The influence of auditory stimulation on binocular rivalry

Student: Nataša Borojević (BBioMedSc)
Supervisor: Dr Guang Bin Liu

2012

In fulfilment of the degree of Bachelor of Biomedical Science (Honours) in the Department of Biological and Physical Sciences, University of Southern Queensland

ABSTRACT

Binocular rivalry is an intriguing visual phenomenon which over recent decades has particularly engaged the interest of scientists. This phenomenon is induced when two different images are viewed, one by each eye, with alternations occurring between perceiving one image for a few seconds, followed by the other image for a few seconds. Thus, despite the constant sensory input, there are striking changes in perception. There are several extrinsic factors (e.g. stimulus variables such as contrast, colour, motion) that are well known to influence rivalry, however, much less work has been conducted on the effect of other extrinsic factors such as non-visual stimulation. Recent studies into multimodal influences (e.g. tactile, olfactory, auditory stimulation) on binocular rivalry indicate that interactions occur between the different senses; whereby there are significant changes in how often subjects perceive either of the presented images.

The aim of the study was to further our understanding of the mechanisms involved in rivalry processing, with implications also for understanding how multiple and often conflicting stimuli from the environment are resolved in the human brain. For this purpose, the influence of auditory stimulation on binocular rivalry was explored using unilateral and bilateral auditory stimuli. The investigation was divided into two stages which differed in the frequencies of the auditory stimuli presented and the task involved subjects viewing vertical and horizontal gratings while indicating visual perception in the presence and absence of auditory stimulation.

The present results indicate that auditory stimulation influences binocular rivalry, confirming the interaction between audio and visual perceptions. More specifically, the higher frequency (3000Hz) increased visual temporal rate and the perception of horizontal gratings to a greater extent than the lower frequency (1000Hz). The results further suggest that auditory stimulation can modulate the functional status of the cerebral hemispheres, and consequently impact the perception of visual stimuli.

TABLE OF CONTENTS

CONTENTS **PAGE NO.**

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BP	bipolar disorder
BR	binocular rivalry
CVS	caloric vestibular stimulation
CNS	central nervous system
DL	dichotic listening
IOG	interocular grouping
LGN	lateral geniculate nucleus
LC	locus coeruleus
LSD	lysergic acid diethylamide
MEG	magnetoencephalography
NE	norepinephrine
PET	positron emission tomography
SPL	sound pressure level
SC	superior colliculus
TMS	transcranial magnetic stimulation
V1	primary visual cortex

ACKNOWLEDGEMENTS

I would like to acknowledge several people, without whom this thesis would probably not have been possible.

I would first like to thank my supervisor, Dr Guang Bin Liu, for his support and advice throughout the year. I would also like to thank Dr Trung Ngo and Amanda Wakefield, for their assistance and encouragement.

Special thanks to the participants in this study and to Julie Christensen for organising the vouchers.

Lastly, I would like to offer thanks to my family, my brother Branko, my mother Spomenka, and my father Ranko Borojević for their continuous support, patience and guidance. *Za vašu bez rezervnu ljubav, podršku i strpljenje, mojim dragim roditeljima se zahvaljujem za sve ono što sam postigla i šta ću još postići, zbog čega sam vam neizmjerno zahvalna.*

CHAPTER 1 – INTRODUCTION AND LITERATURE REVIEW

1.1 Overview of Binocular Rivalry

During our everyday normal vision, the sensory input received by both eyes is nearly identical, which the brain combines to produce a single stable image (binocular fusion) that enables depth perception. However, in an experimental setting, when each eye is presented with a different image, perception instead alternates or *rivals* between the two images (Figure 1). Such binocular rivalry (BR) involves alternating periods of dominance and suppression of the presented images (Blake 1989).

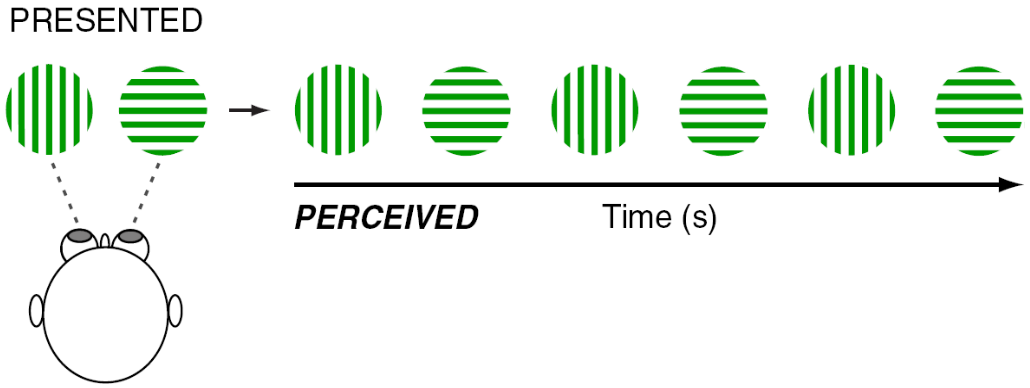

Figure 1: Binocular rivalry. When conflicting stimuli are presented, such as vertical gratings to the left eye and horizontal gratings to the right eye, alternations occur between perceiving the vertical image and then the horizontal image and back to the vertical image and so on, for as long as the stimuli are presented. These perceptual alternations typically occur every few seconds.

Various methods can be used to present rivalling stimuli (e.g. anaglyphs, mirror stereoscope, autostereoscopic monitor; Howard & Rogers 2012) but the basic principle underlying them is the simultaneous presentation of two different images, one to each eye (i.e. dichoptic presentation). Commonly used stimuli in rivalry studies are shown in Figure 2, including the well-known Necker cube, which is instead viewed dioptically (i.e. same image to both eyes), but like BR there is constant visual input and perception alternates between two different configurations.

A B C

Figure 2: Types of perceptual rivalry stimuli. **(A)** Conventional/classical rivalry between orthogonal oblique gratings. **(B)** Rivalry between an image of a house and an image of a face. **(C)** The Necker cube is a two-dimensional image which alternates between two different depth perspectives. Source: Alais et al. 2010.

Although the psychophysical characteristics of BR are well known, its precise brain mechanisms remain unclear (Blake & Logothetis 2002). Over the past twenty years investigators have used the phenomenon to examine brain activity during constant visual input and in dissociation from brain activity during the actual changes in perception (Crick & Koch 1998). This resurgence of interest in studying the phenomenon to explain the neural basis of conscious perception has lead to a series of findings, which suggest rivalry occurs through a series of processes mediated at multiple levels of the visual hierarchy (Blake & Logothetis 2002). Over recent years, a small number of studies have also explored the rivalling phenomenon in non-visual modalities, as well as non-visual stimulation effects on BR, with remarkable findings to date. The focus of the current literature review will be on such multimodal influences on rivalry, in particular auditory stimulation effects as background for the current study on auditory influences on BR.

1.2 Features of Binocular Rivalry

There are two key features of BR, the rate and the predominance. The rate describes perceptual alternations between presented images, where several studies have shown that the BR rate is relatively stable within individuals but varies between individuals (McDougall 1906; George 1936; Enoksson 1963; Aafjes, Hueting & Visser 1966; Pettigrew & Miller 1998; Miller et al. 2003; 2010). Alternations in the dominant percept are also known to be irregular (or stochastic) over a viewing period (Fox & Herrmann 1967). The other key feature of BR is predominance, which describes the amount of time that one image is perceived relative to the other image within a given viewing period. However, perceptual dominance on the other hand refers to the image that is perceived at any one particular time during BR. Perceptual dominance and/or predominance of rivalling stimuli is influenced by factors such as their emotional content, meditation and non-visual stimulation (i.e. tactile, olfactory or auditory; Alpers et al. 2005; Carter et al. 2005b; van Ee et al. 2009; Lunghi, Binda & Morrone 2010). In addition, increasing the strength of a stimulus (i.e. salience) during BR is known to increase its predominance over the other presented (rival) image.

