition to the features of the stimulus, the participant’s direction of attention also impacts ear advantages. During typical forced attention dichotic presentation, participants are instructed to focus on a target dimension (i.e. the linguistic aspect of speech) presented to one ear and to ignore a competing stimulus (typically consisting of the same dimension) to the unattended ear. In the experiments reported in this thesis a forced attention paradigm will be employed, making the target ear explicit and thus keeping the instructions constant between the three stimulus presentation conditions. However, in contrast to the traditional forced attention paradigm, the target dimension (i.e. emotion) will only be apparent in one ear and either silence or a neutral unattended stimulus will occur in the unattended ear. If only one target dimension (i.e. one emotion) occurs irrespective of the presentation condition, participants will be less likely to switch their attention in dichotic or distractor noise conditions, because they should more easily attend to the target ear. If different ear advantages emerge from each presentation procedure, then any differences will reflect varying stimuli presented to the unattended ear rather than changes in a participant's direction of attention.

Screening participants' handedness

In addition to participants' attention, handedness is another factor that has not always been considered in laterality research. For most right-handed individuals (96%), language is predominately processed in the left cerebral hemisphere (Alfano & Cimino, 2008; Freburg, 2006; Gazzaniga, Ivry & Mangun, 2002; Rasmussen & Milner, 1977). In contrast, in left-handed individuals language processing seems to occur in the left hemisphere in approximately 70% while the remaining are equally split between right hemisphere dominance and bilateralised dominance (Rasmussen & Milner, 1977). Overall, left-handed individuals generally display more varied patterns of lateralisation than right-handed individuals. These differences create a potential confound in research investigating hemispheric asymmetry because ear advantages could reflect variations in lateralisation associated with handedness rather than hemispheric asymmetry. In the experiments reported in this chapter, only individuals who are right handed will be tested to ensure ear advantages reflect hemispheric asymmetry for each aspect of speech rather than variations in lateralisation associated with individuals’ handedness.

Screening participants’ hearing sensitivity

Finally, differences in hearing sensitivity are often an overlooked potential contributor to observed ear differences. Differences in hearing sensitivity between the ears is going to decrease an individual’s ability to recognise stimuli presented to the less sensitive ear. In addition, extra cognitive resources might be required to detect the task relevant feature of a stimulus presented to the less sensitive ear giving rise to apparent difference in speed and accuracy of task completion. A sound presented to the individual’s more sensitive ear could also be more arousing than the same sound presented to the less sensitive ear. If participants are not accurately screened for equal hearing sensitivity in both ears, ear advantages may be an artifact of these factors rather than hemispheric asymmetry. Surprisingly, many studies have failed to measure hearing sensitivity (e.g. Altenmuller, Schurmann, Lim & Parlitz, 2002; Bryden et al., 1982; Hatta & Ayetani, 1985; Ley & Bryden, 1982; Safer & Leventhal, 1977; Techentin, Voyer & Klein, 2009) or have relied on self-report measures (Rodway & Schepman, 2007). Self-report measures are unlikely to be an accurate measure of hearing sensitivity since individuals are often unaware that they have differences in hearing sensitivity (Bexelius et al., 2008). In the following experiments, only participants who have equal hearing sensitivity in both ears will be tested to ensure ear advantages reflect hemispheric asymmetry rather than differences associated with unequal hearing sensitivity.

Summary and current focus

While the classic right ear advantage from processing the linguistic aspect of speech is well established, ear advantages related to how individuals process the emotional aspects of speech are still unclear. Existing data from divided visual studies is consistent with both the right hemisphere hypothesis and the valence effect. However, dichotic listening research investigating lexical emotion and the emotional prosody of speech is almost always consistent with the right hemisphere hypothesis. It remains unclear whether the right hemisphere superiority in listening studies investigating how individuals process the emotional aspects of speech is a consequence of emotional processing or an artifact of the presentation procedure employed. The aim of this chapter is to determine whether consistent ear advantages arise when participants process the emotional aspects of speech and the stimulus to the unattended ear is systematically varied and which method best detects such effects. Comparing a non-emotional and an emotional classification will provide a relative estimate of linguistic versus emotional processing across each listening task. To ensure ear advantages reflect hemispheric asymmetry rather than other factors known to moderate ear advantages the following experiments will use stimuli equated in arousal, employ a focused attention paradigm, and screen all participants for handedness and hearing sensitivity. Experiment 1 investigates ear advantages in response to linguistic versus lexical emotion spoken without any emotional prosody. Experiment 2 investigates ear advantages in response to making a classification of emotional prosody.

Experiment 1

Experiment 1 directly compared ear advantages in response to linguistic and lexical emotion classifications across each listening procedure. To distinguish between linguistic and lexical emotion processing, words were selected on the basis that participants could make a non-emotional and emotional classification. The non-emotional classification required determining whether each word was a “noun” or an “adjective”. The emotional classification required determining whether each word was “pleasant” or “unpleasant”. Thus, participants were separately assigned to make either a non-affective or affective classification to provide a relative estimate of linguistic versus lexical emotion processing.

The three stimulus presentations included *monaural* (only silence occurred in the unattended ear), *distractor noise* (pink noise presented to the unattended ear), and *dichotic* (a competing word presented to the unattended ear). The stimuli presented to the target ear varied in emotional valence, while the affect of stimuli presented to the unattended ear was neutral in emotional valence to ensure that only one discrete emotion was processed per trial (Prete et al., 2015).

The distractor noise condition was a laboratory analog of the background noise of a nightclub as in the Marzoli and Tommasi (2009) study. Pink noise was presented because it is less aversive than white noise thus less likely to interact with the valence of the target stimulus (Stefanatos et al., 2008). Being broadband noise pink noise spans the frequency range of the target words. In the dichotic presentation condition, words that were neutral in valence were presented to the unattended ear similar to the approach adopted by Sim and Martinez (2005).

Most behavioural research has used differences in response time and accuracy between the left and right visual field or the left and right ear as an index of laterality effects **(**Bryden and MacRae, 1989; Graves & Landis, 1981; Holtgraves & Felton, 2011; Sim & Martinez, 2005, Strauss, 1983**)**. In listening studies, response accuracy is deemed an appropriate measure of hemispheric specialisation because if one hemisphere (i.e. the left hemisphere) is superior in processing a specific emotional valence (i.e. pleasant words) then more target words containing that emotional valence should be accurately detected when presented to the contralateral ear (i.e. the right ear). Similarly, if one hemisphere is superior to processing a specific emotional valence, then response times should be quicker when words containing that emotional valence are presented to the contralateral ear.

Predictions

In the non-affective control task, since language is predominately processed in the left cerebral hemisphere, the time taken to classify the non-emotional aspect of words (noun or adjective) should be quicker in the right ear compared to the left ear. In addition, response accuracy to classify these words should be greater in the right ear than the left ear (Bryden & MacRae, 1989; Sim & Martinez, 2005).

In the affective classification task, if ear advantages are consistent with the right hemisphere hypothesis, the time taken to affectively classify the words should be quicker in the left ear than the right regardless of the valence of the word. In addition, the number of correctly classified words should be greater in the left ear compared to the right (Bryden & MacRae, 1989; Sim & Martinez, 2005). On the other hand, if ear advantages are consistent with the valence effect, the pleasant words should be appraised faster than the unpleasant words when presented to the right ear and the opposite effect should occur when the same words are presented to the left ear. In addition, response accuracy should be greater when the pleasant words are presented to the right ear and unpleasant words are presented to the left ear (Holtgraves & Felton, 2011; Grimshaw et al., 2009).

Regarding the three stimulus presentation conditions, Kimura (1964) suggested that stimuli must be presented dichotically to obtain an ear advantage. Should this be the case, dichotic presentation should produce the strongest ear advantage compared to monaural and distractor noise. Since most emotion laterality research using dichotic listening supports the right hemisphere hypothesis (e.g. Bryden et al., 1982; Haggard & Parkinson, 1971; Hatta & Ayetani, 1985; Ley & Bryden, 1982; Safer & Leventhal, 1977; Saxby & Bryden, 1984; Sim & Martinez, 2005), it is possible that an overall left ear advantage will occur when participants make an emotional classification of words and a burst of pink noise or a competing word is presented to the unattended ear. However, the valence effect has been reported in studies where participants processed one discrete emotion per trial (e.g., Bryden et al., 1982; Gagnon & Peretz, 2000; Prete et al., 2015). If this is a critical condition for the demonstration of a valence effect then one would expect to see a valence effect in the distractor pink noise and dichotic presentation conditions. Finally, since Gagnon and Peretz (2000) found evidence for the valence effect from monaural listening using musical stimuli it is also possible that a valence effect could occur when no stimulus is presented to the unattended ear. Any differences between monaural, distractor noise (i.e. pink noise) and dichotic (i.e. words) procedures will be due to the unattended stimulus.

Thus, a right ear advantage for classifying words in the non-affective classification task irrespective of what is presented to the unattended ear is predicted. In the affective classification task, evidence to support the valence effect during monaural listening and evidence for either the right hemisphere hypothesis or the valence effect during the distractor noise and dichotic presentations is expected to be found.

Method

Design

Experiment 1 was a 2 (Attended Ear) x 2 (Valence) x 3 (Stimulus Presentation) x 2 (Classification Task) mixed factorial design with the classification task (affective or part of speech judgement) the only between subjects factor.

Participants

Seventy-four undergraduate psychology students volunteered for Experiment 1. All were native English speakers. Eligible students received nominal course credit in exchange for their participation. The sample size was determined based on previous literature that has used between 16 and 90 participants and demonstrated significant emotion laterality effects (Bryden et al., 1982; Gagnon & Peretz, 2000; Grimshaw et al., 2009; Prete et al., 2015). Given the practical constraints of recruiting participants from a limited participant pool, a sample size in the middle of this range was considered appropriate. Approval to recruit these participants was granted by the James Cook University Experimental Ethics Review Committee (approval number H3678).

Participant screening

Participants were screened for handedness and discrepancies in hearing sensitivity between their ears.

Handedness: To ensure ear advantages reflected hemispheric asymmetry for each aspect of speech rather than variations in lateralisation associated with differences in handedness, only right-handed individuals were tested (Bourne, 2006;

Pujol, Deus, Losilla & Capdevila, 1999). Handedness was measured using the Edinburgh Handedness Inventory (Oldfield, 1971; see Appendix A). This inventory includes a list of 10 activities such as handwriting, using scissors, and tooth brushing. Participants who reported using the same hand for eight or more tasks were classified as strongly dominant for that hand. Participants who were left hand dominant were excluded from subsequent data analysis.

Between ear hearing discrepancies: An abridged hearing test from Digital Recordings Online Digital Audiometer Professional version 6.2 was used to measure hearing sensitivity in each ear to 500 Hz, 1 kHz, 3 kHz, and 5 kHz tones. Participants with a difference between their left and right ear of more than 10 dB at any of these tested frequencies were also excluded from subsequent data analysis.

Following screening, seven participants were excluded due to differences in hearing sensitivity between the left and right ear, and four for being strongly left handed. Participants who met the inclusion criteria were randomly assigned to either the affective or non-affective classification task. Thus 38 participants (32 female) ranging in age from 17 to 53 years ($M = 26.4$, $SD = 8.7$ years) undertook the affective task while the non-affective group consisted of 36 participants (28 female) with an age range of 17 to 54 years ($M = 26.3$, $SD = 9.3$ years).

Materials

Stimuli

A pilot study was conducted to determine the valence and arousal of a set of nouns and adjectives of which the emotional content was intended to be pleasant or unpleasant. Initially, one hundred and ten words spoken in a neutral prosody were generated from the software program Text Aloud with the voice named “Lee22

(Australian English)" (Nextup Technologies, 2000-2016). Fifteen participants (11 female) ranging in age from 17 to 22 years (*M* = 19.3, *SD* = 5.1) rated each word using the Semantic Differential Scale that was developed to determine the valence and arousal of stimuli (Mehrabian & Russell, 1974). Participants selected a number between one and five that best suited each word for 10 pairs of descriptors (e.g. "Arousing" or "Soothing", "Happy" or "Sad": see Appendix B). Participation in the pilot study took approximately 50 minutes.

Data from the Semantic Differential Scale was analysed using Multidimensional Scaling that resulted in two dimensions: valence (pleasant and unpleasant) and arousal (low and high). From this analysis 16 pleasant and 16 unpleasant words were selected to be the target words for the affective classification task. In addition, 16 words neutral in emotional valence were selected to be the unattended words for the dichotic presentation condition. In order to include a non-affective comparative (control) task half of all word sets were nouns while the other half were adjectives. Each word set was matched for word frequency, emotional valence, and arousal. For example, the valence of each pleasant word (e.g. angel, puppy, loving, and cuddly) was a minimum of 0.6 (pleasant nouns: *M* = 0.9, *SD* = 0.2; pleasant adjectives: *M* = 0.8, *SD* = 0.2). The valence of each unpleasant word (e.g. hatred, coffin, jealous, and spiteful) was a minimum of -0.6 (unpleasant nouns: *M* = -0.9, *SD* = 0.3; unpleasant adjectives: *M* = -0.8, *SD* = 0.2). The valence of a neutral word (e.g. beetroot, baboon, brittle, and patchy) ranged within plus or minus 0.3 (neutral nouns: *M* = 0.2, *SD* = 0.2; neutral adjective: *M* = 0.0, *SD* = 0.1). For a full list of the stimulus set please refer to Appendix C. The duration of each word was approximately 600 ms at a peak sound-pressure level of 60 dB measured at the headphones.

Distractor stimuli

The competing unattended stimuli differed between conditions. For the distractor noise presentation procedure, a 600 ms burst of pink noise was presented to the unattended ear each time a target word occurred. For the dichotic procedure, each time a target word occurred one of the neutral words was presented to the unattended ear. In both cases, the distractors were presented at the same peak sound-pressure level as the target words (60 dB). In the monaural condition, no sounds were presented to the unattended ear.

Apparatus

A custom PsyScope X (Cohen, MacWhinney, Flatt, & Provost, 1993; Bonatti, n.d.) script that controlled stimulus presentation and data recording was utilised. Responses were made on a toggle switch connected to an ioLab USB button box which timed responses to an accuracy of ±1 ms. Stimuli were presented via sound-occluding headphones (Sennheiser HDA200).

Procedure

Participants were tested individually, in a dimly lit sound-attenuated room. Each participant first completed the Handedness Questionnaire and the hearing test. Right-handed individuals with equal hearing sensitivity in each ear were then randomly allocated to the affective or the non-affective (control) task.

The presentation procedure was the same for each task other than the response instructions. The target words were presented in six blocks of 32 trials so that all pleasant and unpleasant (noun and adjective) words occurred in each block. The six blocks consisted of the three stimulus presentation conditions (monaural, distractor noise and dichotic) with each presented once to each ear. The order of blocks varied randomly between participants. The order of stimulus presentation varied randomly within each block.

Participants assigned to the affective task were asked to classify each word as pleasant or unpleasant by pushing a toggle switch up for “pleasant” or down for “unpleasant”. In the non-affective task participants were asked to classify the same words as a noun or an adjective by pushing the toggle switch up to indicate a “noun” or down for an “adjective”. The hand they responded with varied randomly between blocks of trials to control for hand of response influencing any observed asymmetries.

In the monaural presentation condition, each word was presented one at a time to the target ear with only silence in the unattended ear. In the distractor noise presentation condition, the same words were presented to the target ear, however each time a word occurred, a burst of pink noise occurred in the unattended ear. In the dichotic presentation, the same target words were presented to a target ear, however each time a word occurred, a neutral distractor word occurred in the opposite ear. Participants were instructed to concentrate on the target ear and to ignore their other ear. Below is an example of the instructions given in a block of trials in the dichotic condition:

> *You will be presented with a number of words to your LEFT ear. You will also hear words in your right ear. Just ignore this and concentrate on your LEFT ear ONLY. After each word please indicate whether it was pleasant or unpleasant as quickly as you can. If the word was pleasant press the black button “UP”. If the word was unpleasant press the black button “DOWN”. Please use your LEFT hand ONLY.*

The instructions were identical for the equivalent non-affective task except “pleasant” was replaced with “noun” and “unpleasant” with “adjective”.

The total duration of testing was approximately 30 minutes.

Results

Mean response times to “correct” responses were calculated for each participant in each condition. In the affective task classifying a pleasant word as pleasant or an unpleasant word as unpleasant was deemed a correct response. Similarly, in the non-affective task a correct response was to classify a noun as a noun and an adjective as an adjective. Participants who correctly classified at least 50% of trials in a condition were included in the analysis. Any response times that differed by more than 2.5 standard deviations from the mean were trimmed to that level (c.f. Tabachnick & Fidell, 2001). Response latency is reported in milliseconds and response accuracy as percentage of correct responses.

Initially a 2 (Attended Ear) x 2 (Valence) x 3 (Stimulus Presentation) x 2 (Classification Task) MANOVA was conducted to compare responses across stimulus presentations and control for any assumptions of sphericity. A set of follow-up 2 x2 x 2 MANOVAs was then conducted on each stimulus presentation to facilitate comparisons with previous research. An alpha level of .05 was adopted in all statistical tests.

Response Time

In the overall response time analysis, there was a significant main effect of stimulus presentation, Wilks λ= .68, $F_{(2, 46)}$= 10.40, p<.001, η_p^2= .31. Participants responded quickest during monaural listening (M = 962 ms, SD = 140 ms) followed by distractor noise (M = 987 ms, SD = 154 ms) and dichotic listening (M = 1020 ms, SD = 140 ms), consistent with reaction time increasing because of the complexity of the competing unattended stimulus (see Figure 1). No other main effects were significant (see Appendix D for a summary of the analyses).

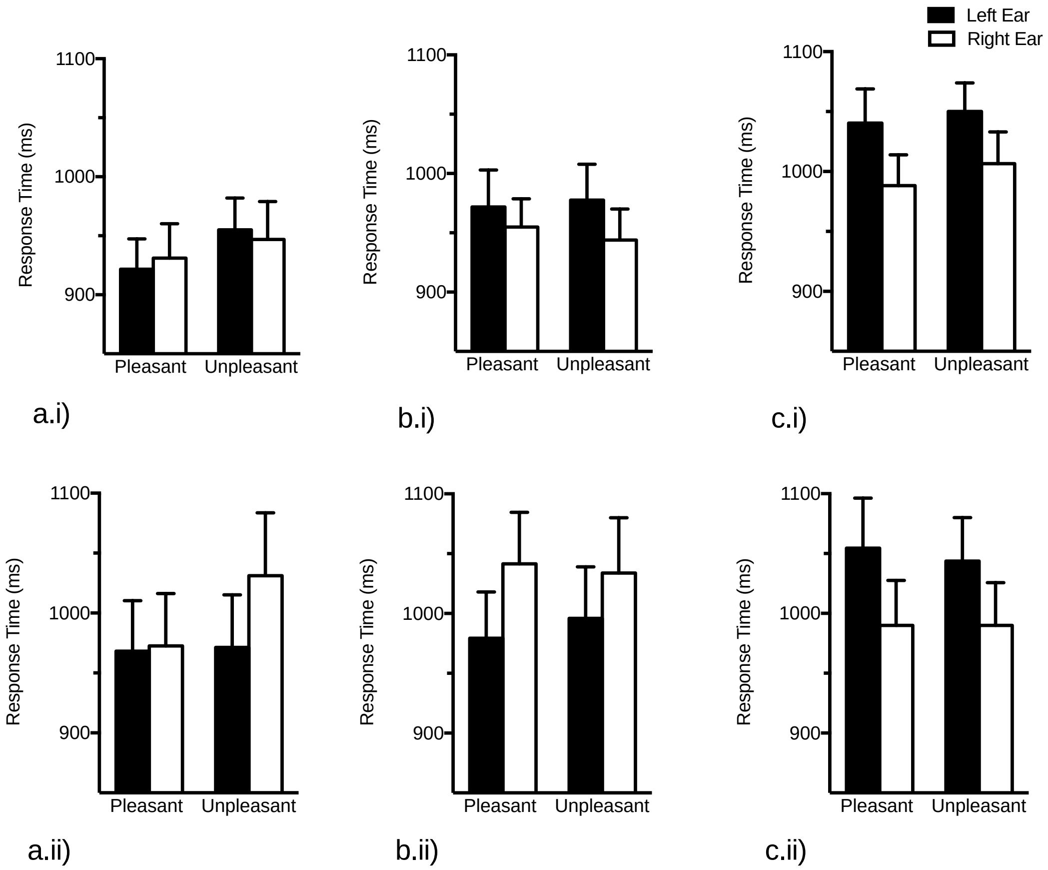

Figure 1. Mean response times (SEM) to correctly classify words to the left and right ear during monaural (a) distractor pink-noise (b) and dichotic (c) presentations in the affective (i) and non-affective (ii) classification task.

The only significant interaction in the overall response time MANOVA was between the ear of presentation and the stimulus presentation, Wilks λ= .80, $F_{(2, 46)}$= 5.70, p<.001, η_p^2= .19. As can be seen in Figure 2, participants responded faster when words were presented to the right ear (M = 993 ms, SD = 147 ms) than the left ear (M = 1047 ms, SD = 147 ms) during dichotic presentation. No other effects or interactions were significant (see Appendix D).

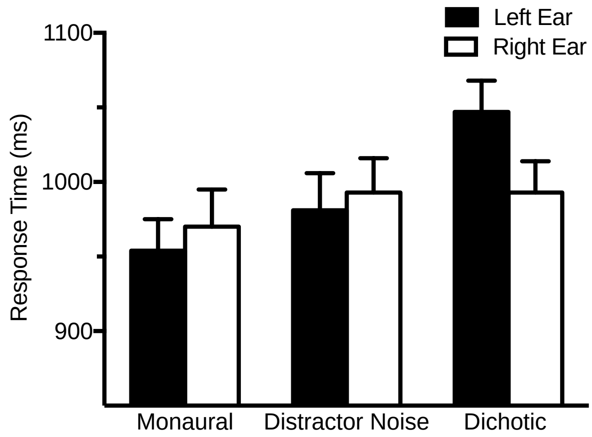

Figure 2. Mean response times (SEM) to correctly classify words to the left and right ear during monaural, distractor pink-noise, and dichotic presentation collapsed over the affective and non-affective classification task.

Monaural presentation

In the monaural listening presentation, overall participants' response times did not differ for words presented to the left ear (*M* = 954 ms, *SD* = 147 ms) and the right ear (*M* = 970 ms, *SD* = 175 ms), Wilks λ= .98, $F_{(1, 47)}$= 0.54, *p*=.46, η_p^2= .01, (see Figure 1a). The ear of presentation and classification task interaction, Wilks λ= .98, $F_{(1, 47)}$= 0.50, *p*=.48, η_p^2= .01, and the ear of presentation, classification task, and emotional valence interaction, Wilks λ= .93, $F_{(1, 47)}$= 3.49, *p*=.06, η_p^2= .06, were both not significant. Thus, the predictions that non-affective classifications would elicit a right ear advantage from language processing and affective classifications an ear advantage consistent with the valence effect were not supported. However, participants did respond significantly more quickly to pleasant words (*M* = 948 ms, *SD* = 140 ms) compared to unpleasant words (*M* = 976 ms, *SD* = 147 ms), Wilks λ= .83, $F_{(1, 47)}$= 9.05, *p*<.001, η_p^2= .16, indicating that pleasant words may have been easier to classify than unpleasant words. No other effects or interactions were significant (see Appendix D).

Noise to the unattended ear

When the same words were presented with pink noise in the unattended ear, no significant main effects or interactions occurred (see Figure 1b and Appendix D). Thus, the predicted right ear advantage from non-affective classifications of words or ear advantages consistent with the right hemisphere hypothesis or the valence effect from affective classifications of the same words did not emerge when a burst of pink noise occurred in the unattended ear.

Dichotic presentation

When participants made the same classifications under dichotic presentation, they responded faster when the target words were presented to the right ear (M = 993 ms, SD = 147 ms) compared to the left ear (M = 1047 ms, SD = 147 ms), Wilks λ= .76, $F_{(1, 47)}$= 14.88, p<.001, η_p^2= .24, (see Figure 1c) regardless of the task. This right ear advantage did not differ by the classification required, Wilks λ= .99, $F_{(1, 47)}$= .16, p=.68, η_p^2= .00, or the valence of the word, Wilks λ= .99, $F_{(1, 47)}$= .36, p=.55, η_p^2= .00. No other effects or interactions were significant (see Appendix D).

Summary

Overall, no ear advantage occurred in response time to classifying words presented monaurally or when distracting pink noise was presented to the unattended ear. During dichotic presentation, participants classified words quickest when they were presented to the right ear compared to the left irrespective of an emotional or part of speech classification required. These results support the contention that dichotic listening is superior to monaural and distractor noise presentation in eliciting an ear advantage in response time when classifying either the linguistic or lexical emotion aspect of words.

Response Accuracy

Like the overall response time analysis, there was a significant main effect of presentation procedure, Wilks λ= .89, $F_{(2, 71)}$= 4.13, p=.02, η_p^2= .10. Participants were most accurate during monaural (*M* = 92 %, *SD* = 6 %), and slightly less during distractor noise (*M* = 91 %, *SD* = 6 %) and dichotic presentations (*M* = 89 %, *SD* = 9 %) indicating that the complexity of the competing stimulus made the task more difficult (see Figure 3). There was a significant difference in accuracy between the tasks, $F_{(1, 71)}$= 10.14, p<.001, η_p^2= .12, with greater accuracy in the affective (*M* = 93 %, *SD* = 8 %) than the non-affective task (*M* = 89 %, *SD* = 8 %). Accuracy was also significantly greater for pleasant words (*M* = 92 %, *SD* = 5 %) than unpleasant words (*M* = 89 %, *SD* = 6 %), Wilks λ= .75, $F_{(1, 72)}$= 23.27, p<.001, η_p^2= .24, regardless of the classification task. However, there was also a significant interaction between the classification task and word valence, Wilks λ= .56, $F_{(1, 72)}$= 56.17, p<.001, η_p^2= .43, where accuracy was similar for pleasant words during affective (*M* = 92 %, *SD* = 8 %) and non-affective (*M* = 93 %, *SD* = 8 %) classifications while unpleasant words were more accurately classified in the affective (*M* = 94 %, *SD* = 9 %) than the non-affective (*M* = 85 %, *SD* = 9 %) task.

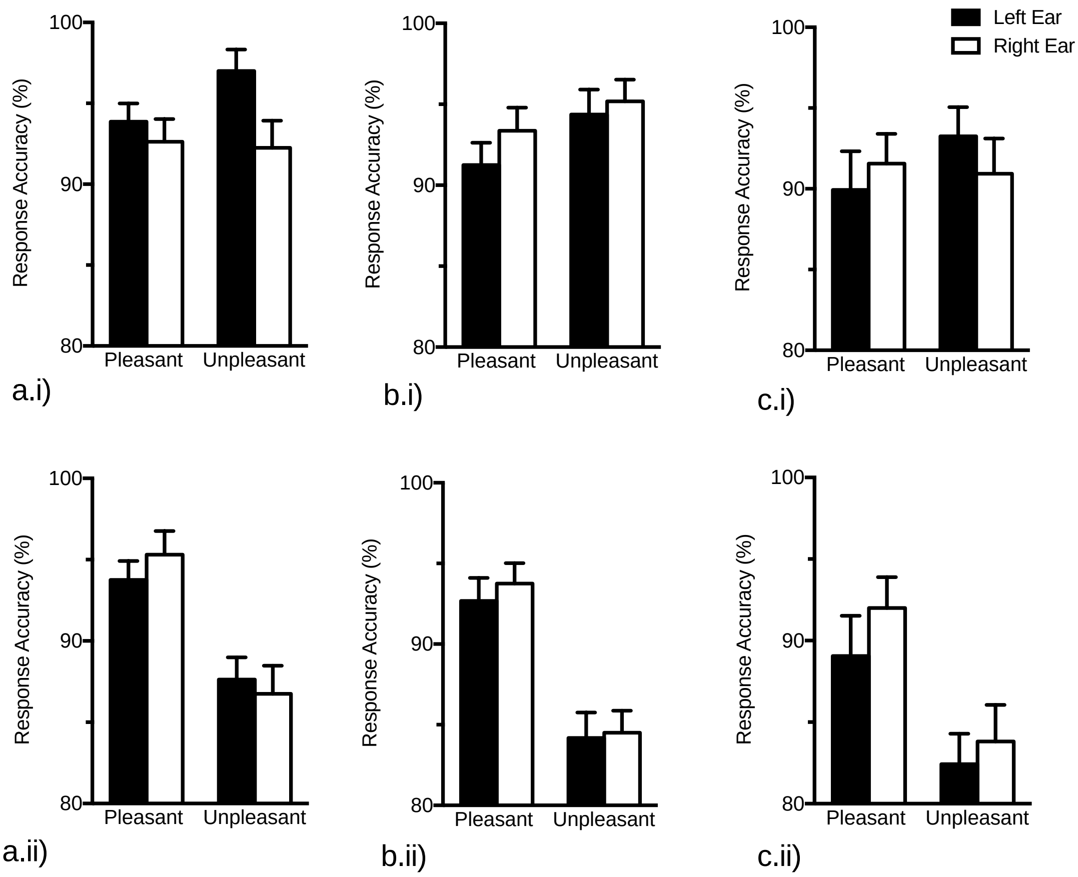

Figure 3. Mean response accuracy (SEM) to correctly classify words to the left and right ear during monaural (a) distractor pink-noise (b) and dichotic (c) presentations in the affective (i) and non-affective (ii) classification task.

In the overall response accuracy analysis, there was a significant interaction between the ear of presentation and the valence of the words, Wilks λ= .93, $F_{(1, 72)}$= 5.44, p=.02, η_p^2= .07. Response accuracy was greatest for pleasant words presented to the right ear (M = 93 %, SD = 6 %) and least for unpleasant words presented to the same ear (M = 89 %, SD = 8 %, see Figure 4). No other main effects or interactions were significant in this analysis, and thus this right ear advantage is independent of stimulus presentation procedure or classification task (see Appendix D).

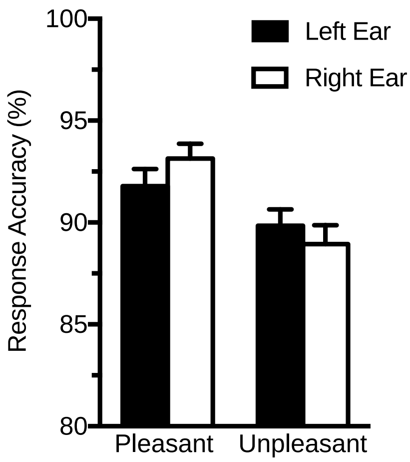

Figure 4. Mean response accuracy (SEM) for pleasant and unpleasant words to the left and right ear collapsed over the three stimulus presentation conditions and classification tasks.

Monaural presentation

During monaural listening, there was a significant interaction between the ear of presentation and the valence of the words, Wilks λ= .91, $F_{(1, 72)}$= 6.58, p=.01, η_p^2= .08. As can be seen in Figure 5, accuracy for unpleasant words was less in the right ear (*M* = 90 %, *SD* = 10 %) than the left ear (*M* = 94 %, *SD* = 8 %) while accuracy did not differ between the left ear (*M* = 94 %, *SD* = 7 %) and the right ear (*M* = 94 %, *SD* = 10 %) for pleasant words. The ear of presentation, word valence, and classification task interaction was not significant, Wilks λ= .99, $F_{(1, 72)}$= 0.25, p=.61, η_p^2= .00, indicating that the reduced performance for classifying unpleasant words when presented to the right ear occurred irrespective of classification task.

In addition, participants were more accurate when making affective classifications (*M* = 94 %, *SD* = 9 %) than non-affective classifications (*M* = 91 %, *SD* = 9 %), $F_{(1, 72)}$= 4.60, p=.03, η_p^2= .06 (see Figure 3a). Accuracy was also better for pleasant words (*M* = 94 %, *SD* = 6 %) than unpleasant words (*M* = 91 %, *SD* = 8

%), Wilks λ= .82, $F_{(1, 72)}$= 15.34, p<.001, η_p^2= .17. There was a signification interaction between classification task and word valence, Wilks λ= .69, $F_{(1, 72)}$= 31.82, p<.001, η_p^2= .30. Accuracy was greater for pleasant words (*M* = 95 %, *SD* = 9 %) than unpleasant words (*M* = 87 %, *SD* = 11 %) for non-affective classifications, while accuracy differed less between pleasant (*M* = 93 %, *SD* = 11 %) and unpleasant (*M* = 95 %, *SD* = 11 %) words for affective classifications.

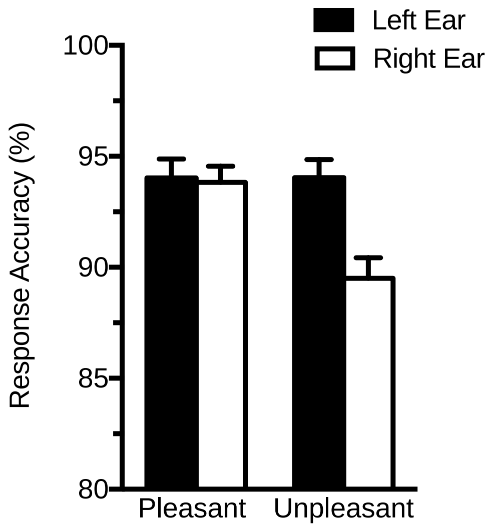

Figure 5. Mean response accuracy (SEM) for pleasant and unpleasant words to the left and right ear during monaural presentation collapsed over the classification task.

Noise to the unattended ear

Like monaural listening, when words were presented with pink noise in the unattended ear, accuracy was significantly greater when subjects classified the emotional content of the words (*M* = 94 %, *SD* = 9 %) than part of speech (*M* = 89 %, *SD* = 9 %), $F_{(1, 72)}$= 10.73, p<.001, η_p^2= .13 (see Figure 3b). In addition, accuracy was greater for pleasant words (*M* = 93 %, *SD* = 7 %) than unpleasant words (*M* = 90 %, *SD* = 8 %), Wilks λ= .85, $F_{(1, 72)}$= 12.43, p<.001, η_p^2= .14. Like monaural listening, there was a significant interaction between classification task and word valence, Wilks λ= .64, $F_{(1,72)}$= 39.05, p<.001, η_p^2= .35. Accuracy was greater for pleasant words (M = 93 %, SD = 10 %) than unpleasant words (M = 84 %, SD = 11 %) for non-affective classifications, while accuracy differed less between pleasant (M = 92 %, SD = 10 %) and unpleasant (M = 95 %, SD = 11 %) words for affective classifications. Otherwise, no other main effects or interactions were significant (see Appendix D).

Dichotic presentation

For dichotic listening, accuracy was also greater in the affective task (M = 91 %, SD = 13 %) than the non-affective task (M = 87 %, SD = 13 %), $F_{(1, 72)}$= 4.52, p=.03, η_p^2= .05 (see Figure 3c). Accuracy was also greater for pleasant words (M = 91 %, SD = 10 %) than unpleasant words (M = 88 %, SD = 10 %), Wilks λ= .86, $F_{(1, 72)}$= 11.66, p<.001, η_p^2= .13. Again, there was a significant interaction between the classification task and word valence, Wilks λ= .75, $F_{(1, 72)}$= 23.98, p<.001, η_p^2= .25 demonstrating greater accuracy for pleasant words (M = 91 %, SD = 14 %) than unpleasant words (M = 83 %, SD = 14 %) for non-affective classifications, while accuracy was similar for pleasant (M = 91 %, SD = 13 %) and unpleasant (M = 92 %, SD = 14 %) words from affective classifications. No other main effects or interactions were significant (see Appendix D).

Summary

Monaural presentation was the only procedure that reliably elicited a difference between the ears in response accuracy: unpleasant words were classified less accurately when presented to the right ear than the left irrespective of the classification task while there was no ear effect for pleasant words regardless of the task. In contrast only the dichotic presentation elicited an ear advantage in response times however this overall right ear advantage was also independent of the task or the content of the words. Thus, there was no evidence of presentations of emotion words to either ear from any stimulus presentation condition resulting in superior processing of lexical emotion consistent with the right hemisphere hypothesis or the valence effect.

Discussion

The objective of Experiment 1 was to determine what ear advantages would emerge when participants classified linguistic or lexical emotion in three presentation procedures. The results demonstrate that ear advantages can occur from both monaural and dichotic presentations, however the ear advantages observed are inconsistent. In the non-affective classification task, it was expected that left hemisphere superiority in language processing would elicit a right ear advantage irrespective of the stimulus presentation condition. A right ear advantage in response time did occur however only from dichotic presentation and this ear advantage was independent of whether participants made an affective or part of speech classification. The most obvious interpretation for this right ear advantage is left hemisphere superiority in language processing (Kimura, 1961; Bryden, 1988; Strauss, 1983). While an affective and non-affective classification task was employed to distinguish linguistic from lexical emotion this right ear advantage for both emotional and part of speech classification is likely to be due to language swamping contributions of emotional processing.

For the affective classification task, the right hemisphere hypothesis would predict an overall left ear advantage for affective classifications irrespective of the emotional valence of words while the valence effect would predict a right ear advantage for pleasant words and the opposite effect for unpleasant words. There was no evidence of classifying lexical emotion from any stimulus presentation condition consistent with the right hemisphere hypothesis or the valence effect. However, when no stimulus was presented to the unattended ear, as in monaural presentation, unpleasant words were classified less accurately when presented to the right ear than the left. However, this reduced performance for unpleasant words was independent of whether an emotional or part of speech classification was required. Therefore, it cannot be attributed to making an emotional classification of these items.

In addition to the reported ear advantages, reaction time increased while accuracy decreased with the complexity of a competing stimulus to the unattended ear. While this result is not surprising it does mean that dichotic listening studies are collecting data under conditions which participants find more difficult than monaural or distractor presentations. However, in the current experiment participants' performance differed only marginally between the stimulus presentations procedures (e.g. 58 ms difference between monaural and dichotic). In addition, response times also differed according to the emotional valence of the words depending on the stimulus presentation procedure. For monaural listening, participants responded quicker to pleasant words than unpleasant words. This result is not surprising since performance for pleasant stimuli is typically faster than unpleasant stimuli (Osgood & Hoosain, 1983; Schneider, Bunch & Kerutis, 1992). However, this difference was not found during distractor noise or dichotic presentations where no differences emerged in response time for pleasant and unpleasant words. If the presence of a competing stimulus to the unattended ear increased task difficulty this may have eliminated differences in performance for pleasant and unpleasant items in these conditions.

Regarding the classification task, there were no differences in the time it took participants to make an affective versus non-affective classification across the three stimulus presentation conditions. However, regardless of the stimulus presentation, participants were better at classifying words as pleasant or unpleasant than distinguishing nouns from adjectives. Moreover, despite equating each word set for frequency, emotional valence and arousal, accuracy was hindered most when classifying the unpleasant nouns and adjectives in the non-affective task regardless of the stimulus presentation condition. Thus, response times to pleasant and unpleasant words differed only from monaural presentation, whereas accuracy for classifying words was contingent on the emotional valence of the word and the classification required; a finding that was consistent across the three stimulus presentation conditions.

Experiment 1 demonstrates both monaural and dichotic presentation can elicit an ear advantage, however the ear advantages are inconsistent. Since the stimulus presented to the unattended ear was the only factor to differ, it is difficult to interpret these ear advantages with confidence as laterality effects. One explanation for different ear effects from monaural and dichotic presentation is asymmetric ipsilateral suppression from dichotic stimulation. Fujiki et al. (2002) demonstrated that dichotic listening elicits a pathway asymmetry effect; when competing stimuli are presented dichotically, the left hemisphere elicits greater hemispheric activation from right ear input than the right hemisphere does from left ear input. If the left hemisphere demonstrated greater activation from all words presented to the right ear, the overall right ear advantage in response time to classifying both linguistic and lexical emotion might be partly due to asymmetric ipsilateral suppression. Response times were best for all right ear presentations than left only from dichotic listening while a distinct difference in response accuracy emerged from monaural presentation between the left and right ear for all unpleasant words. Thus, one explanation for different ear advantages between monaural and dichotic listening is asymmetric ipsilateral suppression from dichotic stimulation showing a bias to all right ear items.

Experiment 1 indicates that different ear advantages are associated with the presence or absence of a stimulus to the unattended ear. In light of this, Experiment 2 explored what behavioural consequences emerged when individuals classify emotional prosody without semantics and the stimulus to the unattended ear is systematically varied as in Experiment 1.

Experiment 2

Experiment 1 compared ear advantages from monaural, distractor noise and dichotic presentation when participants classified linguistic versus lexical emotion. Given that inconsistent ear advantages emerged depending on the stimulus presented to the unattended ear, it is difficult to interpret these results as a true estimate of laterality effects. One limitation of using linguistic stimuli to investigate hemispheric asymmetry for lexical emotion is that the left hemisphere superiority for language processing might have swamped contributions of emotional processing. A further complication is that asymmetric ipsilateral suppression from dichotic stimulation is also associated with the left hemisphere. This is especially relevant since a right ear advantage emerged in response time for each aspect of speech during dichotic stimulation while accuracy was reduced for unpleasant words presented to the right ear with monaural listening also from each aspect of speech. It is still unclear to what extent these ear advantages reflect linguistic versus lexical emotion processing or the stimulus presented to the unattended ear. To further explore ear advantages associated with emotional processing from each presentation procedure it may be more useful to remove the linguistic aspect of speech and strictly focus on emotional prosody.

Several studies have employed low-pass-filtered stimuli to isolate the emotional prosody of speech from semantic or syntactical information (Bowers, Coslett, Bauer, Speedie, & Heliman, 1987; Pell & Baum, 1997; Ross, Thompson, & Yenkosky, 1997). When a stimulus is low-pass filtered, it no longer contains any coherent semantic or syntactic information. Under such circumstances, participants only process the emotional prosody of speech. Removing the linguistic aspect of speech leaving only emotional prosody is associated with greater performance to repeat and comprehend emotional prosody in individuals with left hemisphere brain damage than right consistent with right hemisphere superiority in processing emotional prosody (Heilman, Bowers, Speedie, & Coslett, 1984; Ross, Thompson, & Yenkosky, 1997). Applying a low pass filter to words with emotional prosody might eliminate laterality effects associated with linguistic processing which seem evident in Experiment 1. It would also shed some light on whether the ear advantages from Experiment 1 are distinct to linguistic and lexical emotion perception or whether they also extend to emotional prosody perception. Moreover, if the right ear advantage from classifying emotionally laden words during dichotic presentation is associated with asymmetric ipsilateral suppression then a similar effect may also emerge from dichotic presentations of emotional prosody. Thus, Experiment 2 varied the emotional prosody of the words from Experiment 1 and applied a low pass filter to degrade the linguistic features to determine what ear advantage would occur when processing emotional prosody across each stimulus presentation.

Some of the strongest evidence for the right hemisphere hypothesis comes from dichotic listening studies demonstrating a left ear advantage when processing emotional prosody (Bryden & MacRae, 1989; Haggard & Parkinson, 1971; Hatta & Ayetani, 1985; Ley & Bryden, 1982; Safer & Leventhal, 1977; Saxby & Bryden, 1984; Voyer et al., 2008). If the behavioural consequence of processing emotional prosody is associated with the right hemisphere, the time taken to classify the prosody of the words should be quicker in the left ear compared to the right ear irrespective of the valence of the prosody. Response accuracy might also show the analogous result with affective classification more accurate to prosody presented to the left ear than the right ear.

However, the valence effect has been reported in studies where participants processed one discrete emotion per trial (Bryden et al., 1982; Gagnon & Peretz, 2000; Prete et al., 2015). If this is a critical condition for the demonstration of a valence effect, then it is also possible that the valence effect could occur irrespective of the stimulus presentation. The valence hypothesis would lead to the prediction that words spoken with a happy prosody will be appraised faster than the words spoken in a sad prosody when presented to the right ear and the opposite effect would occur when the same words are presented to the left ear. In addition, response accuracy should be greater when the words spoken in a happy prosody are presented to the right ear and words spoken in a sad prosody are presented to the left ear.

Finally, in Experiment 1, different ear advantages emerged in response to classifying both the linguistic and lexical emotion aspect of words according to the stimulus presentation condition; a right ear advantage from all words using dichotic listening and reduced accuracy for unpleasant words presented to the right ear using monaural listening. If ear advantages from dichotic listening are related to asymmetric ipsilateral suppression favouring the right ear to left hemisphere route, then a right ear advantage may also occur from dichotic presentation even when the linguistic information is removed and participants only classify emotional prosody.

Thus, evidence for the valence effect or the right hemisphere hypothesis from any stimulus presentation might be expected to be observed, however it is also possible that a left hemisphere effect might occur from dichotic presentation.

Method

Design

The design was the same as Experiment 1 except emotional prosody of the same words varied (“*Is the voice happy or sad?”*). It was not possible to include a non-affective (control) task because once a low pass filter was applied participants would be unable to distinguish a noun from an adjective. Thus, Experiment 2 only included an affective classification task where participants classified the emotional prosody of words during monaural, distractor noise, and dichotic presentation.

Participants

Thirty-seven undergraduate psychology students volunteered for the second experiment. Three participants were excluded from the study due to differences in hearing sensitivity between the left and right ear of greater than 10 dB over the frequencies assessed. Data from an additional four left handed participants was excluded using the same criteria as Experiment 1. Thus, the final sample consisted of 30 participants (21 female) ranging in age from 17 to 45 years (*M* = 26.9, *SD* = 9.8 years), and thus comparable to the sample size of the affective task in Experiment 1. Eligible students received nominal course credit in exchange for their participation.

Approval to recruit these participants was granted by the James Cook University Experimental Ethics Review Committee (approval number H3678).

Materials

Target Stimuli

The words used in this experiment were the same 32 words from Experiment 1. Initially, a female colleague with an Australian accent was recorded speaking each word in a happy, sad and neutral prosody. A 270 Hz low pass filter was then applied to each word to degrade semantic information. A pilot study of 14 subjects (10 female) ranging in age from 17 to 46 years (M = 29.8 SD = 10.9 years) ensured that participants could not recognise linguistic or lexical emotion and that the prosody of the words were considered happy, sad and neutral. The same procedure from Experiment 1 was used to equate the happy, sad and neutral words for valence and arousal (please see Appendix E for a full list of the stimulus set). Happy and sad items were then used as the target words and the neutral prosody words were used as the unattended stimuli for dichotic presentation. The duration of each word was approximately 600 ms.

Presentation conditions

The noise and monaural presentation conditions were the same as Experiment 1. In the dichotic procedure, each time a target word occurred a neutral prosody word was presented to the unattended ear.

Procedure

The stimuli were presented in the same set of six blocks as described in Experiment 1 except that participants were only asked to classify whether the person saying each word was happy or sad by pushing a toggle switch up for “happy” or down for “sad”. In all other ways stimulus presentation and data collection was the same.