Extrinsic factors such as contrast and semantic context of the stimuli have been shown to affect both predominance and rivalry rate (Howard & Rogers 2012) (Table 1). However, while such influences on rivalry are well known, only recently has it been demonstrated that intrinsic factors, such as genetic factors, contribute substantially to the wide variation in rivalry rate observed between individuals (Miller et al. 2010). Hence, this genetic basis of rivalry may be useful in diagnosing clinical conditions, such as bipolar disorder (BP), where individuals have a slower than normal BR rate (Miller et al. 2010; Ngo et al. 2011).

Table 1: Factors influencing binocular rivalry

Extrinsic Factors	**Other**
1. Colour 2. Contrast 3. Spatial frequency 4. Contour density 5. Luminance 6. Grouping (motion, orientation) 7. Motion velocity 8. Semantic context 9. Non-visual stimulation (tactile, olfactory, auditory)	1. Drugs, caffeine, alcohol 2. Meditation 3. Genetics

Note: Most extrinsic factors decrease the rate and increase predominance times.
Source: Alais & Blake (2005); Howard & Rogers (2012).

In other psychophysical experiments, emotional images have been found to influence visual perception by taking predominance over neutral pictures, with implications for biopsychological theories of visual fear processing (Alpers et al. 2005). In drug intervention studies, substances such as lysergic acid diethylamide (LSD) have been shown to increase perceptual alternations during BR, while psilocybin, a mixed 5-HT_{2a} and 5-HT_{1a} agonist, decrease alternation rate (Carter et al. 2005a). Although both drugs show an affinity for serotonin receptors, unlike LSD, psilocybin and its active metabolite psilocin, have no affinity for dopamine D2 receptors. Hence, the slowing of the rate following psilocybin administration occurred due to the drug's negative-type symptoms, which caused subjective changes in the conscious state (i.e. reduced arousal and attention) (Carter et al. 2005a). These findings suggest that while rivalry rates between two different visual stimuli are generally stable (within individuals), they can be altered pharmacologically. According to Carter and colleagues (2005b), meditation can also alter BR by increasing and prolonging the dominance duration of an image, which lends support to the high-level, top-down view of rivalry. Additional support for this view comes from studies showing voluntary attentional control can influence the speed of rivalry alternations (Paffen, Alais & Verstraten 2006). Experiments that have examined the influence of non-visual stimulation (e.g. tactile, olfactory, auditory) on perceptual rivalry will be discussed in details in Section 1.5.

1.3 History of Binocular Rivalry

1.3.1 Early Views on Binocular Rivalry

The history of BR dates back to as early as 1593, but scientific studies of the phenomenon did not gain wider interest until two and a half centuries later following the invention of the stereoscope (Table 2).

Table 2: Historical landmarks in binocular rivalry observations

1593	Giovanni Battista della Porta discovered the phenomenon by presenting two books, one to each eye, to induce rivalry.
1712	Général Leclerc first reported binocular colour rivalry.
1716	John Theophilus Desaguliers also recorded binocular colour rivalry when looking at different colours from spectra of a mirror.
1760	Etienne-Francois Dutour first clearly described colour rivalry.
1761	Etienne-Francois Dutour described contour rivalry, and considered the idea that attention influenced perception during rivalry.
1838	Charles Wheatstone invented the stereoscope and provided the first clear description of BR in English.
1899	Breese found that each rival stimulus was dominant for around half of the viewing time, revealing the involvement of different processes in the selection of and alternations between the images.
1970	Robert Fox suggested that it is the eyes and not the stimuli that are suppressed during BR.

Source: Alais & Blake (2005)

In 1760, the suppression theory of BR was proposed by Dutour, who experimented with colour by viewing blue taffeta with one eye and yellow taffeta with the other (Wade 1998). The colours did not combine to yield green but rather perception alternated between the two. Dutour concluded that through dichoptic viewing, the natural state of human vision can be revealed, as only one of the two patterns presented to the corresponding retinal points is perceived (Alais & Blake 2005). Therefore, according to the eye suppression theory, the visual system alternates in suppression of monocular input during rivalry (Asher 1953; Fox & Check 1966).

In 1838, Wheatstone questioned the suppression theory as he found that fusion of stereoscopic depth occurred despite viewing different stereo-images (Wheatstone 1962). Later he discovered binocular contour rivalry by revealing that in fact perceptual alternation, and not fusion, took place when different monocular stimuli were viewed. In 1866, Helmholtz proposed that rivalry was due to spontaneous fluctuations in visual attention and that input from the two eyes were not physiologically combined as in Wheatstone's theory, but only combined to form stereoscopic depth due to psychical events (Helmholtz & Southall 1924). That is, rivalry takes place between contrasting stimuli, suggesting that until the later stages of attention, selection input from either eye is available to awareness (Lack 1978). Helmholtz also discovered a weaker form of rivalry known as monocular rivalry, which involves two objects superimposed and presented to the same eye (Enoksson 1963).

1.4 Modern Theories of Binocular Rivalry

In 1989 Blake proposed the eye-based hypothesis, in which rivalry resulted from competition between monocular primary visual cortex (V1) neurons (Figure 3; Blake 1989). The theory was proposed due to previous physiological and psychophysical studies, which found cortical neurons to vary in their ocular dominance, further suggesting the occurrence of neural processes such as interocular inhibition (Abadi 1976; Sugie 1982; Sloane 1985; Cogan 1987). Thus, the eye-based theory involved low-level processing and was supported by further psychophysical studies, which suggested that rivalry occurred due to reciprocal inhibition (Blake 1989). Subsequent psychophysical, brain stimulation and electrophysiological studies however challenged this eye-based rivalry model.

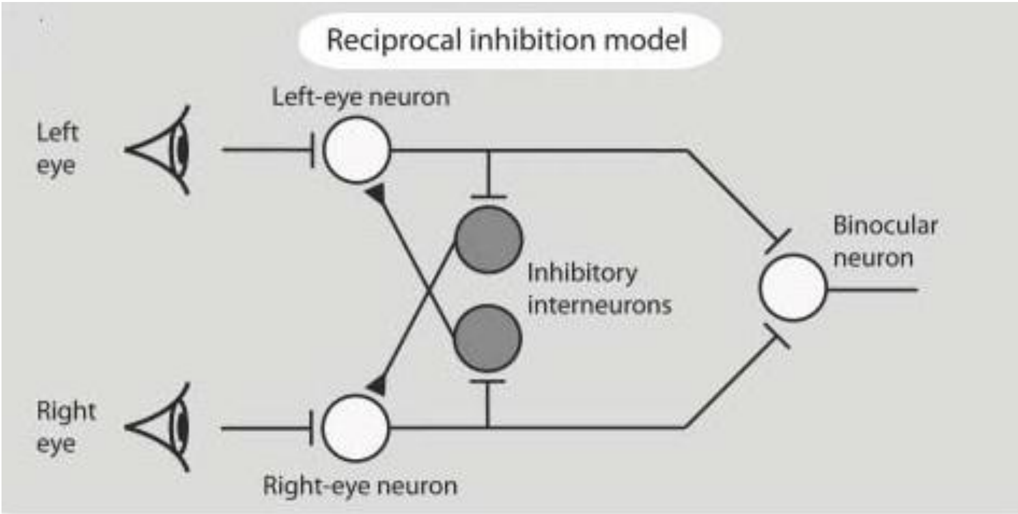

Figure 3: Eye-based suppression theory. This classical model of BR proposes there is reciprocal inhibition between monocular channels, and shows how an image becomes suppressed during BR. Source: Alais (2012).

Using presented stimuli such as that shown in Figure 4, Kovács and colleagues (1996) demonstrated that observers perceived coherent images formed from elements of both eyes' images. Such interocular grouping (IOG) suggested the brain's ability to perceptually reorganise elements into coherent wholes, and supported the role of high-level mechanisms in BR. Over half a century earlier, Díaz-Caneja (cited in Alais et al. 2000) had also observed such re-grouping of stimulus features from both eyes into coherent percepts, and proposed that rivalry resulted from competition between perceptual representations rather than competition between left-eye and right-eye channels.

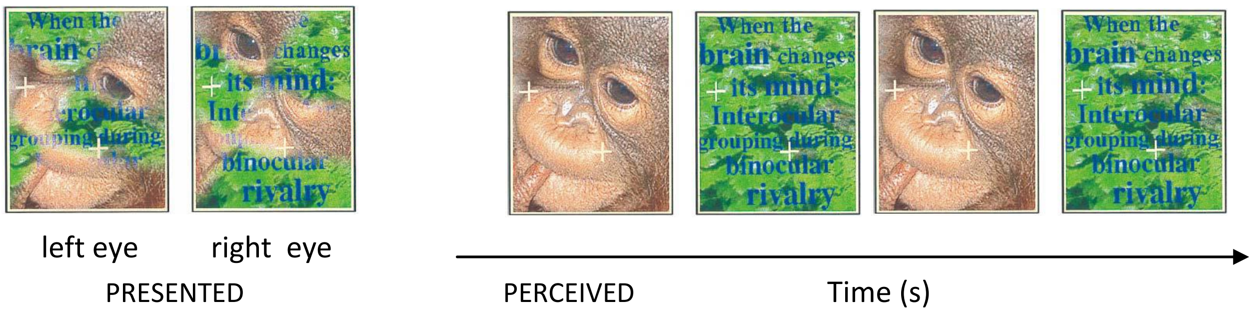

Figure 4: Interocular grouping during binocular rivalry. The two presented images are complementary patchwork stimuli of a monkey and jungle scene. Viewing such stimuli results in alternations between perceiving a coherent monkey face and a coherent jungle image.
Source: Kovács et al. (1996).

In keeping with Kovács and colleagues' (1996) high-level account of BR, Pettigrew and Miller (1998) proposed that rivalry was mediated by a process of interhemispheric switching, whereby one image was selected by one hemisphere and the rival image was selected by the other hemisphere, and the perceptual alternations correspond to a switching between the hemispheres (Pettigrew & Miller 1998). This model was supported in a series of experiments employing unihemispheric brain stimulation techniques that activated or disrupted high-level attentional regions (Miller et al. 2000; Ngo et al. 2007; Ngo et al. 2008).

Other evidence for high-level competition during BR came from a study by Leopold and Logothetis (1996). These investigators rapidly swapped each eye's presented image at a rate of 3Hz and found that instead of perceiving rapid perceptual alternations (which would support eye-based models), there were smooth and slow transitions every few seconds, similar to that seen during conventional rivalry presentation. These findings supported the view that rivalry occurs between the stimuli or 'stimulus rivalry', rather than between the eyes. This view was supported by seminal electrophysiological experiments in awake monkeys which were trained to report their rivalry perceptions (Figure 5). The study showed that up to 90% of neurons in highest level of the visual hierarchy (inferotemporal cortex) were associated with the monkey's perceptions compared to ~20% in V1 monocular neurons (Leopold & Logothetis 1996; Sheinberg & Logothetis 1997). This body of work resulted in a renewed interest in BR research and its underlying mechanisms, which has continued to grow.

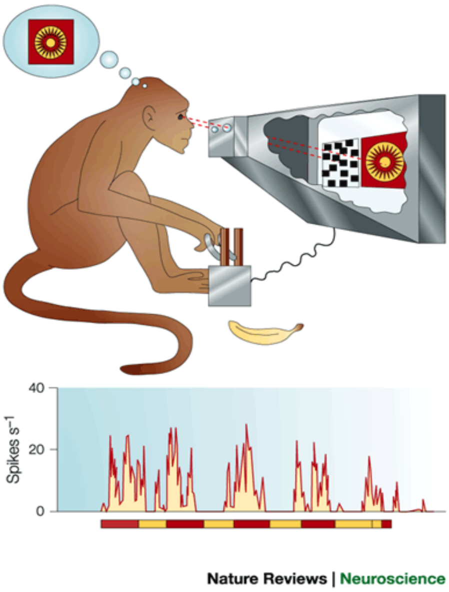

Figure 5: An electrophysiological study of rivalry in monkeys. Single-cell recordings use a microelectrode system to measure perception-dependent activity of single neurons at different levels of the visual hierarchy. Source: Blake & Logothetis (2002).

Further studies following the monkey experiments employing various investigative techniques, such as electrophysiological, psychophysical, brain-imaging, have provided conflicting data in regard to low- vs. high-level accounts of BR. The various studies were reviewed by Blake and Logothetis (2002), who proposed an amalgam view of the phenomenon of low vs. high level BR. This view suggests rivalry involves multiple processes occurring at different levels of the visual hierarchy. More recent findings from various studies are also consistent with this multi-level distributed processing model of BR (e.g. Ooi & He 2003; Pearson & Clifford 2005; Tong, Meng & Blake 2006).

1.5 Processing of Sensory Information

The ability of a single physical stimulus to produce alternations between different subjective percepts is known as multistability (Schwartz et al. 2012). It was first described for vision and now also describes other sensory modalities such as audition, touch and olfaction. Therefore, in BR multistability involves perceptual competition between two images. Multimodality on the other hand, refers to different sensory inputs that combine together in a process called multisensory integration (Schwartz et al. 2012).

According to Stein and Meredith (1990), multisensory integration is described by three general rules: the spatial rule, temporal rule, and the principle of inverse effectiveness. The spatial and temporal rules state that multisensory integration is stronger when the stimuli arise from approximately the same location and time, respectively. The principle of inverse effectiveness states that a stimulus that produces a weak response when presented on its own, would produce a stronger effect when presented with another stimulus. The processing of sensory stimuli from various modalities has been studied in cognitive science, behavioral science, and neuroscience, where the focus of this study will be on multimodal influences on perceptual rivalry, in particular investigating multisensory integration between visual and auditory stimuli.

1.5.1 Visual Pathway

In order to resolve visual ambiguities in BR, the brain collects information from multiple senses such as vision and audition (Kelso 2012). In both the visual and auditory pathway (Figure 6 & 7, respectively), the final destination is the primary cortex, where information is either transmitted to the visual cortex or the auditory cortex (Purves & Williams 2001). The visual cortex is part of the cerebral cortex and located in the occipital lobe, which is responsible for processing visual stimuli (Hubel 1963). The primary auditory cortex processes sound and is located in the temporal lobe, where it is the first cortical region of the auditory pathway (Purves & Williams 2001). In addition, visual motion pathways are more clearly understood than auditory motion processing.

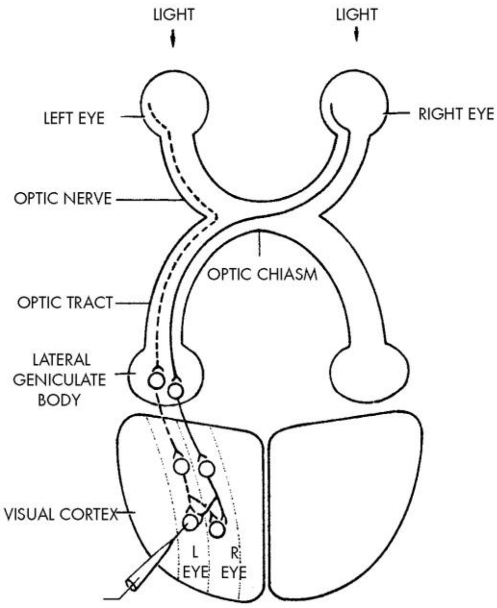

Figure 6: The visual pathway. In the central visual pathway, light rays reflected by an object enter the eye and pass through the lens, which inverts the observed image onto the retina located at the back of the eye. The signals produced by photoreceptors travel to the brain via the optic nerve, where they are divided (left half/right half) and then conveyed to the lateral geniculate nucleus (LGN) in the thalamus, until finally reaching the primary visual cortex (V1). The V1 is located in both cerebral hemispheres, where the right and left V1 contain a map of the left and right visual field, respectively. Source: Kandel (2001).