Results

Classifying a word spoken in a happy prosody as happy or a sad prosody as sad was deemed a correct response. Otherwise, the analysis strategy in Experiment 2 was the same as described in Experiment 1.

Response Time

In the overall response time analysis, there was a significant difference in response times between the stimulus presentations, Wilks λ= .68, $F_{(2, 24)}$= 5.43, p=.01, η_p^2= .31, with participants taking the longest to respond during dichotic listening (*M* = 976 ms, *SD* = 122 ms) followed by monaural listening (*M* = 945 ms, *SD* = 112 ms) and when a burst of pink noise occurred in the unattended ear (*M* = 931 ms, *SD* = 122 ms) (see Figure 3). There was no significant difference in response times to words presented to the left ear (*M* = 957 ms, *SD* = 112 ms) compared to the right (*M* = 944 ms, *SD* = 112 ms), Wilks λ= .95, $F_{(1, 25)}$= 1.16, p=.29, η_p^2= .04. Participants did however respond quicker to words spoken with a happy prosody (*M* = 922 ms, *SD* = 112 ms) than a sad prosody (*M* = 979 ms, *SD* = 112 ms) Wilks λ= .41, $F_{(1, 25)}$= 35.68, p<.001, η_p^2= .58. Finally, there was a significant interaction between the stimulus presentation procedures and prosody, Wilks λ= .75, $F_{(2, 24)}$= 3.89, p=.03, η_p^2= .24. As can be seen in Figure 6, participants responded quicker to words spoken in the happy prosody than the sad prosody during monaural listening and the distractor noise presentation, while response times for happy and sad prosody differed less during dichotic listening. No other interactions were significant See Appendix F for full MANOVA tables.

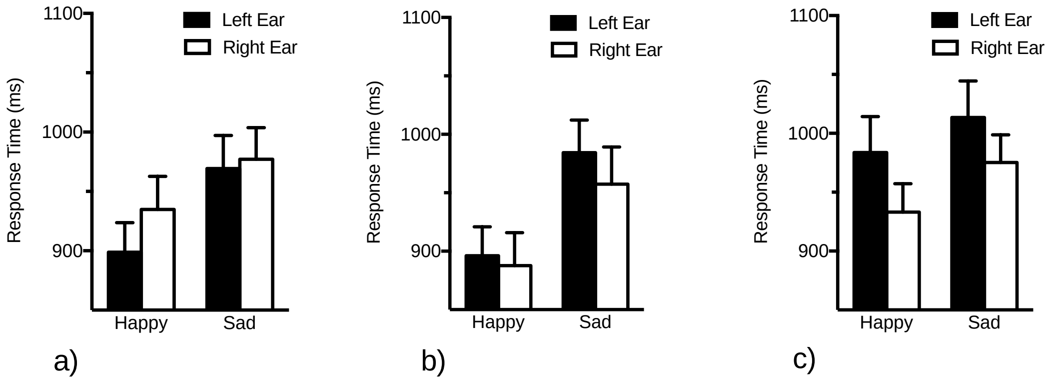

Figure 6. Mean response times (SEM) to correctly classify prosody to the left and right ear during monaural (a) distractor pink-noise (b) and dichotic (c) presentations.

Monaural presentation

Like Experiment 1, in the monaural stimulus presentation, there was no significant difference in response times between the left (M = 934 ms, SD = 122 ms) and right ear (M = 955 ms, SD = 132 ms), $F_{(1, 25)}$= 0.79, p=.38, η_p^2= .03. There was a significant main effect for the prosody, $F_{(1, 25)}$= 14.72, p<.001, η_p^2= .37, with participants responding quicker to happy items (M = 916 ms, SD = 117 ms) than sad items (M = 973 ms, SD = 112 ms) (see Figure 6a). The interaction between the ear of presentation and the prosody of the words was not significant, $F_{(1, 25)}$= 1.87, p=.18, η_p^2= .07.

Noise to the unattended ear

Presenting noise to the unattended ear resulted in the same pattern of reaction times as monaural presentation. There was no significant main effect of ear of presentation, (M_{left} = 940 ms, SD = 122 ms; M_{right} = 922 ms, SD = 147 ms), $F_{(1, 25)}$=

0.56, p=.45, η_p^2= .02 (see Figure 6b). Again, participants responded quicker to happy items (M = 891 ms, SD = 122 ms) than to sad items (M = 970 ms, SD = 127 ms), $F_{(1, 25)}$= 30.78, p<.001, η_p^2= .55, and the interaction was not significant, $F_{(1, 25)}$= 0.68, p=.41, η_p^2= .02.

Dichotic presentation

When participants responded to words presented dichotically, a significant ear of presentation effect emerged, $F_{(1, 25)}$= 4.47, p=.04, η_p^2= .15 (see Figure 6c). Like Experiment 1, participants were quicker to classify the affect conveyed by the stimuli when presented to the right ear (M = 954 ms, SD = 112 ms) than the left (M = 998 ms, SD = 147 ms). Participants also responded quicker to happy items (M = 958 ms, SD = 122 ms) than sad items (M = 994 ms, SD = 127 ms), $F_{(1, 25)}$= 8.91, p<.001, η_p^2= .26, however, the interaction between the ear of presentation and the prosody of the words was not significant $F_{(1, 25)}$= 0.32, p=.57, η_p^2= .01.

Summary

In summary, a right ear advantage occurred in the time taken to classify the prosody of words presented dichotically. When the same prosody was classified and silence or a burst of pink noise occurred in the unattended ear this right ear advantage did not emerge.

Response Accuracy

In the overall response accuracy analysis, there was a significant main effect for stimulus presentation, Wilks λ= .73, $F_{(2, 27)}$= 4.97, p=.01, η_p^2= .26. Participants classified the prosody of words most accurately during monaural listening (M = 94 %, SD = 6 %), followed by distractor noise (M = 91 %, SD = 8 %) and dichotic listening (M = 89 %, SD = 9 %) (see Figure 7). When participants classified prosody as happy or sad there was no significant difference in response accuracy between the left ear (M = 91 % SD = 7 %) and the right (M = 92 %, SD = 6 %) Wilks λ= .89, $F_{(1, 28)}$= 3.30, p=.08, η_p^2= .10. No other main effects or interactions were significant (see Appendix F).

In the follow up analyses of each listening presentation, no significant main effects of ear of presentation, valence of prosody, or any interactions occurred from any stimulus presentation condition (see Figure 7).

Figure 7. Mean response accuracy (SEM) to correctly classify prosody to the left and right ear during monaural (a) distractor pink-noise (b) and dichotic (c) presentations.

Summary

Overall, a right ear advantage occurred in the time taken to classify prosody presented dichotically irrespective of the valence of the prosody. When the same words were presented monaurally or with a burst of pink noise to the unattended ear this ear effect did not emerge. No significant ear advantages emerged in response accuracy to classifying the prosody of words from any stimulus presentation.

Discussion

The aim of Experiment 2 was to determine what ear advantages would emerge when participants classified the emotional prosody of speech where the meaning of the word was unavailable and the stimulus to the unattended ear varied. The only ear advantage to emerge was a right ear advantage in response time when participants classified emotional prosody under dichotic presentation. This result is identical to the response time data from Experiment 1 when participants classified the non-emotional and emotional content of words during dichotic presentation. Unlike Experiment 1, there was no ear advantage in response accuracy from any stimulus presentation. The results suggest that dichotic listening is the best method to elicit an ear advantage in the time taken to classify the emotional prosody of low pass filtered words. That dichotic presentation was superior to monaural and distractor noise to elicit an ear advantage is consistent with Kimura (1964) who suggested that stimuli must be presented dichotically to obtain an ear advantage.

In addition to the ear advantage observed, participants classified emotional prosody fastest during distractor noise presentation, then monaural and dichotic presentation. Response accuracy was best during monaural presentation, followed by distractor noise, and dichotic listening. Thus, across both experiments, dichotic listening seemed to be the most demanding task in classifying each aspect of speech. In addition, participants classified happy prosody quicker than sad prosody from each stimulus presentation, whereas in Experiment 1, pleasant words were classified quickest only from monaural presentation. In addition, in Experiment 1, response accuracy for pleasant and unpleasant words was more determined by the classification required than the stimulus presentation procedure. However, in Experiment 2, a non-affective classification task was not incorporated as a low pass filter was applied to each word. Accuracy did not differ between classifying prosody as happy or sad in any stimulus presentation condition. Thus, only response times differed between happy and sad prosody classifications however, this difference did not interact with the right ear advantage from dichotic presentation as the ear advantage was irrespective of whether emotional prosody was happy or sad.

Regarding hemispheric specialisation of emotional processing, the finding that participants responded quickest to emotional prosody when presented to the right ear than the left during dichotic presentation is not consistent with research that report a left ear advantage for emotional prosody perception consistent with the right hemisphere hypothesis (Haggard & Parkinson, 1971; Hatta & Ayetani, 1985; Ley & Bryden, 1982; Safer & Leventhal, 1977; Saxby & Bryden, 1984; Voyer, Bowes, & Soraggi, 2008). The right ear advantage from dichotic presentation is however consistent with left hemisphere superiority in language processing (e.g. Kimura, 1961; Bryden, 1988). It was expected that the low pass filter would degrade the linguistic features of each word, and thus only the emotional features would be present. One possible explanation for this right ear advantage is that prosody is still being treated as a language related feature. That is these stimuli may have still been recognised as speech, although only conveying emotion through prosody. Since speech is processed primarily in the left hemisphere in most right handed individuals this may have elicited the right ear advantage (e.g. Costafreda et al., 2008; Kuchinke et al., 2005; Luo et al., 2004). Alternatively, filtering the speech may have altered the acoustic parameters associated with the perception of emotional prosody. However, participants could clearly classify the emotional prosody as happy or sad thus applying a low pass filter was unlikely to adversely impact participants' perception of emotional prosody.

Finally, the right ear effect in response time to classify emotional prosody with dichotic presentation may be less related to processing language or emotional prosody but instead the stimulus presentation condition. In Experiment 1, different ear advantages emerged in response to classifying both linguistic and lexical emotion according to the stimulus presentation condition; a right ear advantage for all words from dichotic listening and reduced accuracy for unpleasant words presented to the right ear from monaural listening. If the ear advantages from dichotic presentation are due to asymmetric ipsilateral suppression favouring all right ear items, then a right ear advantage would also occur from dichotic presentation even once linguistic information is removed and participants only classify emotional prosody. Across both experiments, a right ear advantage occurred in the time taken to classify all words from dichotic presentation irrespective of the aspect of speech being processed. Thus, one explanation is asymmetric ipsilateral suppression from dichotic stimulation is showing a bias to all right ear items.

General Discussion

While left-brain / right-brain theories are too coarse as explanations for the neural organisation of emotion, distinct ear advantages do occur when individuals classify emotionally laden speech. However, the ear advantages reported are not consistent with the right hemisphere hypothesis or the valence effect and differ according to the stimulus presentation procedure employed. One consistent result across each experiment is a right ear advantage in the time it took participants to classify each aspect of speech from dichotic presentation: non-emotional content, lexical emotion, and emotional prosody. These results indicate that dichotic listening is the most reliable method to elicit an ear advantage in response time to classifying these aspects of speech. However, monaural presentation elicited a different ear advantage with unpleasant words being classified least correctly when presented to the right ear, except for emotional prosody. The contribution of Chapter 2 is that when participants classify emotionally laden speech and the stimulus to the unattended ear is systematically varied the ear advantages can be inconsistent. If the stimulus presented to the unattended ear is the only factor that differs and monaural and dichotic presentation elicit different ear advantages, then there needs to be caution when interpreting ear advantages as an absolute index of laterality effects.

In Experiment 1, it was unclear to what extent the ear advantages reflected language processing. One limitation of using linguistic stimuli is that language might have swamped contributions of emotional processing. To further explore ear advantages associated with emotional processing the linguistic aspect of speech was removed by applying a low pass filter to words to strictly focus on emotional prosody. It was anticipated that this approach would eliminate laterality effects associated with linguistic processing and determine whether the ear advantages from Experiment 1 also extend to processing emotional prosody. The right ear advantages from classifying linguistic and lexical emotion did extend to processing emotional prosody for dichotic presentations, however the ear effect from monaural presentations of reduced accuracy for unpleasant words presented to the right ear did not extend to emotional prosody. One explanation this ear effect did not extend to emotional prosody is that words consisting of both linguistic and emotional content were likely to be more salient than low pass filtered emotional prosody items. If dichotic presentation is the more robust presentation procedure then monaural presentation may have been less able to elicit an ear an advantage specific to emotional prosody.

Regarding the stimulus presentation condition, if language swamped contributions of emotional processing, and emotional prosody was still treated as a language related feature, then it is possible that each right ear advantage from dichotic presentation is a consequence of language processing. However, if these right ear advantages are associated with asymmetric ipsilateral suppression they would occur irrespective of what aspect of the stimulus is being processed, which was the case. Given that language and asymmetric ipsilateral suppression are both associated with the left hemisphere it is not possible to conclude whether either of these, or the interaction of both contributed to these effects. What is clear is that monaural and dichotic presentation elicit different ear advantages from presentations of the same stimuli and while dichotic presentation was the most reliable stimulus presentation procedure, monaural presentation did not detect the same effect. This questions the validity of dichotic listening as a method to measure emotional processing. This is the first systematic investigation of the behavioural consequences of emotional processing with speech to explicitly compare the three presentation procedures. Thus, this area of research would certainly benefit from further investigation. The current experiments are restricted to behavioural methods, which is the focus of this thesis. Imaging studies would provide further insight into emotion speech perception according to the stimulus presentation condition employed and help to determine how the unattended stimulus from dichotic presentation is moderating ear advantages that are intended to measure emotional processing.

Another approach to extend this preliminary investigation would be to conduct the same comparison of three presentation procedures utilising an emotional stimulus that is not language and does not elicit the typical right ear advantage. In contrast to language, which is associated with the left hemisphere indicated by a right ear advantage, music is often associated with the right hemisphere indicated by a left ear advantage (Hugdahl, 1999; Wioland, Rudolf, Metz-Lutz, Mutschler, Marescaux, 1999; Roucher & Bryden, 1997). Removing language altogether to compare ear advantages from each stimulus presentation procedure would eliminate laterality effects associated with linguistic processing that seem evident in Chapter 2. It would also shed some light on whether the ear advantages from Chapter 2 are distinct to processing emotionally laden speech or whether they also extend to processing the emotional aspect of other stimuli such as music. Moreover, if the right ear advantages from classifying emotionally laden words presented dichotically are associated with asymmetric ipsilateral suppression then a similar effect may also emerge using emotionally laden music. Considering this, Chapter 3 explores how individuals process the non-emotional and emotional aspect of music when the stimulus presented to the unattended ear is systematically varied.

Chapter 3. Processing the emotional aspect of music

Chapter 2 explored the best listening method to measure the behavioural consequences of processing emotionally laden speech and demonstrated ear advantages can differ according to the listening method employed. Since the stimulus presented to the unattended ear was the only factor to differ, the inconsistent ear advantages appear to be an artifact of the stimulus presentation. Thus, the validity of dichotic listening to measure the behavioural consequences of emotional processing requires further examination. Since there is evidence consistent with the valence effect using musical stimuli from monaural and dichotic presentation (on trials when only one emotional unit was processed), music might be a more appropriate stimulus to explore whether behavioural consequences of emotional processing are consistent when the listening method is systematically varied as well as which method best detects such effects. However, melodies are typically longer in duration than words and there is evidence from divided visual research investigating the perception of facial affect that the valence effect is more robust when stimuli are presented briefly. Thus, to extend the findings from the experiments reported in Chapter 2, the experiments reported in this chapter investigated the impact of stimulus duration on ear advantages while further exploring the reliability of the three stimulus presentations to measure emotional processing of musical stimuli. Thus, this chapter initially briefly reviews research on how individuals process the emotional aspect of music and how stimulus duration might moderate emotion laterality effects.

How individuals process the emotional aspect of music

Like facial affect and the emotional appraisal of language, processing the emotional aspects of music requires a system of complex neural networks and there is good evidence of bilateral organisation (Kreutz & Lotze, 2007). However, electroencephalography studies do provide evidence for the valence effect when individuals simply listen to music (Altenmuller, Schurmann, Lim & Parlitz, 2002; Schmidt & Trainor, 2001; Tsang, Trainor, Santesso, Tasker & Schmidt, 2001). For example, Schmidt and Trainor (2001) instructed neurologically healthy participants to "feel the mood" of orchestral music excerpts designed to induce joy, happiness, fear and sadness. Electroencephalography demonstrated bilateral activation with positively valanced pieces expressing joy and happiness associated with greater activity in the left frontotemporal lobe, while negatively valanced pieces expressing sadness and fear were associated with greater activity in the right fronto-temporal lobe. Similarly, Altenmuller, Schurmann, Lim, and Parlitz (2002) presented short sequences of jazz, rock-pop, and classical music to neurologically healthy participants and also recorded electroencephalography activation patterns. They reported bilateral frontotemporal activation with heightened left hemisphere activity when participants listened to positively valanced pieces, while heightened right hemisphere activity was observed for negatively valanced versions of the same genres. Thus, while neural organisation of processing emotional aspect of music is bilateral, there is evidence from electroencephalography studies consistent with the valence effect.

In behavioural studies, like emotional prosody, evidence of the valence effect from music depends on the affect of the unattended stimulus during dichotic presentation. As noted in Chapter 1, dichotic listening studies demonstrate a left ear advantage when participants emotionally appraise melodies consistent with the right hemisphere hypothesis (Bryden et al., 1982; Leichner & Broscher, 1999). Despite an overall left ear advantage, Bryden et al. (1982) found that the valence of competing melodies interacted with a valence effect occurring on trials when the affect of the target and competing melody was the same. Finally, the valence effect has been reported from the affective appraisal of melodies presented monaurally (Gagnon & Peretz, 2000). Thus, it remains unclear whether the overall left ear advantage from dichotic listening studies investigating the emotional appraisal of music is a consequence of right hemisphere superiority from processing the emotional aspect of music or the competing stimulus presented to the unattended ear. Chapter 2 demonstrated inconsistent ear advantages can emerge from monaural and dichotic presentations of the same target stimuli. The methodological implication of this finding is that ear advantages might partly be an artifact of the listening method employed. Thus, the aim of the experiments in this chapter was to use musical stimuli to further explore whether ear advantages are consistent with either of the two major theories of hemispheric specialisation of emotional processing independent of the listening method employed, while also determining which method best detects such effects.

A major strength of Bryden, Ley and Sugarman’s (1982) study is that they provided evidence that the affect of the unattended stimulus in a dichotic presentation affected ear advantaged observed. However, one limitation is that the authors did not determine the relative contribution of music versus emotional processing, as they did not employ a non-affective control condition. This means it is not possible to conclude whether the overall right hemisphere superiority indicated by their left ear advantage is predominately a consequence of music or emotional processing. A thorough review of the literature suggests that Gagnon and Peretz (2000) are the only authors to demonstrate the valence effect in listening research using simple melodies. They incorporated a non-affective control task to verify their emotion effect. To recap, they presented simple melodies to participants monaurally and asked them to report if the melody heard was pleasant or unpleasant. Half of the melodies were tonal which are usually described as pleasant while the other half were atonal usually described as unpleasant. Responses from classifying tonal melodies as “pleasant” were quicker when presented to the right ear than the left and the reverse occurred for classifying atonal melodies as “unpleasant” consistent with the valence effect. Importantly, this effect was not present when a separate group of participants made a non-affective classification of the same melodies as “in key” or “out of key” confirming this valence effect was a consequence of emotional processing. However, this study only employed monaural listening and the effect has not been equivalently demonstrated from dichotic presentation with the inclusion of a non-affective control task to verify it is the valence effect being observed. Thus, the experiments reported in this chapter employ a non-affective control condition so that any ear advantages from each listening method can be directly attributed to affective versus non-affective processing.

Another factor to consider when investigating emotion laterality effects using musical stimuli is that melodies can be longer in duration than words. Importantly, divided visual studies investigating facial affect have demonstrated that the valence effect is more robust when stimuli are presented briefly (Prete, Laeng & Tommasi, 2014). In dichotic listening research, when emotional stimuli of longer durations are employed, such as sentences, the result is almost always consistent with the right hemisphere hypothesis. For example, when Ley and Bryden (1982) presented sentences spoken in happy, sad, angry, and neutral prosody to participants they reported a right ear advantage for verbal processing and a left ear advantage for emotional prosody consistent with left hemisphere superiority in language processing and right hemisphere superiority for emotional prosody. However, when Bryden and

MacRae (1989) adopted the same method using words, while the same effect occurred, a larger left ear advantage emerged for angry and sad words interpreted as a partial valence effect. The primary difference between Ley and Bryden (1982) and Bryden and MacRae's (1989) study is the use of sentences and words and while there are many differences between the two one obvious difference is duration. If the valence effect is more robust when stimuli are presented briefly, the use of words rather than sentences might have facilitated the partial valence effect. Thus, melodies, longer in duration, might result in right hemisphere dominance indicated by a left ear advantage, while brief versions of the same melodies might elicit results consistent with the valence effect. To explore the impact of stimulus duration on the behavioural consequences of emotional processing the experiments in this chapter use longer duration melodies as well as brief versions of the same melodies both presented via each listening method.

Thus, Experiment 3 compares the non-emotional and emotional classification of melodies via monaural, distractor noise and dichotic listening, and Experiment 4 compares classifications of brief versions of the same melodies from each stimulus presentation.

Experiment 3

Experiment 3 compared listeners' appraisal of pleasant and unpleasant melodies using the same stimulus presentations, *monaural* (silence in the unattended ear), *distractor noise* (pink noise presented to the unattended ear), and *dichotic* (melodies presented to the unattended ear). In this experiment, a similar method was adapted from Gagnon and Peretz (2000). Tonal and atonal melodies made it possible to implement an affective (*"Is the melody pleasant or unpleasant?"*) and non-affective ("*Is the melody in key or out of key?*") classification task to compare the relative contribution of emotional versus musical judgment. Such an approach yields data comparable to the experiments in Chapter 2 that explored the non-emotional and emotional aspects of speech.

To strengthen the analysis employed in Chapter 2, this chapter introduced Signal Detection theory to provide a measure of sensitivity *(d')* and response bias (c) (Stanislaw, & Todorov, 1999). Observers are both sensors and decision makers and sensitivity *(d')* and response bias (c) measure these distinct processes respectively. Sensitivity *(d')* is defined as how sensitive a participant is to a particular stimulus in the presence of noise. Response bias is whether the individual is responding from neutral criteria or whether they are biased in responding in one direction more than the other. For example, two participants could both obtain 80% accuracy for classifying pleasant words, however why they do so can differ; one individual might make 20% false alarms (classifying an "unpleasant" word as "pleasant") while the other might make 60% false alarms. While both detect the same number of items, the first participant has greater sensitivity, while the second is simply biased to responding 'pleasant' more often. It was not possible to incorporate sensitivity *(d')* and response bias (c) in Chapter 2 because data obtained from classifying a word as pleasant or unpleasant did not directly correspond to nouns and adjectives. Half of the pleasant words were nouns while the other half were adjectives (this was also the case for unpleasant words) to prevent nouns and adjectives confounding observed ear advantages. Thus, sensitivity *(d')* and response bias (c) could not be directly compared between affective and non-affective (control) classifications. However, tonal and atonal melodies respectively correspond to pleasant and unpleasant classifications allowing for a direct comparison of sensitivity *(d')* and response bias

(c) between each classification task. Sensitivity (*d’*) is deemed an appropriate measure because differences in the lateralisation of emotional processing (or musical processing) will correspond to differences in sensitivity to the emotion (or tonality) of melodies between each ear. Similarly, response bias (c) is considered an appropriate measure to determine whether participants are biased in responding pleasant or unpleasant (or in key or out of key) between the left and right ear or whether no differences in bias occur between the ears. Finally, response time was employed in the same manner as Chapter 2.

If the valence effect applies to the affective appraisal of melodies, pleasant melodies will be classified faster than unpleasant melodies when presented to the right ear and the opposite effect should occur when the same melodies are presented to the left ear. In addition, sensitivity to emotion will lead to the pleasantness of these melodies being greatest when the melodies are presented to the right ear. Finally, participants should be biased to responding pleasant when the melodies are presented to the right ear irrespective of the valence of the melodies and the opposite effect should occur when the same melodies are presented to the left ear.

If the affective appraisal of melodies is consistent with the right hemisphere hypothesis, the time taken to affectively classify the melodies will be quickest in the left ear compared to the right regardless of the valence of each melody. In addition, sensitivity to the pleasantness of these melodies should be greatest for the left ear items. Finally, there should be no bias in responding pleasant or unpleasant for melodies presented to the left ear since this hypothesis is based on superiority of emotional processing in the right hemisphere irrespective of the valence of the melodies.

However, Experiments 1 and 2 demonstrated ear advantages were mediated by the presentation procedure employed. Since an ear advantage occurred from each dichotic presentation, it is likely that an ear advantage will occur when a competing melody is presented to the unattended ear. Since Gagnon and Peretz (2000) found evidence for the valence effect with monaural presentation of melodies it is likely that monaural presentation could elicit the valence effect. Since participants only process one target emotion per trial it is also possible that the distractor pink noise and dichotic presentation condition could elicit the valence effect (Bryden et al., 1982; Gagnon & Peretz, 2000; Prete et al., 2015). Any differences in ear advantages between the three stimulus presentations will reflect the result of systematically varying the stimulus presented to the unattended ear (i.e. silence, distractor pink noise, or a competing melody).

Finally, stimulus duration can impact emotion laterality effects with robust valence effects observed when stimuli are brief (Prete et al., 2014) while longer duration stimuli generally result in right hemisphere superiority indicated by a left ear advantage (Ley & Bryden, 1982). Thus, longer duration melodies might elicit results consistent with the right hemisphere hypothesis, while brief versions of the same melodies might elicit the valence effect.

Thus, no ear advantages for classifying melodies in the non-affective task is predicted irrespective of the stimulus presentation. In the affective task, evidence for either the right hemisphere hypothesis or valence effect from monaural, distractor noise and dichotic presentation is expected to occur. Finally, longer and brief versions of the same melodies might result in evidence consistent with the right hemisphere hypothesis and valence effect respectively regardless of the stimulus presentation condition.

Method

Design

Experiment 3 was a 2 (Attended Ear) x 2 (Valence) x 3 (Stimulus Presentation) x 2 (Classification Task) mixed factorial design. The three presentation conditions (monaural, with noise and dichotic) and attended ear were within subjects factors, while the classification task (affective or tonality) was a between subjects factor. The non-affective task served as a control condition to ensure that any observed ear differences were due to affective classification rather than simply classifying a melody correctly.

Participants

Sixty-two undergraduate psychology students volunteered for Experiment 3 and were randomly assigned to either the affective or non-affective classification task. Four participants were excluded from participation because they were assessed as left-handed on the Edinburgh Oldfield's Handedness Inventory (Oldfield, 1971). An additional five participants were excluded due to differences in hearing sensitivity between the left and right ear of greater than 10 dB. Thus 28 participants undertook the affective task (14 female) ranging in age from 18 to 49 years (M = 30.7, SD = 8.3). Twelve participants self-reported musical training which was measured in years (M = 3.5 years, SD = 5). The non-affective group consisted of 25 participants (17 female) with an age range of 17 to 51 years (M = 32.2, SD = 9.8). Eight participants in this group reported some musical training (M = 1.8 years, SD = 3.3). Eligible students received nominal course credit in exchange for their participation. Approval for the research was granted by the James Cook University Experimental Ethics Review Committee (approval number H3678).

Materials

Target Stimuli

Forty-eight, five note melodies similar to those presented by Gagnon & Peretz (2000) were created using the grand piano synthesizer in GarageBand (© Apple, 2009). Half of the melodies were constructed in accordance with the tonal system (i.e. written in a major mode). These were the tonal (or "in key") melodies. To create the atonal (or "out of key") melodies at least one note in each of the tonal melodies was changed to a note from a different unrelated key. This was done in such a way that the contour of the tonal melodies was preserved. Each melody consisted of five notes of equal duration with the same interval between notes (375 ms). The duration of each melody was thus 1800 ms.

To ensure that the tonal melodies were pleasant and the atonal melodies unpleasant and that each set were matched for valence and arousal, the pilot procedure from Experiment 1 was applied. The pilot sample consisted of 12 naïve participants (9 females) ranging in age from 23 to 49 years (M=30.7, SD=10.3) who did not take part in the main experiment. Multidimensional Scaling resulted in two dimensions: valence (pleasant and unpleasant) and arousal (low and high). From this analysis the twelve most pleasant (M = 0.6, SD = 0.2) tonal melodies and the twelve most unpleasant (M = -0.6, SD = 0.2) atonal melodies were selected to be the target melodies. The neutral melodies for the unattended ear during dichotic presentation were melodies that were not selected as target melodies and were of intermediate rated pleasantness (tonal, M= 0.2, SD=0.5 and atonal, M=-0.2, SD=0.4).

For a full list of the stimulus set please refer to Appendix G.

Unattended Stimuli

The noise presentation condition, an 1800 ms burst of pink noise was presented to the unattended ear each time a target melody occurred. For the dichotic procedure, each time a target melody occurred one of the melodies neutral in emotional valence was presented to the unattended ear.

Procedure

The procedure for Experiment 3 was identical to Experiment 1 except that participants in the affective task were asked to classify each melody as either “pleasant” or “unpleasant” while those in the non-affective task classified each melody as either “in key” or “out of key”. Like Experiment 1, responding was via a toggle switch with a push up indicating a pleasant or in key melody and a push down indicating an unpleasant or out of key melody. Otherwise, the procedure was identical to Experiment 1.

Results

Mean response times to “correct” responses were calculated for each participant in each condition. In the affective task classifying a tonal melody as pleasant or an atonal melody as unpleasant was deemed a correct response. Similarly, in the non-affective task a correct response was to classify a tonal melody as in key and an atonal melody as out of key. Any response times that differed by more than 2.5 standard deviations from the mean were trimmed to that level (Tabachnick & Fidell, 2001). Data from any participant who failed to classify at least 50% of trials in a condition correctly were removed from the analysis.

Sensitivity (*d’*) and bias (c) were calculated based on the same criteria for what constituted a correct response. In the affective task, classifying a tonal melody as pleasant constituted a “Hit” whereas a “False Alarm” was defined as classifying an atonal melody as pleasant. Thus a “Correct Rejection” was correctly classifying an atonal melody as unpleasant and a “Miss” was when a tonal melody was classified as unpleasant. In this task, (*d’*) is sensitivity to pleasantness. Similarly, in the corresponding non-affective task, a tonal melody classified as “in key” was treated as a “Hit” whereas the same response to an atonal melody constituted a “False Alarm”. “Correct rejections” were correct classifications of an atonal melody as “out of key” and a “Miss” was when a tonal melody was classified as “out of key”. In this task, (*d’*) is sensitivity to tonality. The loglinear approach was adopted to deal with any extreme scores of 0 or 1, by adding 0.5 to the number of hits and false alarms, and by adding 1 to both the number of signal and noise trials (see Stanislaw & Todorov,1999 for a discussion of how to calculate SDT measures using common software packages).

In interpreting (c) as a measure of response bias, negative values indicate a bias toward responding “pleasant” in the affective task or “in key” in the non-affective task.

Otherwise the analysis strategy was the same as that applied in Experiment 1.

Response Time

In the overall response time analysis, affective classifications (M = 2241 ms, SD = 330 ms) were significantly quicker than non-affective classifications (M = 2572 ms, SD = 342 ms), $F_{(1, 33)}$= 46.81, p<.001, η_p^2= .59; see Figure 8). There was also a significant interaction between the classification task and ear of presentation, Wilks λ= .83, $F_{(1, 33)}$= 6.62, p=.01, η_p^2= .17. In the affective task, mean response times were faster to melodies presented to the left ear (M = 2219 ms, SD = 323 ms) than the right ear (M = 2265 ms, SD = 380 ms) whereas the reverse was true for the non-affective task (*M* = 2589 ms, *SD* = 337 ms and *M* = 2556 ms, *SD* = 390 ms respectively). There was also a significant main effect for presentation procedure, Wilks λ= .58, $F_{(2, 32)}$= 11.19, p<.001, η_p^2= .41, with responses to dichotic presentations being longer (*M* = 2463 ms, *SD* = 291 ms) than either the monaural (*M* = 2368 ms, *SD* = 241 ms) or with distractor noise (*M* = 2390 ms, *SD* = 262 ms) presentations. No other main effects or interactions were significant in the overall analysis (see Appendix H for a full summary of the MANOVA analysis).

To directly compare these results with those obtained by Gagnon and Peretz (2000) a separate 2 (ear of presentation) x 2 (tonality) x 2 (classification task) analyses of each presentation procedure was conducted.

Monaural presentation

As in the overall analysis, participants were significantly faster, $F_{(1, 44)}$= 74.60, p<.001, η_p^2= .62, making an affective classification (*M* = 2193 ms, *SD* = 281 ms) than a non-affective classification (*M* = 2546 ms, *SD* = 280 ms; see Figure 8a). No other main effects or interactions were significant (also see Appendix H).

Noise to the unattended ear

Similar to the monaural presentation, when melodies were presented with pink noise to the unattended ear, affective classifications were made significantly faster (*M* = 2224 ms, *SD* = 320 ms) than non-affective (*M* = 2565 ms, *SD* = 330 ms) classifications, $F_{(1, 47)}$= 52.88, p<.001, η_p^2= .52 (see Figure 8b). No other main effects or interactions were significant (see Appendix H).

Dichotic presentation

When similar melodies were presented to the unattended ear, the task main effect was again significant $F_{(1, 39)}$= 20.9, p<.001, η_p^2= .35. As with the other presentation procedures the affective (M = 2342 ms, SD = 381 ms) classifications were faster than non-affective (M = 2608 ms, SD = 432 ms) classifications. No other main effects or interactions were significant, however figure 8c suggests that there might have been an ear of presentation effect in the affective task but not in the non-affective task as reported by Gagnon and Peretz (2000). To examine this possibility more closely, separate ANOVAs were calculated for each task. There were no significant main effects nor an interaction in the non-affective task (as would be expected of a control task) however there was a significant effect of ear of presentation ($F_{(1, 22)}$= 5.95, p=.023, η_p^2= .21) in the affective task. When melodies were presented to participants' left ear they were faster to make an affective classification than when presented to their right ear (M = 2291 ms, SD = 392 ms Vs M = 2394 ms, SD = 347 ms). There was no evidence that this effect was greater for pleasantly appraised melodies than unpleasant melodies as the interaction was not significant, $F_{(1, 22)}$= .08, p=.78, η_p^2= .00 (see Figure 8c).

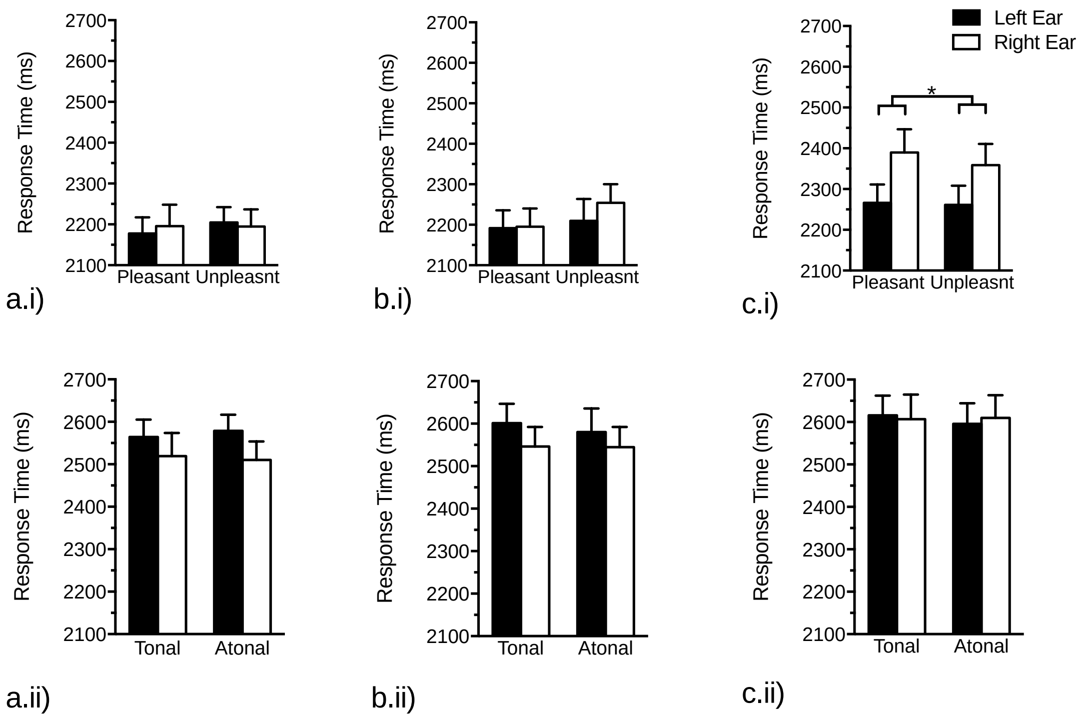

Figure 8. Mean response times (SEM) to correctly classify 1800 ms melodies to the left and right ear during monaural (a) distractor pink-noise (b) and dichotic (c) presentations in the affective (i) and non-affective (ii) classification task.

Sensitivity and bias

Signal detection theory measures of sensitivity and bias were calculated for pleasantness in the affective task and tonality in the non-affective task. Separate MANOVAs were conducted for each task and for both sensitivity and response bias. Figure 9a illustrates the 95% CI for sensitivity to both pleasantness (i) and tonality (ii). Sensitivity did not vary with the ear of presentation in either the affective, Wilks λ= .93, $F_{(1, 27)}$= 2.08, p=.16, η_p^2= .07, or non-affective, Wilks λ= .97, $F_{(1, 24)}$= 0.64, p=.43, η_p^2= .03, tasks. Also, evident in Figure 9a is the lower sensitivity to pleasantness and tonality when a melody was presented to the unattended ear (the dichotic presentation conditions). This reduced sensitivity during dichotic presentation likely accounts for the significant main effect of presentation procedure in both the affective, Wilks λ= .50, $F_{(2, 26)}$= 12.9, p<.001, η_p^2= .50, and non-affective, Wilks λ= .57, $F_{(2, 23)}$= 8.77, p= .001, η_p^2= .43, tasks.

The difference between the dichotic presentation and the other conditions was also evident in response bias. Participants were biased to respond "pleasant" in the affective task and "in key" in the non-affective task in all presentation conditions other than in the dichotic presentation condition, where responding was not significantly biased (the confidence interval spans 0) (Figure 9b).

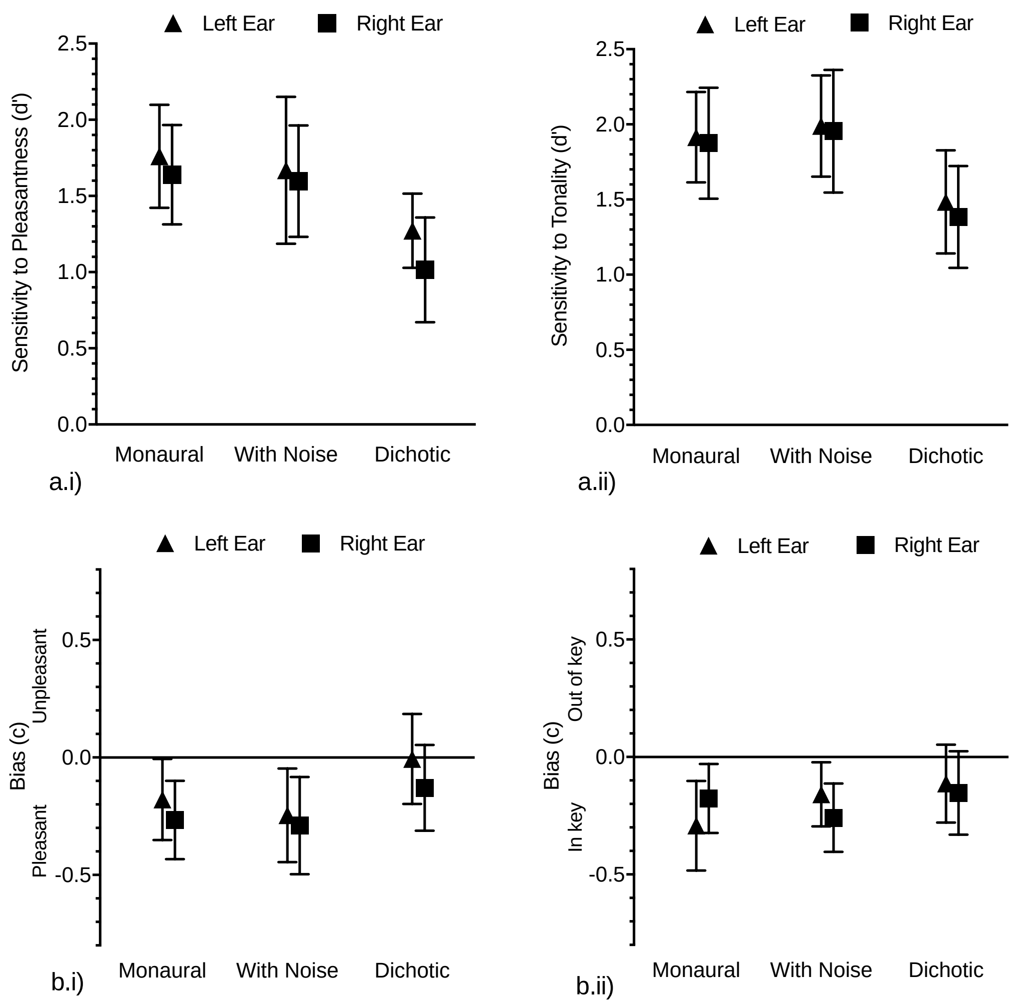

Figure 9. Mean Sensitivity (a) and bias (b) with 95% confidence intervals to pleasantness in the affective judgment task (i) and tonality in the non-affective judgment task (ii) for 1800 ms duration melodies.

Summary

Overall a left ear advantage occurred in the time taken to make an emotional classification of melodies presented dichotically irrespective of the valence of the melody. When the same melodies were presented monaurally or with a burst of pink noise to the unattended ear this ear effect did not emerge. No ear advantages emerged in response time from any stimulus presentation when a musical classification of the same melodies was required. There were no differences between the ears for sensitivity or response bias from any stimulus presentation or classification. However, sensitivity to pleasantness (and tonality) was compromised most from dichotic presentation and dichotic presentation was the only stimulus presentation to demonstrate no response bias.

Discussion

The aim of Experiment 3 was to determine which listening task would most effectively demonstrate ear effects in the affective appraisal of simple melodies. Consistent with Kimura's (1964, 2011) assertion, only the dichotic presentation procedure produced measurable differences in response time between the ears. Participants were faster to affectively classify melodies presented to the left ear than the right regardless of the valence of the melodies. This effect did not occur when participants made a non-affective classification of the same melodies consistent with this ear advantage being a consequence of emotional processing. The ear difference in response time was not reflected in differences in sensitivity between ears for dichotic presentation. However, it was only from dichotic presentation response bias did not differ significantly from 0. Hence of the three presentation procedures the dichotic method appears to be the most likely to detect unbiased difference between the ears.

The unambiguous finding of a left ear advantage in emotional processing of melodies during dichotic presentations is consistent with several studies that demonstrate such an effect (e.g. Bryden et al., 1982; Haggard & Parkinson, 1971; Hatta & Ayetani, 1985; Ley & Bryden, 1982; Safer & Leventhal, 1977; Saxby & Bryden, 1984) consistent with the right hemisphere hypothesis.

The distractor noise condition (itself a form of dichotic presentation) was designed to create similar listening conditions to the background noise in the Marzoli and Tommasi (2009) nightclub study where a female confederate approached individuals to request a cigarette. Those approached met the request twice as often when it was addressed to the right ear compared to the left. However, there was no evidence of any ear effects in the appraisal of melodies with this procedure. The only effect observed in the distractor noise presentation procedure was that tonal melodies were classified as pleasant more quickly than atonal versions as unpleasant irrespective of the ear of presentation. It is unclear why the distractor noise presentation does not produce measurable differences between the ears since the dichotic presentation procedure does produce measurable effects. Perhaps competing unattended stimuli are required to be similar to target stimuli in both meaning and or complexity to detect such effects.

In the affective monaural listening task, there was no significant difference between the ears in the time taken to classify the melodies as either pleasant or unpleasant. Similarly, in the non-affective control task, there was no significant difference between the ears in the time taken to classify the melodies as either in key or out of key. There were also no differences between the ears for sensitivity and response bias from any classification of the melodies presented monaurally. Thus, unlike Gagnon and Peretz (2000), no evidence of a valence effect was found when melodies were presented monaurally. This was despite using melodies of the same type.

One explanation for the lack of observed valence effect might be the duration of the melodies. Divided visual studies of facial affect demonstrate that the valence effect is more robust when the stimuli are presented briefly (Prete et al., 2014). Moreover, in dichotic listening studies, longer duration stimuli, such as sentences varying in emotional prosody, have tended to show left ear advantages (i.e. Ley & Bryden, 1982) while a partial valence effect has been reported from the use of words varying in prosody (Bryden & MacRae, 1989). It is possible that ear advantages consistent with the valence effect might only occur for auditory stimuli that are relatively brief as there is less time for processing to spread within and between the hemispheres. Moreover, participants might respond more quickly to relatively brief melodies than longer versions, which perhaps might provide a more accurate measure of hemispheric specialisation of emotional processing. Should this be the case then the duration of the melodies might have been too long to produce a valence effect.

Considering this, the aim of Experiment 4 is to determine which listening procedure most efficiently demonstrates ear advantages in the emotional appraisal of simple melodies under conditions in which the stimuli are relatively brief. Indeed, if differences in response times, sensitivity and response bias between the ears critically depend on relatively brief stimuli such items would better indicate which presentation procedure is the most efficient in detecting any hemispheric specialisation in the affective processing of simple melodies.

Experiment 4

In Experiment 4, the melodies were identical to those presented in Experiment 3. However, the duration of each sequence was reduced. The rationale for this approach is that subjects were likely to respond quicker to relatively brief melodies compared to longer versions. Such immediate responses might provide a more accurate measure of contralateral hemispheric processing, as there is less time for both hemispheres to become activated by the melodies. Thus, the purpose of Experiment 4 was to determine whether the valence effect was more likely to be observed in the emotional appraisal of melodies when the presentation time is briefer. In addition, the experiment further explored the reliability of the three stimulus presentation procedures.