1.5.2 Auditory Pathway

Hearing is an important sensation relying on the auditory system to transmit sound waves to the auditory cortex (Lewis, Beauchamp & DeYoe 2000). The early stage of central processing occurs at the cochlear nucleus, and later processing in the superior olivary complex and inferior colliculus of the midbrain (Mittmann & Wenstrup 1995). Information from the two ears first interacts at the superior olivary complex, while the inferior colliculus is the major integrative centre and the first place of interaction between the auditory information and motor system (Shneiderman & Henkel 1987). The inferior colliculus also relays information to the thalamus and cortex and has integrative aspects (temporal or harmonic combinations) of sound processed (Shneiderman & Henkel 1987). Moreover, the auditory cortex receives and transmits signals back to the ear and lower centres of the brain (i.e. the thalamus), which are tonotopically organised (Stepp-Gilbert 1988). Tonotopy describes the spatial arrangement of where sounds of different frequency are processed in the primary auditory cortex (Romani, Williamson & Kaufman 1982). Furthermore, the topographically organised receptive fields in audition, containing fibres that project to neurons with receptive fields in V1, have been found to increase the perception of visual stimuli (Romani, Williamson & Kaufman 1982).

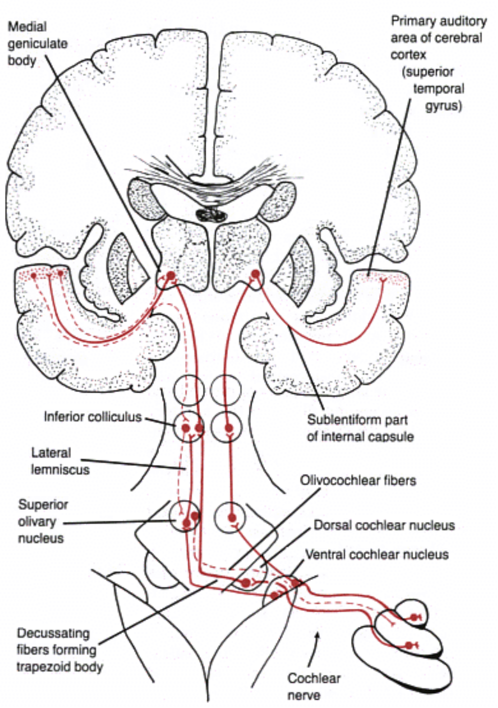

Figure 7: The auditory pathway. Sound vibrations are collected externally and transmitted mechanically to the middle ear, followed by the inner ear. Within the inner ear, mechanical sound energy is converted to electrical signals by hair cells in the organ of Corti (found within the fluid filled tube called the cochlea), which stimulates auditory nerves and higher neural pathways. The final destination is the auditory cortex in the temporal lobe. There are two auditory streams, the ascending (coloured lines) and descending (broken lines) pathways, and humans can detect sounds in frequencies ranging from 20Hz to 20,000Hz. Source: Patel (2011).

1.5.3 Integration of the Visual and Auditory Pathway

The central nervous system (CNS) combines sensory input across modalities and functions in the detection, localisation and discrimination of external stimuli, and in producing faster responses to the stimuli. More specifically, multiple sensory stimuli are processed in different regions of the cerebral cortex, where the visual and auditory cortex transfer low-level sensory modalities to high-level features through mapped sensory systems, such as the visual and auditory system (Cappe, Rouiller & Barone 2012). Thus, the coordination and integration of visual and auditory pathways is essential in providing a unified perception of the environment (King & Calvert 2001).

The superior colliculus (SC) is important to study in order to understand multisensory integration in neural, behavioural, and perceptual systems. The structure is part of the tectum and is located in the midbrain, superior to the brainstem and inferior to the thalamus (Joseph 2000). According to Lund (1972), the SC contains seven layers of alternating white and grey matter, with the superficial layers containing topographic maps of the visual field, while the deeper layers contain overlapping spatial maps of the visual, auditory and somatosensory modalities. Furthermore, SC receives afferent neurons from the retinae, the cortex (mostly from the occipital lobe), spinal cord and the inferior colliculus, and sends efferent neurons to the spinal cord, cerebellum, thalamus and occipital lobe (via the LGN). Further still, the structure contains a large number of multisensory neurons, and functions in motor control of the eyes, ears and head (Vroomen & de Gelder 2000).

Therefore, the visual (superior) and auditory (inferior) colliculi of the midbrain are responsible for the integration and analysis of auditory, visual-tactile and motor stimuli (Joseph 2000). Moreover, auditory information influences vision at different locations in the midbrain, specifically at the superior colliculus, the main site of multi-modal integration (Vroomen & de Gelder 2000). Welch, DuttonHurt and Warren (1986) suggested that audition had a stronger influence on perception than vision, known as modality appropriateness. It is believed that vision processes spatial information, while audition processes temporal information and according to Welch and Warren (1980), temporal processing involved in the auditory system is given precedence over spatial processing.

1.6 Multimodal Influences on Perceptual Rivalry

The renewed interest in visual rivalry research in recent decades has more recently extended to investigations of other forms of perceptual rivalry. Recent studies have demonstrated novel forms of perceptual competition (e.g. tactile rivalry) as well as examined olfactory and auditory rivalry, along with experiments exploring the influence of one modality (e.g. touch stimulation) on rivalry in another modality (i.e. BR). Such studies seek to understand how the brain receives input from multiple senses to resolve ambiguities and conflicts in multistable perception (Conrad et al. 2010). The study of multimodal influences on perceptual rivalry may also provide a better understanding of perceptual systems that are based on binding different characteristics of objects in the environment (Schwartz et al. 2012).

Currently the precise brain mechanisms underlying perceptual multistability remain unclear. However, based on a series of rivalry studies employing transcranial magnetic stimulation (TMS; a type of brain stimulation technique), Kleinschmidt, Sterzer and Rees (2012) suggested that different regions in the parietal cortex produce opposing effects on perceptual alternations and have diverse roles in bistable perception. They also suggested that perceptual alternations are associated with transient activity in the parietal cortex, particularly in the frontoparietal regions associated with spontaneous alternations during perceptual bistability (Kleinschmidt, Sterzer & Rees 2012). This is consistent with the view that supra-modal brain regions may be involved in the processing of multistability of different modalities (e.g. Miller, Ngo & van Swinderen 2011).

Several studies have demonstrated the effect of sensory stimuli on visual perception, particularly on binocular rivalry. In one study that presented horizontal and vertical gratings to induce BR, subjects were instructed to use their right thumb to explore the haptic stimulus of either horizontal or vertical orientation at regular intervals (Figure 8A) (Lunghi, Binda & Morrone 2010).

In a separate study, images of a rose and a marker pen were viewed dichoptically by subjects who then smelled the odour of a marker pen or rose at different times (Figure 8B) (Zhou et al. 2010). The findings from both studies illustrated that non-visual stimulation significantly affected visual processing, with subjects perceiving the image that was congruent with the tactile/olfactory stimulus (Lunghi, Binda & Morrone 2010; Zhou et al. 2010). Earlier work also supported that voluntary attention to non-visual congruent stimuli (i.e. auditory and tactile) enhanced attentional control of visual dominance (van Ee et al. 2009).

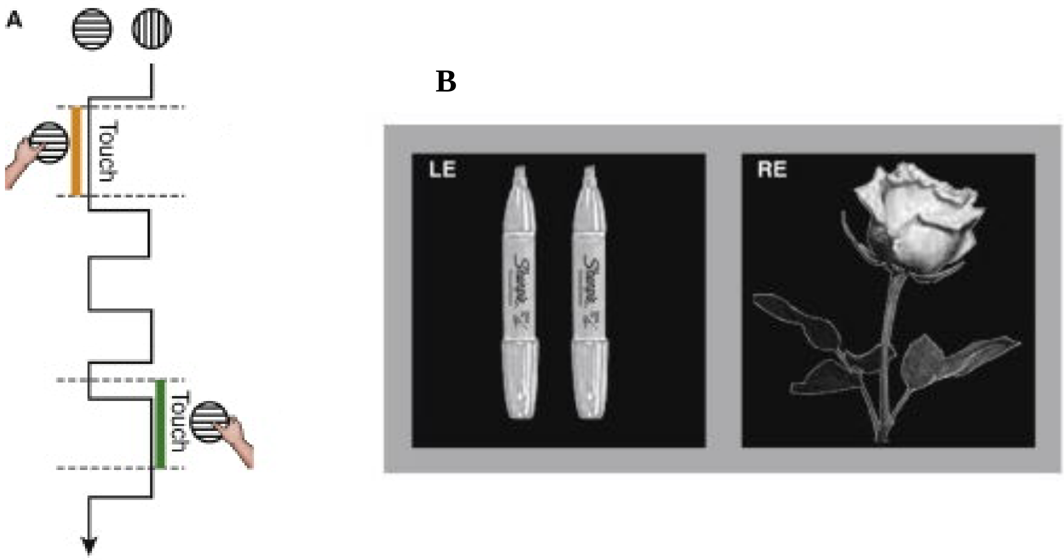

Figure 8: Tactile and olfactory stimulation in rivalry. **(A)** In the tactile stimulation study, during BR between horizontal and vertical gratings, subjects explored a haptic tactile stimulus. **(B)** In the olfactory stimulation study, the left eye viewed an image of a marker pen while the right eye viewed an image of a rose, and subjects were presented with either the smell of a marker pen or a rose Source: Lunghi, Binda & Morrone (2010); Zhou et al. (2010).