The same methodological factors addressed in the previous three experiments were also addressed in Experiment 4 and the predictions are the same as those outlined in Experiment 3.

Method

Participants

Sixty-two undergraduate students participated in Experiment 4. Four participants were excluded from participation due to differences in hearing sensitivity between their left and right ear. Two participants were removed because they were left-handed as assessed by the Edinburgh Oldfield’s Handedness Inventory (Oldfield, 1971). Five additional participants were removed from the affective condition because they could not correctly classify at least half of the melodies as pleasant or unpleasant. Overall, there were 28 participants in the affective task (19 females) and 28 participants (18 females) in the non-affective task. Ages ranged from 17 to 44 years

(*M* = 25.8, *SD* = 9.3). Participants were awarded course credit in exchange for their participation and were treated in accordance with James Cook University ethical guidelines for human experimentation (approval number H3678).

Materials

Stimuli

The target and distractor melodies from Experiment 3 were modified to reduce the duration of each melody to 850 ms by reducing the interval between the individual notes from 375 ms to 150 ms. The duration of the distractor pink noise stimulus was also reduced to 850 ms. This modification was the only difference between Experiment 3 and Experiment 4 so the comparison between the studies is a direct manipulation of melody duration. It is possible that increasing the tempo of the melodies in this way would change the valence of the melodies, since faster tempo melodies are usually regarded as “happier” (Husain, Thompson, Schellenberg, 2002). To determine if this was the case, 11 naïve participants (9 females) ranging in age from 17 to 46 years (*M* = 27.1, *SD* = 8.3) were asked to classify the target melodies as either pleasant or unpleasant. The participants were able to correctly classify each melody, and thus any change in the emotional valence of the melodies was not great enough to cause an unpleasant melody to be regarded as pleasant.

Procedure

The procedure was the same as described in Experiment 3.

Results

The analysis strategy in Experiment 4 was the same as described in Experiment 3. The same inclusion and exclusion criteria were also applied and sensitivity and bias were calculated in the same way. An alpha level of .05 was adopted in all statistical tests.

Response Time

As in Experiment 3 there was an overall main effect for stimulus presentation, Wilks λ= .39, $F_{(2, 31)}$= 23.47, p<.001, η_p^2= .60. Figure 10 suggests that response times were longer in the dichotic (M = 1408 ms, SD = 371 ms) than in the monaural (M = 1243 ms, SD = 251 ms) or distractor noise (M = 1278 ms, SD = 371 ms) presentation conditions. Unlike Experiment 3, there was no significant difference in the time taken to make affective (M = 1351 ms, SD = 381 ms) and non-affective (M = 1268 ms, SD = 429 ms) classifications, $F_{(1, 32)}$= 2.05, p=.16, η_p^2= .06, or any significant difference in response time between the left ear (M = 1313 ms, SD = 280 ms) and the right (M = 1306 ms, SD = 300 ms), Wilks λ= .99, $F_{(2, 32)}$= 0.18, p=.67, η_p^2= <.001. No other main effects or interactions were significant (see Appendix I for the complete MANOVA table).

Monaural presentation

When the melodies were presented monaurally, there was no significant difference in response time to melodies between the affective (M = 1298 ms, SD = 330 ms) and non-affective (M = 1238 ms, SD = 344 ms) classifications, $F_{(1, 46)}$= 1.57, p=.21, η_p^2= .03. There was also no significant difference in response time between the left ear (M = 1278 ms, SD = 262 ms) and the right ear (M = 1257 ms, SD = 237 ms), Wilks λ= .95, $F_{(1, 46)}$= 2.04, p=.16, η_p^2= .04. Participants' responses to tonal (M = 1248 ms, SD = 226 ms) melodies was slightly quicker than atonal (M = 1287 ms, SD = 286 ms) melodies, however this effect was not significant, Wilks λ= .92, $F_{(1, 46)}$=

4.03, p=.051, η_p^2= .08. The ear of presentation by classification task interaction also approached significance, $F_{(1, 46)}$= 3.65, p=.06, η_p^2= .07), but fell short of the conventional level of acceptance (see Figure 10a)

Noise and Dichotic presentations

When melodies were presented with either pink noise or other melodies to the unattended ear, response times were not significantly influenced by the classification task, ear of presentation or tonality (all p > .1) nor were there any significant interactions (see Figure 10b and 10c). Refer to Appendix I for the complete MANOVA tables.

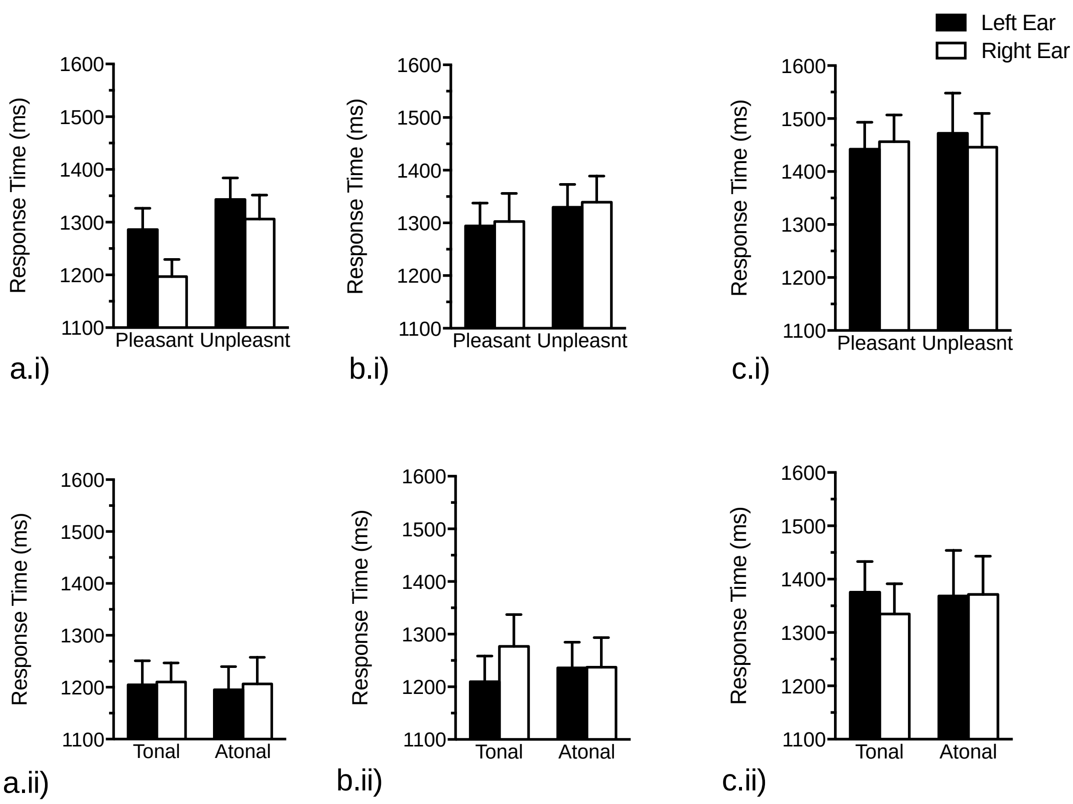

Figure 10. Mean response times (SEM) to correctly classify 850 ms duration melodies during monaural (a), distractor noise (b) and dichotic (c), presentations in the affective (i) non-affective (ii) classification task.

Sensitivity and bias

In the affective classification task, there was a significant main effect for presentation condition for sensitivity to pleasantness, , Wilks λ= .63, $F_{(2, 32)}$= 9.15, p=.001, η_p^2= .36, however the significant interaction between the presentation condition with the ear of presentation, Wilks λ= .65, $F_{(2, 32)}$= 8.59, p=.001, η_p^2= .34, indicates that this effect depended on the attended ear. Figure 11a illustrates clearly that sensitivity to pleasantness was greater when the target melody was presented to the right ear than the left during dichotic presentation. In all other stimulus presentations the overlap in the 95% CI's illustrates the similarity in sensitivity to pleasantness between the ears. Response bias also differed between the presentation conditions. Figure 11b illustrates that participants were biased toward responding "pleasant" (indicated by negative vales of c) in the monaural and "with noise" conditions regardless of the ear the target stimulus was presented to. However, for dichotic presentation, participants were only biased to responding pleasant when the target melody was presented to the right ear while response bias did not differ from zero for left ear presentations.

In the non-affective control task, sensitivity to tonality was greater in the left ear than the right, Wilks λ= .78, $F_{(1, 27)}$= 7.49, p=.011, η_p^2= .22. There was also a significant main effect for presentation procedure, Wilks λ= .33, $F_{(2, 26)}$= 26.6, p<.001, η_p^2= .67, although the ear by presentation interaction was not significant, Wilks λ= .82, $F_{(2, 26)}$= 2.78, p=.08, η_p^2= .18. Figure 11b illustrates that the ear of presentation effect though significant was modest and is only clearly evident in the dichotic presentation condition. Similarly, sensitivity was lower when noise was presented to the unattended ear then the other presentation conditions, although the CI's still overlap. As in the affective task, response bias was negative in the monaural and "with noise" conditions indicating that participants were biased toward classifying the target melody as "in key" in these conditions. Response bias did not differ from 0 in the dichotic presentation condition. There were no differences in response bias between the left and right ear when classifying any of the melodies as in key or out of key.

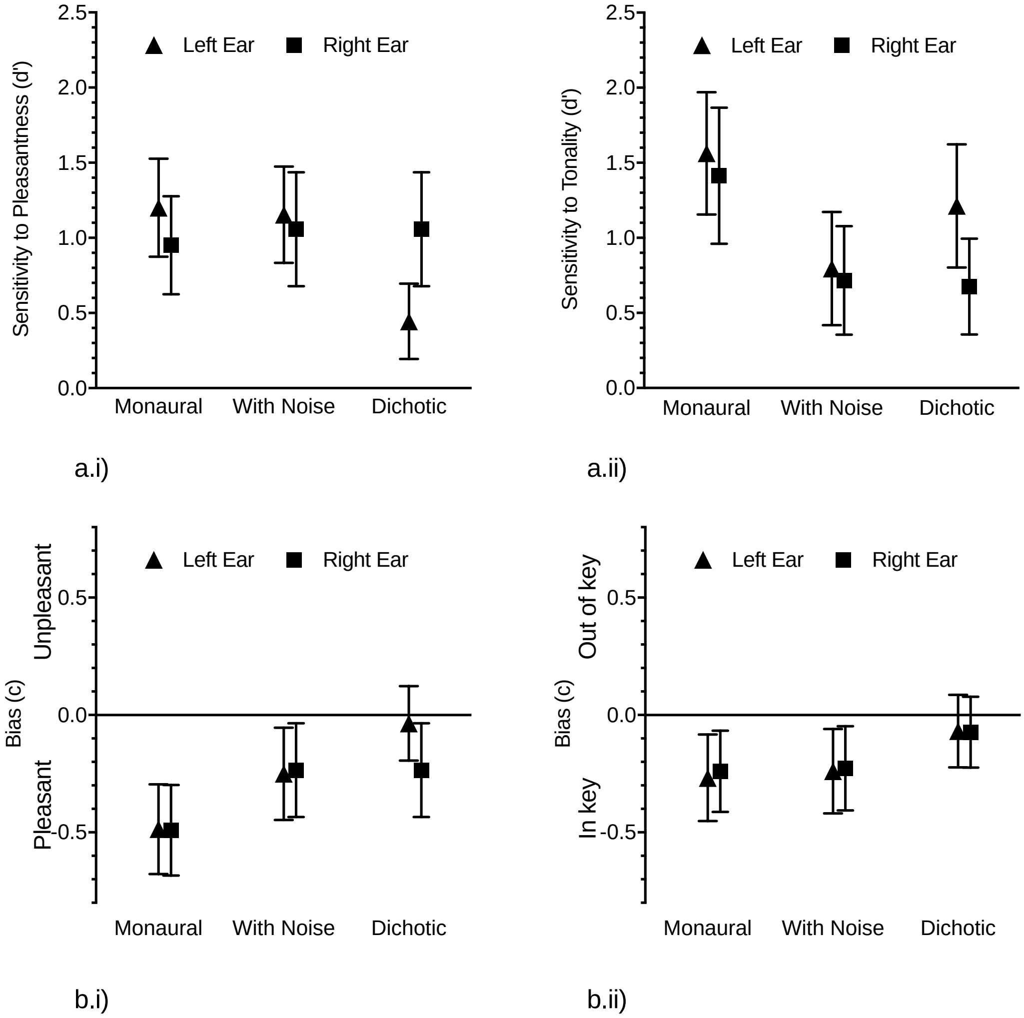

Figure 11. Mean Sensitivity (a) and bias (b) with 95% confidence intervals to pleasantness in the affective judgment task (i) and tonality in the non-affective judgment task (ii) for 850 ms duration melodies.

Summary

Overall, there were no differences in response time between the ears when participants affectively appraised melodies or made a musical classification from any stimulus presentation. However, sensitivity to pleasantness was greater when the target melodies were presented to the right ear than the left during dichotic presentation and the opposite effect occurred when a musical judgment was required. Finally, participants were biased to responding pleasant and in key during monaural and distractor noise presentations while dichotic presentation resulted in no response bias when attending to the left ear but a bias to classify the melodies as pleasant when presented to the right ear. This difference in bias between the ears was not present when a musical classification of the same melodies as in key was made.

Discussion

When the stimulus duration of the melodies was reduced the results of the fourth experiment differed from the third. There was no significant difference between the left ear and the right in the time taken to classify the affect or tonality of the melodies in any of the stimulus presentation conditions. However, in the dichotic presentation procedure, in which a competing melody was presented to the unattended ear, participants were more sensitive to the pleasantness of the target melodies when they were presented to the right ear than to the left. Critically, when classifying the same melodies in the non-affective task, this ear effect was reversed with sensitivity to tonality being greater in the left ear than the right. Thus, the ear effect observed in the affective task appears to be specific to emotional processing and distinct from non-affective processes associated with simply making a musical judgment. The sensitivity data is consistent with the valence effect in which stimuli processed by the left hemisphere are likely to be appraised more positively than stimuli processed by the right hemisphere (Gagnon & Peretz, 2000; Marzoli & Tommasi, 2009; Prete et al., 2015).

The finding that participants were more sensitive to making tonal classifications of the same melodies presented to the left ear than the right in the control task is consistent with studies showing that many aspects of music processing appear to be right hemisphere processes (e.g., Hugdahl et al, 1999; Wioland et al., 1999; Roucher & Bryden, 1997; Morais et al., 1982). While affective processing of melodies resulted in distinct ear differences only from dichotic presentation, the non-affective data indicates that over the three procedures tested all appear to be able to detect non-affective behavioural consequences that are assumed to result from hemispheric specialisation. However, this left ear advantage was modest and only appears evident with dichotic presentation despite the ear of presentation and stimulus presentation interaction not being significant.

Importantly, in the affective classification task response bias was also consistent with a right ear presentation being appraised more positively during dichotic listening, since any stimulus presented to the right ear during dichotic presentation condition was more likely to be classified as pleasant regardless of valence. Importantly, this response bias was not present when a comparative tonality judgment was required indicating that the bias to classify the melodies as pleasant when presented to the right ear is related to emotional processing. There was however no equivalent bias toward appraising stimuli presented to the left ear as unpleasant in the same dichotic presentation condition. Thus, in addition to the sensitivity data, the response bias data is also consistent with a valence effect in which stimuli processed by the left hemisphere are likely to be appraised more positively.

The response bias results also suggest another advantage of dichotic presentations. Responding appeared to be consistently negatively biased toward either a “pleasant” or “in key” response in the monaural and distractor noise conditions. On the other hand, dichotic presentations resulted in the least biased responding of all the procedures tested here. In only one dichotic condition was there evidence of significant response bias, and that was in the affective task when the target melodies were presented to the right ear, a result with theoretical implications. In this one condition, bias to responding *pleasant* did not appear to result in a decrease is sensitivity to the pleasantness of the stimuli, since sensitivity to pleasantness was greater in this right ear condition than in the unbiased opposite left ear condition. Thus, of the three stimulus presentations compared, dichotic presentation resulted in the least biased responding other than in one instance that lends support to the valence effect.

Thus, like Experiment 3, dichotic listening appears to be the best method to detect an ear advantage when participants affectively appraise melodies, and thus might be the best procedure to detect behavioural consequences of emotional processing. However, in contrast to Experiment 3 that found evidence consistent with the right hemisphere hypothesis, the results of Experiment 4 are consistent with the valence effect.

General Discussion

The aim of Experiments 3 and 4 was to explore whether consistent ear advantages emerged when participants classified the non-emotional and emotional aspect of melodies from monaural, distractor noise, and dichotic presentation. Only with longer melodies were any ear differences in response time observed and then only in the dichotic listening task. Participants classified both pleasant and unpleasant melodies faster when presented to the left ear than the right. Since no equivalent ear advantage occurred in the non-affective control task, this left ear advantage appears to be specific to making an emotional appraisal of the melodies. This failure to find a valence effect was surprising as the melodies were similar to those presented by Gagnon and Peretz (2000) who did observe a valence effect. Nevertheless, this result is consistent with dichotic listening research that demonstrates a left ear advantage in processing the affective features of stimuli irrespective of emotional valence consistent with the right hemisphere hypothesis (e.g. Bryden et al., 1982; Haggard & Parkinson, 1971; Hatta & Ayetani, 1985; Ley & Bryden, 1982; Safer & Leventhal, 1977; Saxby & Bryden, 1984).

However, when reduced duration versions of the same melodies were presented to participants in Experiment 4, unlike Experiment 3, there was no difference between the ears in the time taken to classify the affect or tonality of the melodies in any stimulus presentation conditions. Then again only during dichotic presentation, participants were both more sensitive to the pleasantness of melodies presented to the right ear than the left, and were also biased to making a “pleasant” classification when the target melodies were presented to the right ear. In contrast, in the non-affective control task, participants were more sensitive to the tonality of the melodies when they were presented to the left ear than the right and response bias did not differ from zero between the ears when a musical classification was made. Thus, with brief melodies, data from both sensitivity and response bias lend support to the valence effect, albeit different from that reported by Gagnon and Peretz (2000) who found the effect with melodies presented monaurally. In neither experiment reported here was there any evidence of a valence effect with monaural presentations of melodies.

The finding that response bias differed between the ears from affective classifications of brief melodies during dichotic presentation is perhaps the most interesting ear difference observed. That participants were more likely to respond “pleasant” when a stimulus was presented to the right ear is very similar to Marzoli and Tommasi’s (2009) finding that a request for a cigarette was more positively appraised when presented to the right ear than the left. This behavioural effect is distinct from sensitivity or reaction time measures which indicate that one hemisphere might be better able to recognise the emotional valence of a target in that it shows that the emotional response to a target varies depending on the ear to which it is presented. In both this study and Marzoli and Tommasi, stimuli presented to the right ear seemed to be appraised more positively. Thus, the ear of presentation might not only enhance the ease with which certain emotions are processed but influence the valence of the emotion experienced. However, this effect was only evident from the affective appraisal of brief melodies presented dichotically. Thus, affective stimuli might be required to be brief and be presented dichotically to detect such effects.

Nevertheless, the primary difference between Experiment 3 and 4 was the duration of the melodies, with longer durations eliciting results consistent with the right hemisphere hypothesis and brief versions a valence effect. Considering this, caution is recommended when attributing these results as emotion laterality effects since the same stimuli differing only in duration can give rise to data consistent with two different theories of the lateralisation of emotion. This outcome certainly questions the validity of testing for ear advantages as indices of hemispheric specialisation of emotional processing. What is clear is that the duration of the stimulus matters. Interpreting these findings as hemispheric processing of auditory emotional stimuli seems unjustified considering the stimuli are the same. All that can be said is that relatively brief melodies provide sensitivity and response bias evidence consistent with the valence effect, while the longer versions lend support to response times consistent with the right hemisphere hypothesis, again both from dichotic presentation.

One issue concerning dichotic presentation has been the impact of asymmetric ipsilateral suppression favouring the right ear to left hemisphere route (Fujiki et al., 2002). In Experiment 3 and 4, neither dichotic listening task revealed shorter response times to stimuli presented to the right ear. Instead, shorter response times for the left ear were observed but only with the longer duration melodies and only in the affectively classification task. The only right ear effects to emerge were from sensitivity and response bias when participants affectively appraised brief versions of the same melodies presented dichotically. However, since neither of these effects emerged in the non-affective control tasks, these results suggest that these ear advantages are more related to emotional processing than asymmetric ipsilateral suppression. Indeed, it is difficult to observe the behavioural consequences of asymmetric ipsilateral suppression with something approaching a real-world stimulus. Thus, even simple melodies might be too complex to observe effects related to asymmetric ipsilateral suppression. However, the ear advantages from both experiments at least demonstrate asymmetric ipsilateral suppression does not interfere with dichotic presentation detecting ear advantages consistent with the right hemisphere hypothesis and the valence effect.

The intention of this chapter was to further explore the behavioural consequences of emotional processing when participants affectively appraised melodies during monaural, with distractor noise, and dichotic presentation. That only a dichotic presentation resulted in observed differences between the ears across both experiments lends empirical support to Kimura's (1964, 2011) claim that dichotic presentations create task demands that yield ear advantages. The results of these experiments also demonstrate that ear advantages obtained from dichotic presentation can be consistent with both the right hemisphere and the valence effect depending on the duration of the stimuli and the behaviour measured. This chapter contributes to understanding in this area of research, that relatively brief duration stimuli might be required to provide a more accurate estimate of sensitivity and response bias related to hemispheric function highlighting the importance of considering stimulus duration when examining hemispheric specialisation. However, given that the same stimuli differing only in duration gave rise to data consistent with the right hemisphere hypothesis and the valence effect, the validity of testing for ear advantages and attributing differences as an absolute index of hemispheric specialisation of emotional processing may be questioned.

Chapter 4. The impact of auditory presentation procedures on behavioural measures of emotion lateralisation

The aim of this thesis was to determine whether the presentation procedure impacts ear advantages in the emotional appraisal of speech and music. This thesis was not concerned with testing whether the right hemisphere hypothesis or the valence effect explain the neural organisation of emotional processing since both theories are too coarse an explanation of emotional processing (Fusar-Poli et al., 2009; Lindquist et al., 2012; Phan et al., 2002; Witteman et al., 2012). Rather, why behavioural experiments produce mixed results was explored to determine why the valence effect is rarely reported in studies with dichotic presentation of stimuli. One possibility is that ear effects in emotional processing are systematically related to the presentation procedure employed. Thus, in the current study, participants appraised emotion in speech and music presented either monaurally or with distractor pink noise or dichotically to explore under what conditions systematic ear effects would be observed.

When participants classified the emotional aspects of speech, different ear advantages emerged as a consequence of the stimulus presentation procedure and the behaviour measured. Dichotic presentations of words produced a right ear advantage in response times regardless of the classification required. This finding perhaps indicates very little about emotional processing since the same effect was found in the emotional and non-emotional classification tasks, however it is consistent with left hemisphere superiority in language processing (Bryden, 1988; Kimura, 1961; Strauss, 1983). Presentation of the same words with distractor pink noise did not produce any ear effects in the classification of any aspect of speech. However, monaural presentations of speech produced a different ear effect to dichotic presentations.

Unpleasant words were classified less accurately when presented to the right ear, however, this ear effect was irrespective of whether participants made an emotional content or part of speech classification, and thus it cannot be attributed to making an emotional appraisal of the words. Overall, dichotic presentation was the most consistent measure to produce ear effects, however no ear effects were consistent with the right hemisphere hypothesis or the valence effect.