1.6.1 Rivalry Studies Employing Auditory Stimulation

Audition in the form of rapid sequences, such as varying frequencies or tones, is either derived from a single source (known as coherent or fusion), or from multiple sources (known as stream segregation or fission), where the percept may alternate between the two (Schwartz et al. 2012).

In order to study multimodal multistability in audition and vision, the effects of visual processing on the perception of sound have been investigated by the McGurk and ventriloquism effects (Kubovy & Yu 2012). The McGurk effect demonstrates the interaction between hearing and vision in speech perception, and occurs when visual and auditory cues are incongruent, (e.g. the voice heard is different to the lip movement). The ventriloquism effect relies on an auditory illusion to separate the two modalities (e.g. sound is perceived as coming from the mouth but the lip movement is coming from a different location), and as a consequence the visual response is spatially misrepresented. Hence, the McGurk and ventriloquism effects suggest that auditory perception is significantly influenced by lip movement and that visual stimuli are stronger than auditory stimuli, respectively (Shams et al. 2005). However, when there is asynchrony between sound and lip movement, then both the McGurk and ventriloquism effects decrease, suggesting that speech comprehension is more accurate when the speaker can be seen as well as heard (King & Calvert 2001). Thus, according to Kubovy and Yu (2012), crossmodal synthesis is necessary for stimulus identification, while neural integration from different modalities, such as in vision and audition, allow conflicting signals to be perceived to a certain degree.

To date a number of studies have examined the effect of auditory stimuli on BR, however the mechanisms involved remain poorly understood. Following earlier work conducted by Urbantschitsch (1903) (cited in Ravey 1969), Ravey (1969) examined the effect of auditory stimulation on BR between red and green visual stimuli. Subjects were assigned to one of four experimental conditions: the first group was the control condition without sound, the second group had sound presented to the left ear (via headphones), the third group had sound presented to the right ear, and the fourth group had auditory stimulation presented to both ears. Although no significant effect of auditory stimulation on perceptual dominance was found during BR, methodological differences, specifically in the type and colour of the visual stimuli between the studies may have accounted for the inconsistent findings.

More recent BR studies have investigated the effects of congruent and incongruent auditory stimulation on visual perception, and have found that both forms of stimulation significantly influenced perceptual dominance of the visual stimuli. For example, when subjects listened to a soundtrack that was incongruent with either of the visual stimuli during BR, there was a reduction in the predominance of both images (Chen, Yeh & Spence 2011). Other studies have found that both auditory and visual stimuli are associated with pupil dilation (Einhauser et al. 2008; Hupe, Lamirel & Lorenceau 2009), and that auditory and visual rivalry rates are also coupled within individuals (Hupe, Joffo & Pressnitzer 2008). The pupil dilation occurs due to norepinephrine (NE) release from the locus coeruleus (LC), which suggests that similar functions may exist between perceptual selection and behavioural decision making (Einhauser et al. 2008; Hupe, Lamirel & Lorenceau 2009) Therefore, the results illustrate that there is competition for both perceptual decision making and awareness.

Conrad and colleagues (2010) investigated the effect of sound on perceptual dominance during BR by conducting three experiments. Each stage included the same auditory conditions: no sound, non-motion and directional sound. In the first stage, subjects' dichoptically viewed stimuli that moved in opposite directions. In the second stage, a visual motion stimulus that alternated in opposite directions was presented to both eyes. In the last stage, one eye was presented with an alternating motion stimulus and the other eye with a random motion stimulus. Overall, it was found that a directional sound increased perceptual dominance of a rivalling visual image whose motion direction was congruent with that of the auditory stimulus.

In a non-rivalry experimental paradigm, Recanzone (2003) tested the interactions of visual and auditory stimuli to determine if auditory after-effects on visual perception could be induced. The experiment involved presenting four auditory stimuli and four flashes of visual stimuli at intervals of one second. Subjects were instructed to ignore one stimulus modality and attend to the other. The findings indicated that the auditory system had a distinct influence on visual temporal rate perception, and that visual after-effects could be induced by auditory stimulation. Further still, Recanzone (2003) suggested that bimodal stimuli produce lasting changes in the neural representation of both space and time, indicating that bimodal and multimodal representations are dynamic. A similar experimental design was employed by Hidaka et al. (2011), using static visual flashes and auditory motion traveling in a horizontal plane as stimuli, to test whether auditory motion information influenced visual motion perception. Their findings indicated direct interactions between auditory and visual motion signals exist, and suggested common neural substrates for both auditory and visual motion processing.

Further investigations on auditory consciousness have been conducted by exposing both ears to varying tone frequencies to induce binaural rivalry (Brancucci & Tommasi 2011). Here the same principle to BR applies: two different stimuli are presented, one to each ear. This dichotic listening (DL) paradigm enabled the subjects to report the auditory perception of one stimulus and not the other. DL investigations have also been examined with brain activity recording techniques such as positron emission tomography (PET) and magnetoencephalography (MEG). An early PET study showed that dichotic verbal and nonverbal stimuli induced a stronger cortical response in the left temporal lobe and the right temporal lobe, respectively (Hugdahl et al. 1999). However, from subsequent MEG studies that recorded neuromagnetic responses during dichotic non-verbal and verbal stimulation, there are conflicting findings in regard to the inhibitory processes that are thought to be involved in the left and right auditory pathways (Brancucci et al. 2004; Della Penna et al. 2007).

A study by Shimojo (2001) confirmed that visual perception can be influenced by other modalities such as audition. The study investigated how sound altered visual temporal resolution, which is the ability to perceive visual stimuli when presented with another stimulus e.g. auditory stimulation. Stage 1 was divided into five conditions, differing in the order in which a sound and image (light emitting diode) were presented (e.g. the presentation of a sound, followed by an image and then a sound). The results showed that the arrangement of auditory/visual stimuli modulated perception due to the sound's effect on visual temporal resolution. In the next stage, flashes of visual stimuli were accompanied by a variable number of beeps, with observers instructed to judge the number of times visual flashes were presented. It was found that multiple flashes were reported but not necessary perceived, suggesting that auditory stimuli caused a perceptual illusion, known as the illusionary flashing phenomenon. The final stage involved presenting two identical visual targets moving across each other. In the absence of auditory stimulation, streaming (objects moving past one another) was observed and explained by the attention hypothesis. However, in the presence of sound, the attentive tracking of the objects were disrupted, which caused the bouncing (objects rebounding of one another) percept. The results suggest that the brain relies on the modality that is strongest, least ambiguous and most accurate to integrate signals from other sensory modalities. In summation, it was found that auditory stimulation affects visual perception (temporal domain) and that visual percepts are malleable by other modalities (Watanabe & Shimojo 2001).

Returning to studies that have investigated BR, previous work using brain stimulation techniques (Section 1.4) are also relevant here in the context of multimodal/interventional influences on rivalry. In a series of experiments, caloric vestibular stimulation (CVS) was used as a brain stimulation intervention to examine its effect on BR predominance (Miller et al. 2000; Ngo et al. 2007; Ngo et al. 2008). These CVS/rivalry studies employed an experimental design (Figure 9) that was adapted for the current study outlined below (Section 1.7). Briefly, the current study will investigate the effect of unilateral and bilateral auditory stimuli on BR, with the auditory stimulation being applied during one of the BR recording blocks, similar to the previous CVS/rivalry experiments (Figure 9B). From a mechanistic view, the CVS technique has been consistently shown in brain-imaging studies to activate cortical areas (e.g. inferior parietal cortex, superior temporal gyrus, somatosensory area II) involved in the processing of different modalities (e.g. vestibular, visual, auditory, somatosensory) (Ngo et al. 2007). This has interesting implications for future studies exploring the technique's effect on non-visual stimulation during BR and also on different types of non-visual rivalry phenomena.

A B

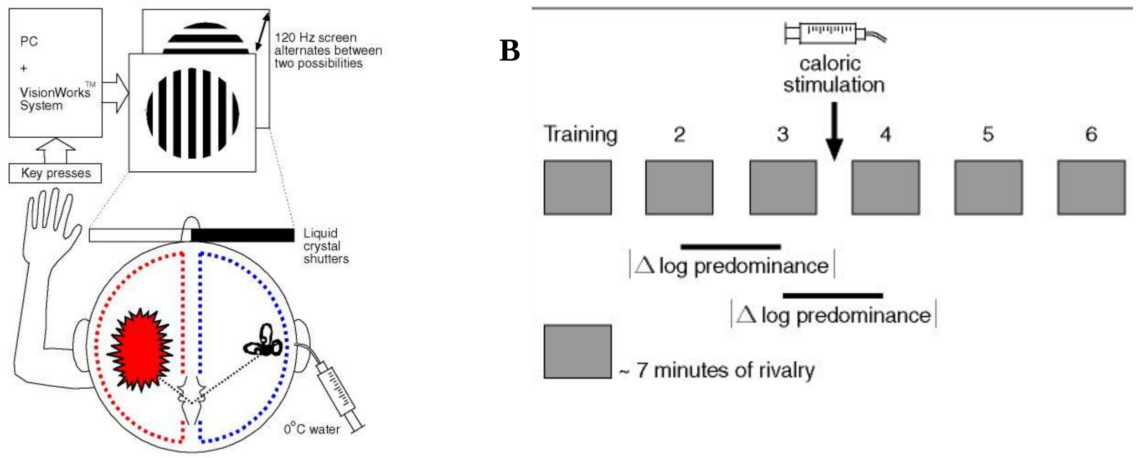

Figure 9: Brain stimulation study design. **(A)** Binocular rivalry involved drifting horizontal and vertical gratings, and subjects were given caloric vestibular stimulation, which activates high-level attentional cortical areas. **(B)** The outline of the experimental design shows six blocks of rivalry recording. The first block was considered as the training block, blocks 2 and 3 as pre-stimulation blocks, and the remaining blocks as post-stimulation blocks. This design enabled assessment of changes in predominance due to the intervention, with random fluctuation in predominance taken into account. Source: Miller et al. (2000).

1.7 Outline of the Current Study

Audio, visual and somatosensory information are important in our daily perception and awareness, where the integration of the cortices involved in vision (occipital cortex), hearing (temporal cortex) and somatosensory (parietal cortex), form cognition and may influence perception (Eimer 2004). Therefore, the project will incorporate the multimodal elements involved in audiovisual interactions by investigating the effect of auditory stimulation on visual perception. Moreover, as sounds with varying frequencies can be expressed by a tonotopic representation throughout the central auditory pathway, then based on this tonotopic model, different frequencies may have dissimilar influences on visual perception. Hence, the effects of different frequencies on BR, a non-invasive method that studies neuronal causes and factors influencing perception, will be investigated.

For this purpose, 15 volunteers between the ages of 18-40 years will be recruited to participate in the study. However, before viewing images and reporting visual perception, subjects are required to complete a preliminary questionnaire, followed by a vision and hearing test. To be eligible to participate, the visual acuity must be 6/9 or better for both eyes and the subject must be able to detect sounds in frequencies between 200Hz to 10,000Hz. The BR test will involve visual stimuli being presented to each eye in the form of horizontal and vertical gratings and require participants to respond to image perception by pressing on the appropriate keys, e.g. one for when vertical gratings are dominant, another for when horizontal gratings are dominant, and space bar for mixed/indeterminate percepts or errors.

The investigation will be divided into two stages which will differ in the strength of the auditory stimuli presented, and tested on a total of 15 subjects, comprising of 10 subjects in the first stage and 5 in the second. The first stage will present a tone of 3000Hz to the left, right and both ears, while the second stage will present 1000Hz to the left and right ear. A control condition without auditory stimulation will also be included. In terms of the experimental design, one session will be divided into 4 blocks, and auditory stimulation will only be presented during the third block. Each subject will attend a minimum of 3 sessions, and each session will differ in the ear to which the sound is presented (i.e. left, right, both ears/control). Hence, the BR task will involve subjects viewing vertical and horizontal gratings and indicating visual perception in the presence and absence of auditory stimulation.

Moreover, binaural rivalry has more voluntary control and synchrony than BR, which suggests a stronger influence in the auditory than the visual modality (Alais & Blake 2005). Therefore, as this project involves investigating audiovisual interactions, it may enable parallels to be drawn between the visual and auditory pathway through the observed influence on BR. Considering the existence of cortico-cortical projections between auditory and visual cortices (Banks et al. 2011) and the audio-visual interaction at different levels of the auditory and visual pathways (Evans & Treisman 2010), we speculate that auditory stimulation with varying harmonic components will have different degree of effects on visual perception.

1.8 Significance of Investigating Binocular Rivalry

Visual scientists have studied BR for nearly two centuries and only in the past few decades, with the rapid development of other advanced scientific tools, is its potential utility beginning to be realised. As a simple and powerful probe into understanding the neural basis of visual consciousness, BR has helped to further illuminate the brain mechanisms of conscious perception. In the clinical realm, differences in BR rate between individuals is being examined on a large scale as a potential diagnostic tool in clinical psychiatry (Ngo et al. 2011), with major treatment and preventative implications. In relation to the current study, examination of multimodal effects such as auditory stimulation on BR may help to further elucidate the mechanisms involved in the integration of visual and auditory information. Furthermore, multimodal effects on rivalry may provide an insight into the dynamics of complex goal-directed systems such as brain-behaviour relations (Kelso 2012). This may also have implications for understanding how multisensory input from the environment is processed, perceived and acted upon in psychiatric conditions known to involve disordered neural circuitry (e.g. schizophrenia).

1.9 Concluding Remarks and Future Directions

Over recent years there has been growing interest in understanding BR mechanisms from a multimodal processing perspective, with a view to further characterising the phenomenon itself. Thus far these studies have employed psychophysical and behavioural manipulations. Future studies that incorporate brain-imaging techniques, animal models and brain stimulation methods will help to more precisely identify the neural mechanisms involved in the resolution of multisensory input during rivalry. In humans, the fact that the visual and auditory systems are well characterised (cf. other senses) will also help to characterise better the competitive and integrative interactions between these two primary modalities.

CHAPTER 2 – MATERIALS AND METHODS

The materials and methodology part of this investigation can be divided into experimental design procedures, interviewing and testing potential subjects, and organising data for analysis and interpretation.

2.1 Binocular Rivalry Experimental Design

In order to investigate the effects of auditory stimulation on binocular rivalry, specifically on the BR rate and predominance, a total of 15 subjects between the ages of 18 to 32 years were recruited to participate in the study. Each subject attended a minimum of 3 sessions, which were conducted over 3 separate days at the University of Southern Queensland (Toowoomba campus). The sessions differed in the experimental condition tested, e.g. differing in whether a sound was presented to left/right or both ears or not presented (control). In addition, individual subjects were scheduled to attend each session during the same time of day, and the experimental conditions were counter balanced amongst subjects (i.e. each subject attended sessions that differed in the order to which sound was presented to the left, right, both ears or control) to ensure randomised data.