In the appraisal of melodies, ear effects only occurred with dichotic presentations and depended on both the duration of the melodies and the behaviour being measured. With the longer melodies, participants were faster to make an emotional classification of the melodies when the target melodies were presented to the left ear, consistent with the right hemisphere hypothesis (Bryden et al., 1982). This ear advantage can be attributed to emotional processing as it was not evident in the non-affective control condition. However, with brief versions of the same melodies, participants were most sensitive to the pleasantness of the melodies when the target melodies were presented to the right ear, consistent with the valence effect (Gagnon & Peretz, 2000; Marzoli & Tommasi, 2009). This effect can also be attributed to emotional processing as the opposite pattern of responses occurred when a non-affective classification was required (an effect consistent with the right hemisphere's role in music processing, c.f. Hugdahl, 1999; Wioland et al., 1999 and Roucher & Bryden, 1997). Participants also showed significant bias in their emotional appraisal of brief melodies as pleasant when presented to the right ear. This response bias did not occur in the non-affective control task, and is thus consistent with the valence effect. This is the first evidence of the valence effect from dichotic listening with music which can be unambiguously attributed to emotional processing, although valence effects have been demonstrated using the divided visual field technique (Prete et al., 2015).

In the experiments reported in Chapter 2 and Chapter 3, dichotic presentation was the only procedure to consistently produce ear effects, and music was the only stimulus to elicit ear effects predicted by the both the right hemisphere hypothesis and the valence effect. However, since it is not possible for both emotion laterality theories to be true, the following discussion will address what might influence an ear advantage in emotional processing and conclude with the broader issue of using an ear advantage to measure something as complex as emotional processing.

Ear effects in emotional processing with speech and music

Dichotic presentation studies with lexical emotion (Sim & Martinez, 2005) and emotional prosody (Haggard & Parkinson, 1971; Hatta & Ayetani, 1985; Ley & Bryden, 1982; Safer & Leventhal, 1977; Saxby & Bryden, 1984; Voyer et al., 2009) generally report a left ear advantage when an emotional appraisal is required, consistent with the right hemisphere hypothesis. However, Marzoli and Tommasi (2009) report a valence effect with verbal requests for a cigarette, although the absence of a control condition in this field study makes it unclear whether the right ear advantage to agree to a cigarette request was due to affective appraisal or other aspects of processing the spoken message. Grimshaw et al. (2009) demonstrated when only one emotional unit (i.e. emotional prosody) is presented per trial the typical right ear advantage to linguistic processing is attenuated (shifted to the left ear) if the emotional prosody is sad, consistent with the valence effect. When Godfrey and Grimshaw (2016) replicated this study with more power, the typical right ear advantage for linguistic processing was attenuated for all emotional prosodies (happy, angry, fearful and sad), consistent with the right hemisphere hypothesis. In both studies, emotional prosody was incidental to the task, whereas in the current experiments emotional processing was task relevant. Despite presenting only one target emotion per trial, there was no evidence of ear effects with lexical emotion or emotional prosody consistent with the right hemisphere hypothesis or the valence effect. The most consistent finding was that dichotic presentations produced a right ear advantage in response times to words regardless of the aspect of speech classified. Since the right ear effects were present in each classification task, the most parsimonious conclusion is that the same process was being used in each task, and thus that these ear effects are related to language rather than emotional processing.

Behavioural studies on the affective appraisal of music report ear effects consistent with both the right hemisphere hypothesis and the valence effect. While Bryden, Ley and Sugarman's (1982) dichotic presentation study demonstrated an overall left ear advantage with affective appraisals of melodies consistent with the right hemisphere hypothesis, the valence effect occurred on trials when the affect of the target and competing melodies were the same. However, these authors failed to include a control condition to verify that the effects observed were due to emotional processing. Gagnon and Peretz (2000) report the valence effect with melodies presented monaurally, and this effect was verified by a comparable control condition. In Experiments 3 and 4, no such ear effect was observed with monaural presentations of melodies despite the similarity between these experiments and Gagnon and Peretz's study. Only the dichotic presentation of melodies produced ear effects, with longer versions consistent with the right hemisphere hypothesis in response time and brief versions the valence effect in sensitivity to pleasantness and response bias. Since none of these effects were evident in the respective control conditions, this seems to indicate that the effects are related to emotional processing.

However, the validity of using ear advantages from dichotic presentation to measure how individuals process the emotional aspect of speech and music might be questioned. Despite using a control condition to distinguish affective appraisal from linguistic judgment, dichotic presentations of emotionally laden words did not produce any behavioural distinction between linguistic, lexical emotion, and emotional prosody. This is problematic considering the neural underpinnings of these aspects of speech are quite distinct (Abbassi et al., 2000). It is also problematic that dichotic presentations of melodies that differed only in duration produced ear effects consistent with both emotion laterality theories since it is not possible for both theories to be true. That dichotic presentations can produce ear effects consistent with both the right hemisphere hypothesis and the valence effect suggests factors beyond the presentation procedure must also contribute to these effects. The next section will address why only dichotic presentation consistently produced ear effects and discuss what might be required for this procedure to produce effects specific to emotional processing.

Presentation procedure

Kimura (1961) has argued that ear advantages can be demonstrated only from dichotic presentation in which different stimuli are presented to each ear simultaneously. This assertion is based on dichotic stimulation resulting in ipsilateral suppression, which enhances processing in the contralateral hemisphere. While it is not possible with any presentation procedure to restrict auditory processing to one hemisphere, the consequence of ipsilateral suppression is that an ear advantage can be attributed to superior processing in the contralateral hemisphere. Ipsilateral suppression with dichotic presentation was demonstrated by Brancucci et al (2004) however only when two competing tones shared the same fundamental frequency.

This dependence on a shared fundamental frequency is problematic for the application of ipsilateral suppression in many dichotic experiments that use complex stimuli such as speech or music since both consist of complex sounds over a wide frequency band that make it unlikely that stimuli share the same fundamental frequency.

The competing words and melodies employed in the experiments in this thesis spanned the same frequency range, however they were not identical in fundamental frequency. Despite this, dichotic presentation was still the only procedure to consistently produce ear effects. However, it is possible that on the odd occasion a musical note within a target melody shared the same fundamental frequency as a note in the distractor melody, but this would have been relatively rare. Thus, it cannot be concluded that ear effects from dichotic presentation are just due to ipsilateral suppression. Moreover, the distractor pink noise spanned the same frequency range as the target stimuli, however no ear effect occurred when distractor pink noise was presented to the unattended ear. Thus, just presenting any competing stimulus that spans the same frequency range as the target stimulus is not sufficient to elicit an ear effect. Since dichotic presentation was the only procedure to consistently produce ear effects and no ear effects occurred with distractor pink noise, this would suggest that there needs to be some relationship between competing stimuli in either meaning and or complexity (Stefanatos et al., 2008). However, this cannot be the only explanation since monaural presentation also produced an ear effect, albeit only in one instance.

Because monaural and dichotic presentations of the same words produced different ear effects, this also questions the validity of using ear advantages from these procedures to measure hemispheric asymmetry. One explanation for why monaural and dichotic presentation produced different ear effects from presentations of the same words is asymmetric ipsilateral suppression. Fujiki, Jousmaki, and Ritta

(2002) measured auditory evoked magnetic fields in each cerebral hemisphere in response to tones presented to participants monaurally and dichotically. When the tones were presented monaurally, sharp peaks occurred in both hemispheres and these peaks were significantly larger in the contralateral than ipsilateral hemisphere. However, when the same tones were presented dichotically, right ear inputs had significantly stronger projections to the left hemisphere than left ear inputs to the right hemisphere. This finding is problematic for the validity of ear advantages from dichotic presentations because it is difficult to distinguish the relative contribution of hemispheric asymmetry from asymmetric ipsilateral suppression effects. If asymmetric ipsilateral suppression has any consequences for something approaching a real-world stimulus the most common ear effect from dichotic presentation would be a right ear effect.

In Experiment 1, dichotic presentations resulted in faster response times to target words presented to the right ear regardless of the classification required, whereas monaural presentation of the same words resulted in unpleasant words being classified less accurately when presented to the right ear, also independent of the classification required. Thus, one explanation of why dichotic presentation elicited a different result to monaural presentation is that asymmetric ipsilateral suppression from dichotic stimulation might have facilitated each right ear effect. However, since both language and asymmetric ipsilateral suppression are associated with the left hemisphere it was not possible to conclude whether either of these or the interaction of both contributed to the right ear effects. Thus, to remove the linguistic aspect of speech to focus on emotional processing, in Experiment 2, a low pass filter was applied to the words to strictly focus on emotional prosody.

When participants classified the emotional prosody of speech and the meaning of the word was unavailable, only a right ear advantage in response times occurred, and again only with dichotic presentations. This finding was inconsistent with dichotic presentation studies that report a left ear advantage when participants classify emotional prosody (Haggard & Parkinson, 1971; Hatta & Ayetani, 1985; Ley & Bryden, 1982; Safer & Leventhal, 1977; Saxby & Bryden, 1984; Voyer et al., 2009), although it was identical to the right ear effect in response time to words reported in Experiment 1. If emotional prosody is treated as a language related feature, then each right ear effect with speech might be a consequence of language processing. However, if these effects are due to asymmetric ipsilateral suppression then a right ear advantage would occur irrespective of linguistic or emotional processing, which was also the case. As it was not possible to determine the contribution of language processing and asymmetric ipsilateral suppression on these right ear effects, the validity of dichotic presentation to measure emotional processing was further explored with musical stimuli.

Ear advantages with melodies only occurred with dichotic presentations. However, the only right ear effects were participants' sensitivity to pleasantness of the brief versions of melodies as well as a bias to classifying the brief melodies as pleasant regardless of being in or out of key. Critically, since neither right ear effect occurred in the corresponding non-affective control tasks, this might indicate that these valence effects are associated with emotional processing rather than asymmetric ipsilateral suppression. These findings also suggest that the right ear advantages with dichotic presentations of each aspect of speech are more likely to be language effects rather than just asymmetric ipsilateral suppression. The ear advantages with melodies thus contributes to knowledge in that asymmetric ipsilateral suppression does not interfere with dichotic presentation producing ear effects associated with emotional processing.

Overall, the experiments reported in Chapter 2 and Chapter 3 further contribute to knowledge in that only dichotic presentations consistently produce ear effects with emotionally laden speech and music. This finding is similar to Hammond's (2010), of a right ear effect in response accuracy to words only in dichotic presentations. However, this is the first study to explicitly explore ear effects in the emotional appraisal of speech and music with monaural, distractor pink noise, and dichotic presentation. Asymmetric ipsilateral suppression from dichotic presentations did not interfere with this presentation procedure producing ear effects consistent with both the right hemisphere hypothesis and the valence effect. However, if dichotic presentation can produce ear effects consistent with both emotion laterality theories, this indicates that factors beyond the presentation procedure also contribute to ear effects being consistent with the right hemisphere hypothesis and the valence effect.

Stimulus duration

Ear effects consistent with the two emotion laterality theories depended not only on dichotic presentation of melodies but the melody duration, with longer versions consistent with the right hemisphere hypothesis and brief versions the valence effect. This finding is similar to Prete, Laeng, Fabri, Foschi, and Tommasi's (2015) divided visual field study investigating the perception of facial affect. They reported that the valence effect is more robust when stimuli are presented briefly. However, the reason why brief visual presentations are required to produce a hemifield effect cannot explain why hemispheric asymmetries with auditory stimuli also depend on stimulus duration. To ensure that an image is initially only processed by the contralateral hemisphere, visual stimuli must be presented to the left or right of a central fixation point and stimulus presentation duration must be short enough to prevent participants' moving their eyes to fixate on the target and thus expose the visual stimulus to both hemiretinas (Sergent, 1997). Thus, divided visual field presentations of images that are brief ensure that the valence of a stimulus is initially processed by only the contralateral hemisphere. In contrast, both hemispheres always process auditory stimuli because a sound presented to one ear is processed bilaterally. Thus, it is not possible to present auditory stimuli briefly to restrict early processing to only one cerebral hemisphere. Why the valence effect occurred from brief presentations of melodies might be better explained by what is required to process visual and auditory stimuli.

In addition to anatomical differences between visual and auditory perception pathways, differences in processing visual and auditory stimuli exist. Processing an image, such as an emotional face, is a parallel process in which the whole face, including its emotional attributes, can be processed simultaneously and thus rapidly. In contrast, an auditory stimulus is temporal in its very nature. Thus, processing a word or a melody, as well as its emotional attributes, is drawn out in time. Participants are required to listen to the whole item (i.e. a melody) before being able to make an emotional appraisal. For example, an atonal note might not occur until later in the melody. Both "unpleasant" and " out of key" judgments depend on this note. This extra time to process and respond to the melodies, with dichotic presentation (which is already a complex task) means processing has plenty of time to spread within and between hemispheres and involve areas of the brain beyond emotional processing (Stefanatos et al., 2008). Thus, presenting visual stimuli with the divided visual field technique is a more precise means of determining hemispheric specialisation than dichotic presentation. Nonetheless, if auditory stimuli are brief, allowing participants to process and respond more quickly, it is reasonable to assume that this might reduce unwanted processes (e.g. changes in attention or decision making) that are more likely to arise if the same stimuli are longer in duration. Thus, brief auditory stimuli should be more reliable than longer versions in experiments designed to detect ear effects.

One possible issue with reducing the intervals between the notes is that this manipulation would have also changed the tempo of the melodies. Importantly, faster tempos are often considered more pleasant than music with a slower tempo (Husain et al., 2002). Thus, one explanation that participants were biased to classify the brief melodies as “pleasant” when presented to the right ear during dichotic presentation might be that the previously unpleasant melodies were now considered pleasant. However, participants in the pilot study in Experiment 4 classified the valence of the melodies correctly, suggesting that altering the tempo did not change the valence of the melodies. If the bias to respond “pleasant” was primarily due to increased tempo, one would expect an overall bias to respond “pleasant” to the brief melodies regardless of the ear of presentation or the presentation condition, which was not the case. The overall pattern of response bias was similar for both melody experiments despite the tempo manipulation. In both experiments, there was a bias to classify melodies as “pleasant” and “in key” during monaural and distractor noise presentation. However, dichotic presentation demonstrated no biased responding in either experiment other than the one instance where brief melodies were classified as “pleasant” when presented to the right ear. Thus, while it is not entirely clear whether this valence effect is a consequence of reducing the melody duration or increasing the tempo, the valence effect depended on melody duration.

Why the longer versions of the same melodies resulted in an overall left ear advantage in response time consistent with the right hemisphere hypothesis is unclear. However, the implication of this finding is that dichotic presentation studies that typically employ longer duration stimuli such as sentences or music and demonstrate a left ear effect consistent with the right hemisphere hypothesis might be unreliable. Dichotic presentation studies generally report emotion laterality effects without considering the impact of stimulus duration. To produce the valence effect with dichotic presentation it seems that briefer stimuli provide the clearest picture. However, it might still be possible to elicit a valence effect with longer stimuli such as sentences since Marzoli and Tommasi (2009) attribute their right ear advantage from verbal requests for a cigarette to the valence effect. The single difference between Experiment 3 and 4 was the length of the melodies. Since only sensitivity to pleasantness and response bias of brief melodies was consistent with the valence effect, and these effects were only demonstrated in the affective appraisal tasks, it suggests that dichotic presentations can produce the valence effect when the duration of stimuli is brief.

The behaviour measured

Most behavioural research using ear advantages as an index of laterality effects report response times and accuracy differences between the left and right ears (Haggard & Parkinson, 1971; Hatta & Ayetani, 1985; Ley & Bryden, 1982; Safer & Leventhal, 1977; Saxby & Bryden, 1984; Voyer et al., 2009). Differences in response time between the ears is interpreted as one hemisphere being faster than the other in processing stimuli, while differences in accuracy are attributed to one hemisphere classifying stimuli more correctly than the other. However, response times or accuracy do not demonstrate why one hemisphere is superior to the other. Individuals are both ‘sensors’ and ‘decision makers’, and in contrast to response time and accuracy, Signal Detection Theory measures of sensitivity and response bias can measure these distinct processes separately. Only dichotic presentations of brief melodies resulted in a right ear effect in sensitivity to pleasantness as well as a bias to respond pleasant in the affective appraisal task, consistent with the valence effect. With longer versions of the same melodies there were no differences between the ears in either sensitivity or response bias. These findings suggest that measures of sensitivity and response bias can detect differences between the ears in emotional processing provided the stimuli are brief.

Dichotic presentation also resulted in the least biased responding of the three presentation procedures compared. Participants were biased to responding pleasant in the affective task, and in key in the non-affective task, with monaural and distractor pink noise presentations, whereas the only instance dichotic presentation produced response bias was when participants made an affective appraisal of brief melodies presented to the right ear, and this result has theoretical implications. This bias to respond pleasant, did not decrease the participants’ sensitivity to the pleasantness of the melodies, since sensitivity to pleasantness remained greater in the same right ear condition than the equivalent opposite unbiased left ear condition. Thus, the advantage of using dichotic presentations over monaural and distractor pink noise is evident in that it was the only presentation procedure that resulted in unbiased responding, other than in one instance consistent with the valence effect.

The finding that participants were biased to respond “pleasant” when brief target melodies were presented dichotically to the right ear is perhaps the most important ear difference observed. Significant bias in responding “pleasant” indicates that the decision criteria for a response is shifted toward making a “pleasant” response for all melodies not just the tonal melodies. This might indicate that right ear presentations tend to be regarded as more pleasant and this might be the same mechanism underlying Marzoli and Tommasi's (2009) observation that questions posed to the right ear were treated more positively. Thus, the ear of presentation might not only enhance the sensitivity with which certain emotions are processed but influence the decision related to the emotion experienced. However, this effect occurred only with brief melodies dichotically suggesting it might depend on dichotic presentation and presenting stimuli briefly.

Overall, the two factors that differed in the music experiments that produced ear effects predicted by the right hemisphere hypothesis and the valence effect were the duration of the melodies and what behaviour was measured. Therefore, it seems unjustified to attribute these ear differences as emotion laterality effects because the same set of emotional stimuli that differed only in duration gave rise to results consistent with two conflicting theories of hemispheric specialisation of emotional processing. These findings certainly question the validity of testing for ear advantages as indices of the lateralisation of emotional processing. What is clear is that ear effects consistent with the right hemisphere hypothesis and the valence effect depend on the presentation procedure, the stimulus and its duration, and what behaviour is being measured. Results produced from longer melodies lend support to this in that response times were consistent with the right hemisphere hypothesis and yet relatively brief versions provided sensitivity and response bias evidence consistent with the valence effect, again both only from dichotic presentation.

Broader issue of the neural organisation of emotional processing

This thesis demonstrates that only dichotic presentation consistently produces ear effects when individuals classify emotionally laden speech and music. However, concluding that an ear advantage is an index of hemispheric specialisation is problematic. Firstly, the broader issue is that affective neuroscience has advanced beyond the point where either the right hemisphere hypothesis or the valence effect adequately explains the neural organisation of emotion. Meta-analyses of the neural organisation of emotional processing (Fusar-Poli et al., 2009; Lindquist et al., 2012; Phan et al., 2002; Witteman et al., 2012) demonstrate complex bilateral processing with many regions of the brain associated with the perception and experience of emotion. A contemporary consensus is that the neural organisation of emotion has advanced beyond any left-brain, right-brain lateralisation theory. Nevertheless, distinct behavioural differences between stimuli presented to one hemisphere and the other are robustly observed with both visual and auditory stimuli. Divided visual field studies investigating the perception of facial affect have been consistent with both the right hemisphere hypothesis and the valence effect while dichotic presentation studies are almost always consistent with the right hemisphere hypothesis. To reconcile these differences a critical review of behavioural experiments was required with a focus on the methods used to measure hemispheric asymmetry as this was thought to be the most likely explanation for the observed inconsistencies.

This thesis demonstrates that dichotic presentation can produce ear advantages predicted by both the right hemisphere hypothesis and the valence effect and this finding is consistent with divided visual field studies investigating the perception of facial affect. Thus, there are several contributions to knowledge from this thesis. Divided visual field studies have begun to report that one versus two competing emotions per trial elicits a visual field advantage consistent with the valence effect and right hemisphere hypothesis respectively. This procedure needs to be employed in dichotic experiments. Similarly, if longer and briefer versions of the same melodies can produce ear effects consistent with the right hemisphere hypothesis and the valence effect respectively, then stimulus duration needs to be addressed in future auditory experiments. Since sensitivity and response bias distinguish between participants' sensitivity to an emotion versus the decision criteria to make an emotion response, these measures can help determine how an ear advantage in emotional processing is theoretically relevant. Finally, systematically addressing general inconsistencies, such as whether the stimulus employed is speech or music, equating its emotional valence and arousal, employing comparative control conditions, a focused attention task, and screening participants for equal hearing sensitivity and handedness, will all help ensure a systematic comparison of ear effects on emotional processing is being undertaken. The exclusion of these potential moderating factors in the current research is a potential explanation for discrepancies between past and current research.

This thesis drew on strengths from divided visual field research investigating the perception of facial affect to highlight issues in auditory research, which was the focus of this thesis. That the findings of this thesis are consistent with divided visual field studies on the perception of facial affect is a strength of this thesis since facial affect perception is a well-established area within visual emotion laterality research. On the other hand, any visual field or ear advantage is always going to be limited to a left brain, right brain theory of emotional processing. Since both behavioural procedures do produce effects consistent with the right hemisphere hypothesis and the valence effect, and it is not possible for both theories to be true, this raises the broader question of why researchers are continuing to use these procedures to ask which theory explains emotional processing. This is certainly not to say researchers should discontinue using these methods to determine the behavioural consequences of emotional processing. The finding by Marzoli and Tommasi (2009) that individuals are twice as likely to accept a cigarette request when the request is addressed to the right ear is a fascinating result. However, asking which emotion laterality theory explains the neural underpinnings of emotion is problematic since the contemporary status has advanced to an understanding beyond what any visual field or ear advantage theory can provide. Thus, caution is recommended in attributing any visual field or ear advantage as an index of emotional processing. Finally, if two competing hypotheses appear to both have support, it might be necessary to reframe the question to determine under what stimulus and task parameters one is likely to observe these effects. The findings of this thesis demonstrate stimulus and task factors can predict ear advantages used to measure emotional processing.

Overall, the difficulty in replicating the valence effect with auditory stimuli is apparent from the findings of the experiments reported in this thesis. Thus, one must be careful not to base any conclusion of these results as fact until the valence effect can be reliably replicated. Given the practical constraints of recruiting participants, the sample in each study reported here was in the mid-range of previously reported sample sizes (Bryden et al., 1982; Gagnon & Peretz, 2000; Grimshaw et al., 2009; Prete et al., 2015) but was still probably not ideal. Given the valence effect only occurred in one instance out of all the stimulus presentations that included language and music, it is possible that the valence effect reported in the current thesis might simply be a type one error (Open Source Collaboration, 2015), Thus, replications are recommended before any firm conclusions can be drawn.

In summary, any contemporary approach to understanding the lateralisation of emotion must recognise that hemispheric asymmetry is too coarse an explanation of emotional processing. However, distinct hemispheric asymmetries demonstrated by visual and auditory experiments do occur. Both divided visual field and dichotic presentations can produce effects consistent with the right hemisphere hypothesis and the valence effect, however which effect occurs depends on the method employed. Like facial affect, dichotic presentation can produce the valence effect with melodies, if they are presented briefly, and if the behaviour measured is sensitivity to pleasantness and response bias. However, concluding that an ear advantage is an index of hemispheric specialisation of emotional processing may be questioned.