The experimental design is similar to Ngo et al. (2007) as each session comprised of 4 blocks, and each block consisted of 4 trials. Short (30 second) and long (110 second) rest periods were allocated between each trial and block, respectively. Block 3 was the only block presenting auditory stimulation, excluding the control condition where all four blocks remained without sound. Blocks 1, 2 and block 4 were pre-stimulation and post-stimulation blocks, respectively. The experimental design is further described below:

Table 3: Experimental design

Block 1 Total length:10 minutes				Block 2 Total length:10 minutes				Block 3 Total length:10 minutes				Block 4 Total length:10 minutes			
Trial 1	Trial 2	Trial 3	Trial 4	Trial 1	Trial 2	Trial 3	Trial 4	Trial 1	Trial 2	Trial 3	Trial 4	Trial 1	Trial 2	Trial 3	Trial 4

The project was divided into two stages, which differed in the frequency of the presented tone. That is, stage 1 presented a frequency of 3000Hz (60dB), while 1000Hz (53dB) was presented as auditory stimuli in stage 2. The two stages are outlined below:

Table 4a: Stage 1

Sound 60dB	Block 1,2,4	Block 3	No. of subjects
Tone at 3000Hz	No Sound	Sound to left ear, right ear or both ears	10

Stage 1: Observers:
- 10 observers in stage 1 (aged from 18-32 years, mean age 22.3, 7 females)

Table 4b: Stage 2

Sound 53dB	Block 1,2,4	Block 3	No. of subjects
Tone at 1000Hz	No Sound	Sound to left and right ear	5

Stage 2: Observers
- 5 observers in stage 2 (aged from 18-20 years, mean age 19.8, 4 females)

2.2 Binocular Rivalry Experimental Procedure

Posters advertising the BR task and the incentive for participating ($30 supermarket voucher for 3 sessions) were placed around the university campus. Individuals expressing an interest in participating were requested to refrain from strenuous exercise, tobacco, as well as alcoholic and caffeinated drinks in the 3 hours before attending the testing session. They were also advised to bring glasses or contact lenses they may need. However, before commencing the BR task, questionnaires and vision and hearing tests were performed based on the inclusion criteria.

The questionnaire was divided into several sections based on personal and familial medical history. It consisted of questions regarding eye health and hearing problems (use of corrective glasses/contact lenses and injuries to eyes, strabismus, double-vision, colour blindness, glaucoma, cataracts); neurological status and medical conditions (history of brain injury, epilepsy, migraines and diabetes); history of medical interventions (major/minor treatments, surgery or chemotherapy); current medication (prescribed or non-prescribed) and familial history of psychiatric illness (e.g. depression, schizophrenia, bipolar disorder, anxiety disorder). Additional questionnaires regarding confidence, patience, coping with stress, hobbies, and history of smoking or meditation were also included.

In order to test visual acuity, subjects viewed an eye chart (Snellen chart) from a distance of 3 meters. They were instructed to cover one eye with their cupped hand and recite each letter in the left to right direction, starting from row 6/18 and continuing for the two rows below. Similarly, the visual acuity of the other eye was tested; however this time reading in the right to left direction until a mistake was made. A visual acuity of 6/9 or better for both eyes was required to participate in the rivalry task. In addition, the hole-in-card test (sighting dominance) was employed to determine the dominant eye. Next, a handedness inventory (Edinburgh) and subjective mood rating questionnaire was performed, with subjects rating their mood on a scale of 0 to 10 before and after the testing session.

The hearing test was conducted using the BR Audio program. Before commencing the test, the computer volume was adjusted with a tone of 3500Hz so that it was slightly inaudible (tone/baseline was different for each person). Headphones were used to present tones with varying frequencies to the left and right ear, starting from low frequency (100Hz) to high frequency (16,000Hz). The subject’s task was to click on the computer mouse whenever a tone was heard and to continue until the tone became inaudible. To participate in the investigation, the required hearing acuity at 1000Hz and 3000Hz frequencies should have been within 10dB from the hearing threshold of 3500Hz (the frequency used to adjust the system volume).

After the preliminary assessments and before the perceptual rivalry task, a participant information sheet and consent form were given to and signed by the subject. The BR test procedure used was essentially as described by Ngo et al. (2007). That is, the task involved presenting visual stimuli in the form of horizontal and vertical gratings to each eye, with subjects required to indicate visual perception by clicking on the appropriate keys, i.e. one key for vertical perceptions, another for horizontal perceptions, and a third key for mixed/indeterminate percepts or errors.

2.3 Visual and Auditory Stimuli

Stationary green vertical and horizontal gratings were used as visual stimuli, displayed on a True3Di monitor and viewed from a distance of 3 meters. The images were generated from software developed by Alfred Psychiatry Research Centre, Monash University. The two images were rendered to the top and back screens of the True3D monitor and reflected through a tilted mirror in order to be viewed through special polarised glasses from the front of the monitor (Ngo et al. 2007). The glasses allowed the subject to view the two images simultaneously, with vertical and horizontal gratings presented to the subject's left and right eye, respectively. Skullcandy G.I. Rasta headphones (Frequency Response: 18-20k Hz) were used to present a constant, stationary and unmodulated tone with a sound pressure level (SPL) of 50-60dB. The SPLs generated from the headphone at different frequencies were measured with the SVAN 953 SPL meter and analyser (Frequency range 20-20k Hz).

Subjects were instructed to focus on the orientation of gratings, which were positioned in a circular area at the centre of the monitor, and to report the predominance of gratings by pressing 3 keys on a computer keyboard. That is, the 'V' and 'B' key were pressed whenever vertical and horizontal gratings were perceived, respectively. However, if an error was made or if subjects experienced a combination of the two orientations, as either a grid or a patchwork that was not considered to be transitional, then they responded by pressing the ‘spacebar’. The same responses were repeated in the presence of auditory stimuli, and the BR test commenced once instructions were understood by the subject. The data collection software was self-developed from Matlab.

2.4 Alterations in Method

2.4.1 Conditions in the Investigation

Stage 1 initially involved presenting 3000Hz frequency to the left, right and both ears. A total of 9 subjects were tested using this method. To improve the understanding of the effects of auditory stimulation on visual perception, control tests, where no sound was presented at all, were included and tested on a total of 11 subjects. The data collected from the control condition was then compared between the remaining two conditions involving left and right ear stimulation.

The key difference between stages 1 and 2 was in the frequency of the auditory stimulation presented. In stage 1, the auditory stimulation was a tone of 3000Hz at the intensity of 60dB, while in stage 2, the frequency of auditory stimulation was 1000Hz at the intensity of 53dB.

2.5 Statistical Analysis of Data

The perception switching rate and predominance data were initially analysed individually for each subject and then grouped as a mean for each condition (control, 3000Hz both ears, 3000Hz right ear, 3000Hz left ear, 1000Hz right ear, 1000Hz left ear). The statistical test one-way analysis of variance (ANOVA) was used to find common means amongst several samples and significant differences in measured characteristic. Meanwhile, the two sample T test was employed for statistical significance through evaluating the P-value amongst the samples (between control and both ears, 3000Hz right and left ears, and 1000Hz right and left ears). Along with the T sample test, the Wilcoxon sign rank test was included to ensure the tested hypothesis was accurate. The 3D plots and boxplots enabled the visualization of the analysed results such as the rate, described as the quotient from the division of total number of perception switches by total times used for those perceptions; V/H ratio, the ratio of the averaged time used for forming vertical and horizontal perceptions; and the V mean and H mean, the mean value of the time pertaining to vertical perceptions and horizontal perceptions, respectively. The individual subject results and mean rate and predominance data for each condition are presented using tables, column charts, 3D plots and boxplots.

Experiments were approved by the Human Ethics Committee of the University of Southern Queensland under the approval number H12REA035.

CHAPTER 3 – RESULTS

Please note that I have only included data showing clear tendencies to increase or decrease based on the stimuli presented. The data included in this section provides the best representation of the changes in the rate and predominance following auditory stimulation. For raw data, please refer to the appendix.