Conclusion

A popular topic regarding the human brain is whether an individual is left brained, or right brained. One question in affective neuroscience is which hemisphere is responsible for emotional processing. This thesis provides a foundation for a more systematic approach to studying behavioural effects of emotional processing so that hemispheric asymmetry does not continue to be a misunderstood or frustrating topic within affective neuroscience. Affective neuroscience continues to use visual field and ear advantages to test the right hemisphere hypothesis and the valence effect or to simply illustrate that these behavioural effects exist. The intention of this thesis is to inform researchers interested in hemispheric specialisation of emotional processing to firstly acknowledge a contemporary account of emotional processing, then consider what methodological factors produce the behavioural patterns observed so that visual field and ear advantages are no longer attributed as absolute indices of emotional processing. This approach could also extend to lesion studies and modern neuroimaging techniques studies intended to test the right hemisphere hypothesis and the valence effect and thus provide more clarity to the extensive body of literature on hemispheric specialisation of emotional processing.

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Appendix A - Edinburgh Handedness Inventory

Please indicate your preferences in the use of hands in the following activities ***putting + in the appropriate column.*** Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, ***put + +.*** If in any case you are really indifferent, ***put + in both columns.***

Some of the activities require both hands. In these cases, the part of the task, or object, for which hand preference is wanted is indicated in brackets.
Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

		LEFT	RIGHT
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom (upper hand)		
9	Striking match (match)		
10	Opening box (lid)		
i	Which foot do you prefer to kick with?		
ii	Which eye do you use when using only one?		

Appendix B - Semantic Differential Scale

Please select the score you feel is closest to the word you just listened to:

More						**More**
Funny	1	2	3	4	5	Serious
Weak	1	2	3	4	5	Strong
Arousing	1	2	3	4	5	Soothing
Tense	1	2	3	4	5	Relaxed
Stimulating	1	2	3	4	5	Calming
Exciting	1	2	3	4	5	Tedious
Dramatic	1	2	3	4	5	Mellow
Emotional	1	2	3	4	5	Placid
Happy	1	2	3	4	5	Sad
Frightening	1	2	3	4	5	Pleasant

Figure G1. Semantic differential scale used to rate words in Pilot Study.

Appendix C - Experiment 1: Word Valence, Arousal, and Frequency

Multidimensional Scaling analysis of participants' ratings of words using the Semantic Differential Scale resulted in two bipolar dimensions: valence (pleasant versus unpleasant) and arousal (low versus high). Each word set was matched for valence, arousal, and word frequency:

Pleasant Nouns

Pleasant Nouns	Word	Valence	Arousal	Frequency
1	Angel	0.7	0.2	3.1
2	Balloon	0.7	-0.1	2.3
3	Candy	0.9	-0.1	0.0
4	Kitten	1.2	0.0	0.8
5	Pillow	0.8	0.2	3.1
6	Puppy	1.2	-0.2	0.0
7	Sunset	1.0	0.5	0.8
8	Teddy	1.2	0.2	3.9
	Mean	0.9	0.1	1.8
	SD	0.2	0.2	1.5

Pleasant Adjectives

Pleasant Adjectives	Word	Valence	Arousal	Frequency
1	Caring	0.6	0.3	6.9
2	Comfy	1.1	0.3	0.0
3	Cuddly	1.0	0.1	0.8
4	Fluffy	1.2	0.2	0.0
5	Joyful	0.6	-0.7	3.9
6	Juicy	0.7	-0.5	2.3
7	Loving	0.8	0.7	2.3
8	Tasty	0.7	-0.3	0.8
	Mean	0.8	0.0	2.1
	SD	0.2	0.5	2.3

Appendix C - Experiment 1: Word Valence, Arousal, and Frequency

Unpleasant Nouns

Unpleasant Nouns	Word	Valence	Arousal	Frequency
1	Burglar	-0.6	-0.2	0.8
2	Coffin	-1.0	0.1	2.3
3	Hatred	-1.3	-0.3	6.2
4	Hostage	-1.2	-0.1	1.5
5	Migraine	-0.6	0.3	0.0
6	Rabies	-0.9	0.1	1.5
7	Trauma	-1.2	0.0	0.8
8	Vandal	-0.6	-0.1	0.8
	Mean	-0.9	0.0	1.7
	SD	0.3	0.2	1.9

Unpleasant Adjectives

Unpleasant Adjectives	Word	Valence	Arousal	Frequency
1	Creepy	-0.6	0.1	0.8
2	Depressed	-1.1	0.3	7.7
3	Frantic	-0.9	-0.3	0.0
4	Gruesome	-0.9	0.1	0.8
5	Grumpy	-0.6	0.2	0.8
6	Jealous	-0.9	-0.1	0.8
7	Selfish	-0.6	0.0	5.4
8	Spiteful	-0.6	0.2	0.0
	Mean	-0.8	0.0	2.0
	SD	0.2	0.2	2.9

Appendix C - Experiment 1: Word Valence, Arousal, and Frequency

Neutral Nouns

Neutral Nouns	Word	Valence	Arousal	Frequency
1	Baboon	-0.3	-0.3	0.0
2	Beetroot	-0.3	0.0	0.8
3	Carriage	-0.3	0.1	5.4
4	Charger	-0.2	0.0	0.0
5	Chimney	-0.3	0.1	0.0
6	Sherriff	0.0	0.1	3.9
7	Stigma	0.1	0.2	2.3
8	Tissue	-0.1	0.3	2.3
	Mean	-0.2	0.0	1.8
	SD	0.2	0.2	2.0

Neutral Adjectives

Neutral Adjectives	Word	Valence	Arousal	Frequency
1	Brittle	0.0	0.1	3.1
2	Civic	0.0	0.4	2.3
3	Cryptic	0.3	-0.2	0.0
4	Dusty	0.0	0.1	3.9
5	Frosty	-0.2	0.0	0.8
6	Innate	-0.1	0.3	6.2
7	Muddy	-0.1	-0.3	0.0
8	Patchy	-0.1	0.1	0.0
	Mean	0.0	0.1	2.0
	SD	0.1	0.2	2.2

Appendix D - Experiment 1 Response time for words analysis

Table 1. *Mean reaction time and SD in milliseconds to classifying words in the monaural presentation condition.*

Task	Ear	Emotion	Mean (ms)	SD (ms)
Affective	Left	Pleasant	921	128
		Unpleasant	955	134
	Right	Pleasant	931	155
		Unpleasant	946	161
Non-affective	Left	Pleasant	968	173
		Unpleasant	971	180
	Right	Pleasant	972	180
		Unpleasant	1031	184

Table 2. *Mean reaction time and SD in milliseconds to classifying words in the distractor pink noise presentation condition.*

Task	Ear	Emotion	Mean	SD
Affective	Left	Pleasant	971	175
		Unpleasant	977	171
	Right	Pleasant	954	135
		Unpleasant	943	148
Non-affective	Left	Pleasant	979	159
		Unpleasant	995	178
	Right	Pleasant	1041	177
		Unpleasant	1033	190

Appendix D - Experiment 1 Response time for words analysis

Table 3. *Mean reaction time and SD in milliseconds to classifying words in the dichotic presentation condition.*

Task	Ear	Emotion	Mean	SD
Affective	Left	Pleasant	1040	161
		Unpleasant	1050	134
	Right	Pleasant	988	144
		Unpleasant	1006	149
Non-affective	Left	Pleasant	1054	172
		Unpleasant	1043	150
	Right	Pleasant	990	154
		Unpleasant	989	147

Appendix D - Experiment 1 Response time for words analysis

Table 4. *Overall MANOVA summary table for response times to words in the three stimulus presentation conditions and both classification tasks.*

Source	*df Hyp*	*df Error*	Wilks λ	*F*	*p*	η_p^2
Ear	1	47	.98	0.54	.46	.01
Valence	1	47	.96	1.87	.17	.03
Stimulus Presentation	2	46	.68	10.40	<.001	.31
Ear*Valence	1	47	.99	0.06	.79	.00
Ear*Stimulus Presentation	2	46	.80	5.70	<.001	.19
Ear*Classification Task	1	47	.95	2.04	.15	.04
Valence*Stimulus Presentation	2	46	.90	2.47	.09	.09
Valence*Classification Task	1	47	1.00	0.01	.90	.00
Stimulus Presentation* Classification Task*	2	46	.88	2.86	.06	.11
Ear*Valence*Stimulus Presentation	2	46	.94	1.32	.27	.05
Ear*Valence*Classification Task	1	47	.97	1.14	.29	.02
Ear* Stimulus Presentation* Classification Task	2	46	.92	1.77	.18	.07
Valence*Stimulus Presentation *Classification Task	2	46	.97	0.68	.50	.02
Ear*Valence* Stimulus Presentation *Classification Task	2	46	.93	1.73	.18	.07

Appendix D - Experiment 1 Response time for words analysis

Table 5. *ANOVA summary table for the between-subjects effect of classification task for response times to words.*

Source	*MS*	*df*	*F*	*p*	η_p^2
Classification Task	136030.93	1	0.67	.41	.01
Error	201051.53	47			

Appendix D - Experiment 1 Response time for words analysis

Table 6. *MANOVA summary table for response time to words in the monaural presentation condition.*

Source	*df Hyp*	*df Error*	Wilks λ	*F*	*p*	η_p^2
Ear	1	47	.98	0.54	.46	.01
Valence	1	47	.83	9.05	<.001	.16
Ear*Valence	1	47	.98	0.93	.33	.02
Ear* Classification Task	1	47	.98	0.50	.48	.01
Valence* Classification Task	1	47	.99	0.11	.73	.00
Ear*Valence* Classification Task	1	47	.93	3.49	.06	.06

Table 7. *Test of between-subjects effects for response time to words in the monaural presentation condition.*

Source	*MS*	*df*	*F*	*p*	η_p^2
Classification Task	98767.07	1	1.32	.25	.02
Error	74538.87	47			

Appendix D - Experiment 1 Response time for words analysis

Table 8. *MANOVA summary table for response time to words in the distractor pink noise presentation condition.*

Source	*df* *Hyp*	*df* *Error*	Wilks *λ*	*F*	*p*	η_p^2
Ear	1	47	.99	0.40	.53	.00
Valence	1	47	1.00	0.00	.93	.00
Ear*Valence	1	47	.96	1.86	.17	.03
Ear* Classification Task	1	47	.92	3.72	.06	.07
Valence* Classification Task	1	47	.99	0.10	.75	.00
Ear*Valence* Classification Task	1	47	.99	0.06	.80	.00

Table 9. *Test of between-subjects effects for response time to words in the distractor pink noise presentation condition.*

Source	*MS*	*df*	*F*	*p*	η_p^2
Classification Task	113476.44	1	1.35	.25	.02
Error	83948.05	47			

Appendix D - Experiment 1 Response time for words analysis

Table 10. *MANOVA summary table for response times to words in the dichotic presentation condition.*

Source	*df Hyp*	*df Error*	Wilks λ	*F*	*p*	η_p^2
Ear	1	47	.76	14.88	<.001	.24
Valence	1	47	.99	0.12	.72	.00
Ear*Valence	1	47	.99	0.36	.55	.00
Ear* Classification Task	1	47	.99	0.16	.68	.00
Valence* Classification Task	1	47	.98	0.65	.42	.01
Ear*Valence* Classification Task	1	47	1.00	0.00	.94	.00

Table 11. *Test of between-subjects effects for response time to words in the dichotic presentation condition.*

Source	*MS*	*df*	*F*	*p*	η_p^2
Classification Task	151.623	1	0.00	.96	.00
Error	73289.23	47			

Appendix D - Experiment 1 Response accuracy for words analysis

Table 12. *Mean response accuracy and SD to classifying words with in the monaural presentation condition.*

Task	Ear	Emotion	Mean	SD
Affective	Left	Pleasant	15.02	1.05
		Unpleasant	15.52	1.19
	Right	Pleasant	14.84	1.79
		Unpleasant	14.76	1.92
Non-affective	Left	Pleasant	15.00	1.19
		Unpleasant	14.02	1.55
	Right	Pleasant	15.25	0.76
		Unpleasant	13.88	1.32

Table 13. *Mean response accuracy and SD to classifying words with in the distractor pink noise presentation condition.*

Task	Ear	Emotion	Mean	SD
Affective	Left	Pleasant	14.60	1.44
		Unpleasant	15.10	1.46
	Right	Pleasant	14.94	1.20
		Unpleasant	15.23	1.12
Non-affective	Left	Pleasant	14.83	1.27
		Unpleasant	13.47	1.57
	Right	Pleasant	15.00	1.24
		Unpleasant	13.52	1.50

Appendix D - Experiment 1 Response accuracy for words analysis

Table 14. *Mean response accuracy and SD to classifying words in the dichotic presentation condition.*

Task	Ear	Emotion	Mean	SD
Affective	Left	Pleasant	14.39	2.42
		Unpleasant	14.92	1.56
	Right	Pleasant	14.65	1.69
		Unpleasant	14.55	2.51
Non-affective	Left	Pleasant	14.25	2.3
		Unpleasant	13.19	1.98
	Right	Pleasant	14.72	1.93
		Unpleasant	13.41	1.69

Appendix D - Experiment 1 Response accuracy for words analysis

Table 15. *Overall MANOVA summary table for response accuracy for words in the three stimulus presentation conditions and both classification tasks.*

Source	*df* *Hyp*	*df* *Error*	Wilks λ	*F*	*p*	η_p^2
Ear	1	72	.99	0.12	.73	.00
Valence	1	72	.75	23.27	<.001	.24
Stimulus Presentation	2	71	.89	4.13	.02	.10
Ear*Valence	1	72	.93	5.44	.02	.07
Ear* Stimulus Presentation	2	71	.95	1.88	.15	.05
Ear* Classification Task	1	72	.97	1.53	.22	.02
Valence* Stimulus Presentation	2	71	.99	0.02	.97	.00
Valence* Classification Task	1	72	.56	56.17	<.001	.43
Stimulus Presentation * Classification Task	2	71	.98	0.67	.51	.01
Ear*Valence* Stimulus Presentation	2	71	.98	0.70	.49	.01
Ear*Valence* Classification Task	1	72	.99	0.52	.47	.00
Ear* Stimulus Presentation * Classification Task	2	71	.96	1.44	.24	.03
Valence* Stimulus Presentation * Classification Task	2	71	.97	1.02	.36	.02
Ear*Valence* Stimulus Presentation * Classification Task	2	71	.99	0.06	.93	.00

Appendix D - Experiment 1 Response accuracy for words analysis

Table 16. Overall *MANOVA summary table for the between-subjects effect of classification task for response accuracy to words.*

Source	*MS*	*df*	*F*	*p*	η_p^2
Classification Task	98.48	1	10.14	<.001	.12
Error	9.71	72			

Appendix D - Experiment 1 Response accuracy for words analysis

Table 17. *MANOVA summary table for response accuracy to words in the monaural presentation condition.*

Source	*df* *Hyp*	*df* *Error*	Wilks λ	*F*	*p*	η_p^2
Ear	1	72	.97	1.65	.20	.02
Valence	1	72	.82	15.34	<.001	.17
Ear*Valence	1	72	.91	6.58	.01	.08
Ear* Classification Task	1	72	.96	2.65	.10	.03
Valence* Classification Task	1	72	.69	31.82	<.001	.30
Ear*Valence* Classification Task	1	72	.99	0.25	.61	.00

Table 18. *Test of between-subjects effects for response accuracy to words in the monaural presentation condition.*

Source	*MS*	*df*	*F*	*p*	η_p^2
Classification Task	18.32	1	4.60	.03	.06
Error	3.97	72			

Appendix D - Experiment 1 Response accuracy for words analysis

Table 19. *MANOVA summary table for response accuracy to words in the distractor pink noise presentation condition.*

Source	*df Hyp*	*df Error*	Wilks *λ*	*F*	*p*	η_p^2
Ear	1	72	.97	2.00	.16	.02
Valence	1	72	.85	12.43	<.001	.14
Ear*Valence	1	72	.99	0.66	.41	.00
Ear* Classification Task	1	72	.99	0.26	.61	.00
Valence* Classification Task	1	72	.64	39.05	<.001	.35
Ear*Valence* Classification Task	1	72	.99	0.06	.80	.00

Table 20. *Test of between-subjects effects for response accuracy to words in the distractor pink noise presentation condition.*

Source	*MS*	*df*	*F*	*p*	η_p^2
Classification Task	43.31	1	10.73	<.001	.13
Error	4.03	72			

Appendix D - Experiment 1 Response accuracy for words analysis

Table 21. *MANOVA summary table for response accuracy to words in the dichotic presentation condition.*

Source	*df* *Hyp*	*df* *Error*	Wilks λ	*F*	*p*	η_p^2
Ear	1	72	.99	0.38	.53	.00
Valence	1	72	.86	11.66	<.001	.13
Ear*Valence	1	72	.97	1.63	.20	.02
Ear* Classification Task	1	72	.99	0.70	.40	.01
Valence* Classification Task	1	72	.75	23.98	<.001	.25
Ear*Valence* Classification Task	1	72	.99	0.30	.58	.00

Table 22. *Test of between-subjects effects for response accuracy to words in the dichotic presentation condition.*

Source	*MS*	*df*	*F*	*p*	η_p^2
Classification Task	40.02	1	4.52	.03	.05
Error	8.84	72			

Appendix E - Experiment 2: Prosody Valence and Arousal

Multidimensional Scaling analysis of participants' ratings of emotional prosody using the Semantic Differential Scale resulted in two bipolar dimensions: valence (happy versus sad) and arousal (low versus high). Each word set was matched for valence and arousal:

Happy Spoken Nouns

Pleasant Nouns	Word	Valence	Arousal
1	Angel	1.0	0.6
2	Balloon	0.6	-0.3
3	Candy	1.0	0.2
4	Kitten	0.8	-0.5
5	Pillow	0.1	-0.7
6	Puppy	1.0	0.2
7	Sunset	1.0	-0.1
8	Teddy	0.6	-0.3
	Mean	0.7	-0.1
	SD	0.3	0.4

Happy Spoken Adjectives

Pleasant Adjectives	Word	Valence	Arousal
1	Caring	0.6	0.6
2	Comfy	1.0	0.4
3	Cuddly	0.6	0.0
4	Fluffy	0.6	-0.1
5	Joyful	0.9	-0.1
6	Juicy	0.6	-0.1
7	Loving	0.9	-0.3
8	Tasty	0.8	-0.4
	Mean	0.7	0.0
	SD	0.2	0.3

Appendix E - Experiment 2: Prosody Valence and Arousal

Sad Spoken Nouns

Unpleasant Nouns	Word	Valence	Arousal
1	Burglar	-1.0	0.4
2	Coffin	-0.6	-0.4
3	Hatred	-1.0	0.5
4	Hostage	-1.0	-0.3
5	Migraine	-0.6	-0.5
6	Rabies	-0.8	-0.1
7	Trauma	-0.6	0.2
8	Vandal	-0.6	0.2
	Mean	-0.8	0.0
	SD	-0.4	0.4

Sad Spoken Adjectives

Unpleasant Adjectives	Word	Valence	Arousal
1	Creepy	-0.8	0.6
2	Depressed	-0.6	0.2
3	Frantic	-0.6	-0.4
4	Gruesome	-1.0	0.5
5	Grumpy	-0.8	0.0
6	Jealous	-0.6	-0.4
7	Selfish	-0.7	0.0
8	Spiteful	-0.7	-0.3
	Mean	-0.7	0.0
	SD	-0.2	0.4

Appendix E - Experiment 2: Prosody Valence and Arousal

Neutral Spoken Nouns

Neutral Nouns	Word	Valence	Arousal
1	Baboon	0.3	0.1
2	Beetroot	0.2	0.3
3	Carriage	0.5	0.4
4	Charger	0.4	0.3
5	Chimney	0.2	0.2
6	Sherriff	0.5	-0.2
7	Stigma	0.2	0.5
8	Tissue	0.3	-0.4
	Mean	0.3	0.2
	SD	0.1	0.3

Neutral Spoken Adjectives

Neutral Adjectives	Word	Valence	Arousal
1	Brittle	0.2	-0.6
2	Civic	0.1	-0.6
3	Cryptic	0.1	-0.5
4	Dusty	-0.1	0.7
5	Frosty	0.1	-0.2
6	Innate	0.1	0.1
7	Muddy	0.6	0.5
8	Patchy	0.4	-0.6
	Mean	0.2	-0.1
	SD	0.2	0.5

Appendix F - Experiment 2 Response time for prosody analysis

Table 23. *Mean reaction time and SD in milliseconds to classifying prosody with monaural presentation.*

Ear	Emotion	Mean	SD
Left	Happy	898	127
	Sad	969	141
Right	Happy	934	142
	Sad	977	136

Table 24. *Mean reaction time and SD in milliseconds to classifying prosody with distractor pink noise presentation.*

Ear	Emotion	Mean	SD
Left	Happy	896	126
	Sad	984	142
Right	Happy	887	144
	Sad	957	162

Table 25. *Mean reaction time and SD in milliseconds to classifying prosody with dichotic presentation.*

Ear	Emotion	Mean	SD
Left	Happy	983	155
	Sad	1013	157
Right	Happy	933	122
	Sad	975	119

Appendix F - Experiment 2 Response time for prosody analysis

Table 26. *Overall MANOVA summary table for response time for prosody from each stimulus presentation condition.*

Source	*df Hyp*	*df Error*	Wilks λ	*F*	*p*	η_p^2
Ear	1	25	.95	1.16	.29	.04
Prosody	1	25	.41	35.68	<.001	.58
Stimulus Presentation	2	24	.68	5.43	.01	.31
Ear*Prosody	1	25	.96	0.82	.37	.03
Ear* Stimulus Presentation	2	24	.87	1.77	.19	.12
Stimulus Presentation *Prosody	2	24	.75	3.89	.03	.24
Ear* Stimulus Presentation *Prosody	2	24	.98	0.79	.46	.06

Appendix F - Experiment 2 Response time for prosody analysis

Table 27. *ANOVA summary table for response time for prosody in the monaural presentation condition.*

Source	*df* *Hyp*	*df* *Error*	*F*	*p*	η_p^2
Ear	1	25	0.79	.38	.03
Prosody	1	25	14.72	<.001	.37
Ear*Prosody	1	25	1.87	.18	.07

Table 28. *ANOVA summary table for response time for prosody in the distractor pink noise presentation condition.*

Source	*df* *Hyp*	*df* *Error*	*F*	*p*	η_p^2
Ear	1	25	0.56	.45	.02
Prosody	1	25	30.78	<.001	.55
Ear*Prosody	1	25	0.68	.41	.02

Table 29. *ANOVA summary table for response time for prosody in the dichotic presentation condition.*

Source	*df* *Hyp*	*df* *Hyp*	*F*	*p*	η_p^2
Ear	1	25	4.47	.04	.15
Prosody	1	25	8.9	<.001	.26
Ear*Prosody	1	25	0.32	.57	.01

Appendix F - Experiment 2 Response accuracy for prosody analysis

Table 30. *Mean response accuracy and SD to classifying prosody with monaural presentation.*

Ear	Emotion	Mean	SD
Left	Happy	15.13	0.95
	Sad	15.06	1.36
Right	Happy	15.24	1.18
	Sad	14.75	1.68

Table 31. *Mean response accuracy and SD to classifying prosody with distractor pink noise presentation.*

Ear	Emotion	Mean	SD
Left	Happy	14.48	1.93
	Sad	14.10	2.91
Right	Happy	14.79	1.56
	Sad	14.69	1.39

Table 32. *Mean response accuracy and SD to classifying prosody with dichotic presentation.*

Ear	Emotion	Mean	SD
Left	Happy	14.34	1.77
	Sad	14.00	2.75
Right	Happy	14.65	1.47
	Sad	14.27	2.53

Appendix F - Experiment 2 Response accuracy for prosody analysis

Table 33. *Overall MANOVA summary table for response accuracy for prosody from each stimulus presentation.*

Source	*df Hyp*	*df Error*	Wilks λ	*F*	*p*	η_p^2
Ear	1	28	.89	3.30	.08	.10
Prosody	1	28	.97	0.81	.37	.02
Stimulus Presentation	2	27	.73	4.97	.01	.26
Ear*Prosody	1	28	.99	0.04	.92	.00
Ear*Stimulus Presentation	2	27	.91	1.18	.32	.08
Stimulus Presentation*Prosody	2	27	.99	0.07	.92	.00
Ear*Stimulus Presentation*Prosody	2	27	.96	0.52	.59	.03

Appendix F - Experiment 2 Response accuracy for prosody analysis

Table 34. *ANOVA summary table for response accuracy for prosody in the monaural presentation condition.*

Source	*df Hyp*	*df Hyp*	*F*	*p*	η_p^2
Ear	1	28	0.38	.54	.01
Prosody	1	28	1.59	.21	.05
Ear*Prosody	1	28	1.13	.29	.03

Table 35. *ANOVA summary table for response accuracy for prosody in the distractor pink noise presentation condition.*

Source	*df Hyp*	*df Hyp*	*F*	*p*	η_p^2
Ear	1	28	1.54	.22	.05
Prosody	1	28	0.47	.49	.01
Ear*Prosody	1	28	0.33	.56	.01

Table 36. *ANOVA summary table for response accuracy for prosody in the dichotic presentation condition.*

Source	*df Hyp*	*df Hyp*	*F*	*p*	η_p^2
Ear	1	28	1.19	.28	.04
Prosody	1	28	0.46	.49	.01
Ear*Prosody	1	28	0.00	.94	.00

Appendix G - Experiment 3 Melody Valence and Arousal

Multidimensional Scaling analysis of participants' ratings of melodies using the Semantic Differential Scale resulted in two bipolar dimensions: valence (pleasant versus unpleasant) and arousal (low versus high). Each melody was matched for valence and arousal:

Pleasant (Tonal) Melodies

Pleasant (Tonal)	Melody	Valence	Arousal
1	C4 D4 E4 F4 G4	0.8	-0.4
2	D3 E3 G3 D3 C3	1.0	0.0
3	C4 G3 A3 G3 C4	0.7	0.2
4	C3 A3 G3 A3 C4	0.5	0.2
5	C4 E4 D4 E4 C4	0.8	0.4
6	C4 C4 D4 E4 C4	0.7	0.0
7	D3 A3 G3 A3 C3	0.6	-0.1
8	C4 D4 B3 A3 G3	0.5	0.1
9	G4 D4 E4 G4 C4	0.9	-0.2
10	E4 A4 G4 G4 C4	0.5	0.2
11	C4 G3 F3 A3 G3	0.5	-0.2
12	C4 B3 C4 A3 G3	0.6	-0.4
	Mean	0.6	0.0
	SD	0.3	0.3

Appendix G - Experiment 3 Melody Valence and Arousal

Unpleasant (Atonal) Melodies

Unpleasant (Atonal)	Melody	Valence	Arousal
1	C4 C#4 D#4 F#4 G4	-0.8	0.0
2	D3 F#3 G3 C#3 B#3	-0.5	0.1
3	C4 G#3 A3 G3 A#3	-0.9	0.5
4	C3 G#3 G3 A3 D#4	-0.5	-0.3
5	C4 C#4 B3 D#4 D4	-0.8	0.4
6	C4 C#4 D4 F#4 C#4	-0.5	0.1
7	D3 A3 G3 G#3 A#2	-0.5	0.1
8	C4 G#4 B3 A#3 A3	-0.7	0.1
9	G4 D#4 E4 F#4 F4	-0.6	0.1
10	E4 A4 G#4 G4 D#4	-0.5	0.5
11	C4 F#3 G3 A#3 F3	-0.6	-0.4
12	C4 A#3 B3 G3 G#3	-0.9	0.0
	Mean	-0.6	0.1
	SD	0.2	0.3

Appendix G - Experiment 3 Melody Valence and Arousal

Neutral (Tonal) Melodies

Neutral (Tonal)	Melody	Valence	Arousal
1	G3 E3 C3 D3 C3	-0.4	0.8
2	C4 G4 E4 B3 C4	0.4	0.0
3	G4 G4 A4 G4 E4	-0.4	0.1
4	E3 D3 C3 B2 C3	-0.1	-0.6
5	C4 A3 F3 D3 C3	-0.3	0.4
6	C4 G4 E4 A3 G3	0.2	-0.4
7	E4 F4 G4 G4 C4	0.3	-0.1
8	E3 B3 D3 A3 C3	-0.3	-0.6
9	C3 D3 E3 F3 E3	-0.4	-0.3
10	C3 D3 C3 B2 C3	0.4	0.2
11	C4 C4 D4 D4 E4	-0.1	-0.8
12	C4 B3 C4 A3 G3	-0.4	0.3
	Mean	-0.2	-0.1
	SD	0.5	0.4

Appendix G - Experiment 3 Melody Valence and Arousal

Neutral (Atonal) Melodies

Neutral (Atonal)	Melody	Valence	Arousal
1	G3 E3 F#3 D3 C#3	-0.4	-0.2
2	G4 G#4 A4 G4 F#4	0.4	-0.6
3	E3 D#3 C3 A#2 C#3	-0.1	0.3
4	C4 G#3 F3 E3 C#3	0.1	-0.1
5	C4 G4 D#4 G#3 B3	0.1	-0.3
6	E4 F#4 G#4 G4 C#4	0.1	0.2
7	E3 A#3 D3 B3 A3	0.1	0.5
8	C3 D#3 E3 G3 F#3	0.3	0.5
9	C3 D#3 C3 A#2 C#3	1.1	0.5
10	C4 C4 D4 D#4 F#4	0.4	0.4
11	C3 C3 D#3 G#2 G#2	0.2	0.5
12	G4 G#4 A4 G4 F#4	-0.3	-0.3
	Mean	0.2	0.1
	SD	0.4	0.4

Appendix H - Experiment 3 Response time for melodies analysis

Table 37. *Mean reaction time and SD in milliseconds to classifying melodies (1800ms) with monaural presentation.*

Task	Ear	Emotion	Mean	SD
Affective	Left	Pleasant	2161	151
		Unpleasant	2206	179
	Right	Pleasant	2183	236
		Unpleasant	2222	196
Non-affective	Left	Pleasant	2549	176
		Unpleasant	2584	162
	Right	Pleasant	2515	159
		Unpleasant	2534	163

Table 38. *Mean reaction time and SD in milliseconds to classifying melodies (1800ms) with distractor pink noise presentation.*

Task	Ear	Emotion	Mean	SD
Affective	Left	Pleasant	2193	198
		Unpleasant	2224	243
	Right	Pleasant	2203	207
		Unpleasant	2278	222
Non-affective	Left	Pleasant	2587	189
		Unpleasant	2575	188
	Right	Pleasant	2553	185
		Unpleasant	2545	175

Appendix H - Experiment 3 Response time for melodies analysis

Table 39. *Mean reaction time and SD in milliseconds to classifying melodies (1800ms) with dichotic presentation.*

Task	Ear	Emotion	Mean	SD
Affective	Left	Pleasant	2279	176
		Unpleasant	2302	197
	Right	Pleasant	2387	295
		Unpleasant	2399	289
Non-affective	Left	Pleasant	2630	220
		Unpleasant	2597	215
	Right	Pleasant	2596	156
		Unpleasant	2607	190

Appendix H - Experiment 3 Response time for melodies analysis

Table 40. *Overall MANOVA summary table for response times to melodies (1800ms) in the three stimulus presentation conditions and both classification tasks.*

Source	*df Hyp*	*df Error*	Wilks λ	*F*	*p*	η_p^2
Ear	1	33	.99	0.17	.67	.00
Tonality	1	33	.99	0.03	.84	.00
Stimulus Presentation	2	32	.58	11.18	.00	.41
Ear*Tonality	1	33	1.00	0.00	.96	.00
Ear*Stimulus Presentation	2	32	.87	2.28	.11	.12
Ear*Classification Task	1	33	.83	6.61	.01	.16
Tonality*Stimulus Presentation	2	32	.94	0.86	.42	.05
Tonality*Classification Task	1	33	.98	0.37	.54	.01
Stimulus Presentation*Classification Task	2	32	.92	1.36	.27	.07
Ear*Tonality*Stimulus Presentation	2	32	.96	0.60	.55	.03
Ear*Tonality*Classification Task	1	33	.99	0.04	.82	.00
Ear*Stimulus Presentation*Classification Task	2	32	.98	0.19	.82	.01
Tonality*Stimulus Presentation *Classification Task	2	32	.95	0.77	.47	.04
Ear*Tonality*Stimulus Presentation *Classification Task	2	32	.98	0.22	.80	.01

Appendix H - Experiment 3 Response time for melodies analysis

Table 41. *Overall MANOVA summary table for test of between-subjects effects for response times to melodies (1800ms).*

Source	*MS*	*df*	*F*	*p*	η_p^2
Classification Task	11500893.70	1	46.80	.00	.58
Error	245710.40	33			

Appendix H - Experiment 3 Response time for melodies analysis

Table 42. *MANOVA summary table for response time to melodies (1800ms) in the monaural presentation condition.*

Source	*df* *Hyp*	*df* *Error*	Wilks λ	*F*	*p*	η_p^2
Ear	1	44	.99	0.32	.57	.00
Tonality	1	44	.95	2.32	.13	.05
Ear*Tonality	1	44	.99	0.10	.74	.00
Ear*Classification Task	1	44	.95	2.20	.14	.04
Tonality*Classification Task	1	44	.99	0.10	.74	.00
Ear*Tonality*Classification Task	1	44	.99	0.02	.87	.00

Table 43. *Test of between-subjects effects for response time to melodies (1800ms) for the monaural presentation condition.*

Source	*MS*	*df*	*F*	*p*	η_p^2
Classification Task	5719225.10	1	74.60	.00	.62
Error	76658.77	44			

Appendix H - Experiment 3 Response time for melodies analysis

Table 44. *MANOVA summary table for response time to melodies (1800ms) in the distractor pink noise presentation condition.*

Source	*df* *Hyp*	*df* *Error*	Wilks *λ*	*F*	*p*	η_p^2
Ear	1	47	1.00	0.00	.99	.00
Tonality	1	47	.97	1.22	.27	.02
Ear*Tonality	1	47	.98	0.53	.46	.01
Ear*Classification Task	1	47	.95	1.98	.16	.04
Tonality*Classification Task	1	47	.94	2.57	.11	.05
Ear*Tonality*Classification Task	1	47	.99	0.38	.53	.00

Table 45. *Test of between-subjects effects for response time to melodies (1800ms) for the distractor pink noise presentation condition.*

Source	*MS*	*df*	*F*	*p*	η_p^2
Classification Task	5682251.77	1	52.88	.00	.52
Error	107437.22	47			

Appendix H - Experiment 3 Response time for melodies analysis

Table 46. *MANOVA summary table for response time to melodies (1800ms) in the dichotic presentation condition.*

Source	*df Hyp*	*df Error*	Wilks *λ*	*F*	*p*	η_p^2
Ear	1	39	.94	2.11	.15	.05
Tonality	1	39	.99	0.02	.86	.00
Ear*Tonality	1	39	.99	0.21	.64	.00
Ear*Classification Task	1	39	.92	3.38	.07	.08
Tonality*Classification Task	1	39	.98	0.48	.49	.01
Ear*Tonality*Classification Task	1	39	.98	0.61	.43	.01

Table 47. *Test of between-subjects effects for response time to melodies (1800ms) for the dichotic presentation condition.*

Source	*MS*	*df*	*F*	*p*	η_p^2
Classification Task	2857461.92	1	20.89	.00	.34
Error	136737.61	39			

Appendix H - Experiment 3 Response time for melodies analysis

Table 48. *ANOVA summary table for response time for melodies (1800ms) in the affective classification task in the dichotic presentation condition.*

Source	*df Hyp*	*df Hyp*	*F*	*p*	η_p^2
Ear	1	22	5.95	.02	.21
Tonality	1	22	0.39	.53	.01
Ear*Tonality	1	22	0.08	.77	.00

Table 49. *ANOVA summary table for response time for melodies (1800ms) in the non-affective classification task in the dichotic presentation condition.*

Source	*df Hyp*	*df Hyp*	*F*	*p*	η_p^2
Ear	1	17	0.06	.79	.00
Tonality	1	17	0.14	.71	.00
Ear*Tonality	1	17	0.50	.48	.02

Appendix H - Proportion of Hits and False Alarms for Melodies

Table 50. *Proportion of Hits and False Alarms for Melodies (1800ms) with Monaural Presentation.*

			Means	SD
Affective Task	Left	Hits	0.84	0.18
		False Alarms	0.25	0.20
	Right	Hits	0.87	0.11
		False Alarms	0.31	0.24
Non-Affective Task	Left	Hits	0.90	0.13
		False Alarms	0.27	0.20
	Right	Hits	0.85	0.18
		False Alarms	0.23	0.15

Table 51. *Proportion of Hits and False Alarms for Melodies (1800ms) with Distractor Pink Noise Presentation.*

			Means	SD
Affective Task	Left	Hits	0.85	0.16
		False Alarms	0.32	0.30
	Right	Hits	0.85	0.17
		False Alarms	0.33	0.26
Non-Affective Task	Left	Hits	0.88	0.12
		False Alarms	0.21	0.16
	Right	Hits	0.89	0.14
		False Alarms	0.26	0.21

Appendix H - Proportion of Hits and False Alarms for Melodies

Table 52. *Proportion of Hits and False Alarms for Melodies (1800ms) with Dichotic Presentation.*

			Means	SD
Affective Task	Left	Hits	0.74	0.18
		False Alarms	0.28	0.19
	Right	Hits	0.72	0.19
		False Alarms	0.37	0.23
Non-Affective Task	Left	Hits	0.80	0.16
		False Alarms	0.28	0.19
	Right	Hits	0.81	0.12
		False Alarms	0.31	0.24

Appendix H - Experiment 3 Sensitivity (d) for melody "pleasantness" and "tonality" analysis

Table 53. *MANOVA summary table for sensitivity (d) for pleasantness of melodies (1800ms) in the affective classification task.*

Source	*Wilks λ*	*df Hyp*	*df Hyp*	*F*	*p*	η_p^2
Ear	.92	1	27	2.07	.16	.07
Stimulus Presentation	.50	2	26	12.93	<.001	.49
Ear*Stimulus Presentation	.96	2	26	0.45	.63	.03

Table 54. *MANOVA summary table for sensitivity (d) for tonality of melodies (1800ms) in the non-affective classification task.*

Source	*Wilks λ*	*df Hyp*	*df Hyp*	*F*	*p*	η_p^2
Ear	.97	1	24	0.64	.43	.02
Stimulus Presentation	.56	2	23	8.76	<.001	.43
Ear*Stimulus Presentation	.99	2	23	0.04	.95	.00

Appendix I - Experiment 4 Response time for melodies analysis

Table 55. *Mean reaction time and SD in milliseconds to classifying melodies (850ms) with monaural presentation.*

Task	Ear	Emotion	Mean	SD
Affective	Left	Pleasant	1286	197
		Unpleasant	1343	173
	Right	Pleasant	1196	125
		Unpleasant	1305	211
Non-affective	Left	Pleasant	1204	186
		Unpleasant	1195	245
	Right	Pleasant	1209	170
		Unpleasant	1205	215

Table 56. *Mean reaction time and SD in milliseconds to classifying melodies (850ms) with distractor pink noise presentation.*

Task	Ear	Emotion	Mean	SD
Affective	Left	Pleasant	1291	193
		Unpleasant	1322	203
	Right	Pleasant	1298	198
		Unpleasant	1343	229
Non-affective	Left	Pleasant	1271	239
		Unpleasant	1273	178
	Right	Pleasant	1299	242
		Unpleasant	1260	222

Appendix I - Experiment 4 Response time for melodies analysis

Table 57. *Mean reaction time and SD in milliseconds to classifying melodies (850ms) with dichotic presentation.*

Task	Ear	Emotion	Mean	SD
Affective	Left	Pleasant	1404	214
		Unpleasant	1468	324
	Right	Pleasant	1419	236
		Unpleasant	1421	292
Non-affective	Left	Pleasant	1382	210
		Unpleasant	1379	280
	Right	Pleasant	1382	206
		Unpleasant	1413	245

Appendix I - Experiment 4 Response time for melodies analysis

Table 58. *Overall MANOVA summary table for response times to melodies (850ms) in the three stimulus presentation conditions and both classification tasks.*

Source	*df Hyp*	*df Error*	Wilks λ	*F*	*p*	η_p^2
Ear	1	32	.99	0.18	.67	.00
Tonality	1	32	.96	1.18	.28	.03
Stimulus Presentation	2	31	.39	23.47	<.001	.60
Ear*Tonality	1	32	1.00	0.00	.98	.00
Ear*Stimulus Presentation	2	31	.92	1.28	.29	.07
Ear*Classification Task	1	32	.97	0.92	.34	.02
Tonality*Stimulus Presentation	2	31	.96	0.63	.53	.03
Tonality*Classification Task	1	32	.96	1.14	.29	.03
Stimulus Presentation*Classification Task	2	31	.99	0.08	.92	.00
Ear*Tonality*Stimulus Presentation	2	31	.97	0.45	.63	.02
Ear*Tonality*Classification Task	1	32	.99	0.04	.83	.00
Ear*Stimulus Presentation*Classification Task	2	31	.96	0.52	.59	.03
Tonality*Stimulus Presentation *Classification Task	2	31	.92	1.33	.27	.07
Ear*Tonality*Stimulus Presentation*Classification Task	2	31	.96	0.64	.53	.04

Appendix I - Experiment 4 Response time for melodies analysis

Table 59. *Overall MANOVA summary table for test of between-subjects effects for response times to melodies (850ms).*

Source	*MS*	*df*	*F*	*p*	η_p^2
Classification Task	682436.90	1	2.05	.16	.06
Error	332066.61	32			

Appendix I - Experiment 4 Response time for melodies analysis

Table 60. *MANOVA summary table for response time to melodies (850ms) in the monaural presentation condition.*

Source	*df Hyp*	*df Error*	Wilks *λ*	*F*	*p*	η_p^2
Ear	1	46	.95	2.04	.16	.04
Tonality	1	46	.91	4.03	.05	.08
Ear*Tonality	1	46	.98	0.87	.35	.01
Ear*Classification Task	1	46	.92	3.65	.06	.07
Tonality*Classification Task	1	46	.93	3.00	.09	.06
Ear*Tonality*Classification Task	1	46	.98	0.51	.47	.01

Table 61. *Test of between-subjects effects for response time to melodies (850ms) in the monaural presentation condition.*

Source	*MS*	*df*	*F*	*p*	η_p^2
Classification Task	171591.20	1	1.57	.21	.03
Error	109255.33	46			

Appendix I - Experiment 4 Response time for melodies analysis

Table 62. *MANOVA summary table for response time to melodies (850ms) in the distractor pink noise presentation condition.*

Source	*df* *Hyp*	*df* *Error*	Wilks λ	*F*	*p*	η_p^2
Ear	1	47	.99	0.32	.56	.00
Tonality	1	47	.99	0.25	.61	.00
Ear*Tonality	1	47	.99	0.16	.69	.00
Ear*Classification Task	1	47	.99	0.03	.85	.00
Tonality*Classification Task	1	47	.95	2.04	.15	.04
Ear*Tonality*Classification Task	1	47	.98	0.59	.44	.01

Table 63. *Test of between-subjects effects for response time to melodies (850ms) in the distractor pink noise presentation condition.*

Source	*MS*	*df*	*F*	*p*	η_p^2
Classification Task	69038.82	1	0.52	.47	.01
Error	132749.37	47			

Appendix I - Experiment 4 Response time for melodies analysis

Table 64. *MANOVA summary table for response time to melodies (850ms) in the dichotic presentation condition.*

Source	*df Hyp*	*df Error*	Wilks *λ*	*F*	*p*	η_p^2
Ear	1	42	1.00	0.00	.98	.00
Tonality	1	42	.98	0.81	.37	.01
Ear*Tonality	1	42	.99	0.10	.75	.00
Ear*Classification Task	1	42	.99	0.28	.59	.00
Tonality*Classification Task	1	42	.99	0.14	.70	.00
Ear*Tonality*Classification Task	1	42	.97	1.19	.28	.02

Table 65. *Test of between-subjects effects for response time to melodies (850ms) in the dichotic presentation condition.*

Source	*MS*	*df*	*F*	*p*	η_p^2
Classification Task	65803.72	1	0.39	.53	.00
Error	166018.11	42			

Appendix I – Proportion of Hits and False Alarms for Melodies

Table 66. *Proportion of Hits and False Alarms for melodies (850ms) with monaural presentation.*

			Means	SD
Affective Task	Left	Hits	0.86	0.14
		False Alarms	0.40	0.27
	Right	Hits	0.82	0.14
		False Alarms	0.44	0.23
Non-Affective Task	Left	Hits	0.84	0.20
		False Alarms	0.33	0.24
	Right	Hits	0.80	0.23
		False Alarms	0.35	0.23

Table 67. *Proportion of Hits and False Alarms for melodies (850ms) with distractor pink noise presentation.*

			Means	SD
Affective Task	Left	Hits	0.76	0.20
		False Alarms	0.34	0.24
	Right	Hits	0.76	0.22
		False Alarms	0.35	0.26
Non-Affective Task	Left	Hits	0.79	0.23
		False Alarms	0.36	0.23
	Right	Hits	0.78	0.23
		False Alarms	0.36	0.27

Appendix I – Proportion of Hits and False Alarms for Melodies

Table 68. *Proportion of Hits and False Alarms for melodies (850ms) with dichotic presentation.*

			Means	SD
Affective Task	Left	Hits	0.61	0.18
		False Alarms	0.40	0.20
	Right	Hits	0.55	0.16
		False Alarms	0.41	0.22
Non-Affective Task	Left	Hits	0.66	0.15
		False Alarms	0.40	0.24
	Right	Hits	0.65	0.16
		False Alarms	0.41	0.24

Appendix I - Experiment 4 Sensitivity (d) for melody "pleasantness" and "tonality" analysis

Table 69. *MANOVA summary table for sensitivity (d) for pleasantness of melodies (850ms) in the affective classification task.*

Source	*Wilks λ*	*df Hyp*	*df Hyp*	*F*	*p*	η_p^2
Ear	.98	1	33	0.62	.43	.01
Stimulus Presentation	.63	2	32	9.15	.00	.36
Ear*Stimulus Presentation	.65	2	32	8.59	.00	.34

Table 70. *MANOVA summary table for sensitivity (d) for tonality of melodies (850ms) in the non-affective classification task.*

Source	*Wilks λ*	*df Hyp*	*df Hyp*	*F*	*p*	η_p^2
Ear	.78	1	27	7.49	.01	.21
Stimulus Presentation	.32	2	26	26.58	.00	.67
Ear*Stimulus Presentation	.82	2	26	2.77	.08	.17