3.1 Analysis of Individual Results

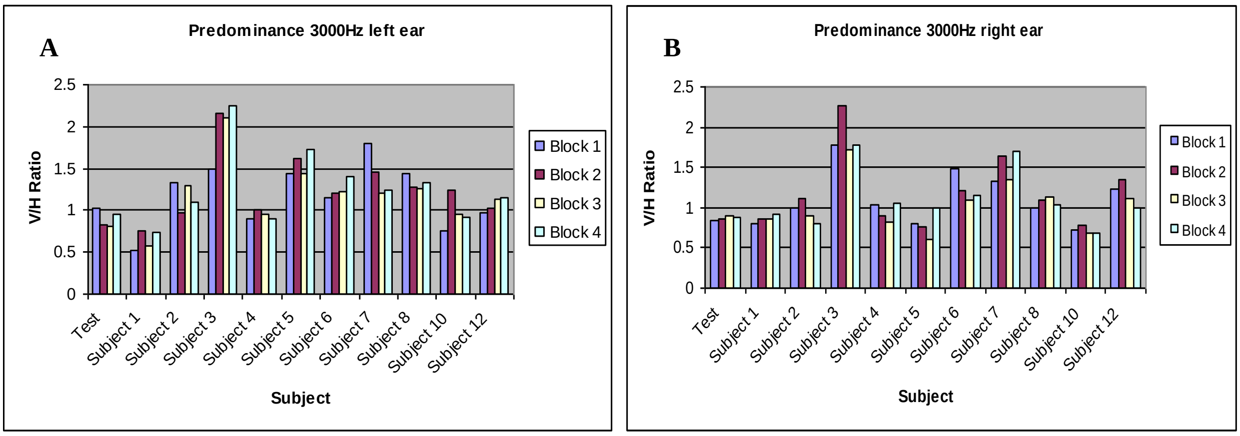

Figure 10 (A & B): Comparing the individual development of V/H ratio against experiment blocks for 3000Hz left ear (A) and 3000Hz right ear (B)

Note: The tone was presented during block 3 only

Blocks 1, 2 and 4 were pre-stimulation and post-stimulation blocks, respectively

For this type of data, there is no standard deviation

Fig 10 shows the individual predominance data when 3000Hz was presented to the left **(A)** and right ear **(B)**.

The predominance is represented by the V/H ratio, where a ratio above one indicates the dominant perception of vertical gratings, while the perception of horizontal gratings is recessive. In Fig 10 **(A & B)**, the presentation of auditory stimulation during block 3 decreased the V/H ratio for most subjects. However, despite the increase in horizontal perceptions during auditory stimulation, vertical gratings remained the dominant percept throughout the four blocks in each condition.

3.2 Analysis of Results Grouped as a Mean for Each Condition

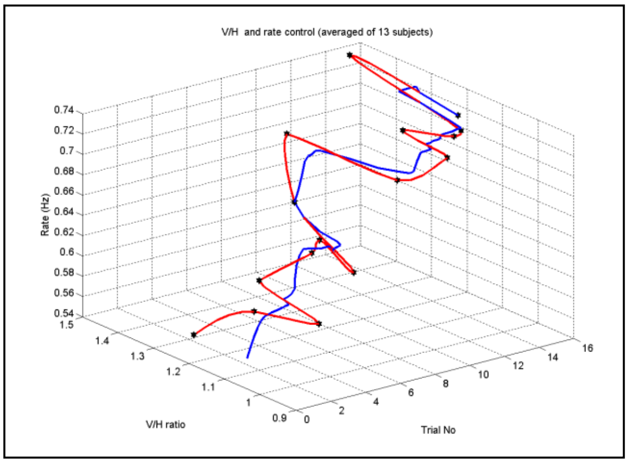

Figure 11: Comparing the development of V/H ratio and rate against experiment trials for control

Note: The red line is the original data (averaged of 13 subjects) and the blue line is the data filtered with one dimensional median filter

Trials 1-4, 5-8, 9-12 and 13-16 refer to blocks 1, 2, 3 and 4 respectively

For the 3D display, the standard deviation is not appropriate as the 3D plot compares the tendencies in the development of perception

Fig 11 shows the averaged data from a total of 13 subjects tested under control conditions.

In Fig 11, vertical perceptions were dominant throughout the control condition as the V/H ratio remained above one during each trial. The rate constantly increased by ≈4.5% after each trial and was highest during trial 15 (block 4).

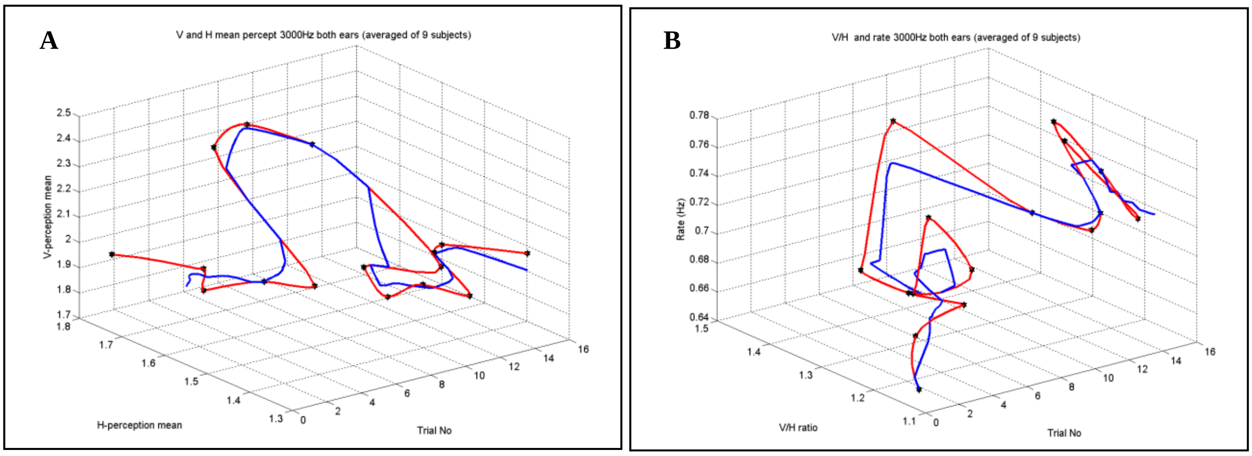

Figure 12 (A & B): Comparing the development of V and H mean percepts (A) against experiment trials, and that of V/H ratio and rate (B) for 3000Hz both ears

In Fig 12, both ears were presented with 3000Hz and the results were averaged from a total of 9 subjects.

The amount of time for vertical gratings to be perceived refers to the V mean percept duration and similarly, the amount of time for horizontal gratings to be perceived refers to the H mean percept duration. In Fig 12 **(A)**, the V mean percept was highest during trials 6-8 (block 2), however decreased by ≈13% following auditory stimulation and continued to decline until trial 13. The H mean percept decreased by ≈16.5% during block 3 (trials 8-9). Fig 12 **(B)** shows that V/H ratio was above one during blocks 1, 2, and 4, and in the presence of sound (block 3), decreased by ≈2%. During block 3, the rate increased by ≈16% (trials 8-9).

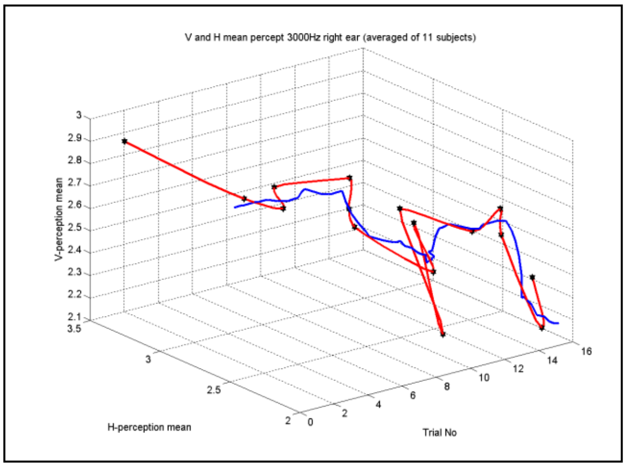

Figure 13: Comparing the development of V and H mean percepts against experiment trials for 3000Hz right ear

Fig 13 represents the averaged data from a total of 11 subjects, collected when a tone of 3000Hz was presented to the right ear.

The perception of horizontal and vertical gratings during auditory stimulation (trials 8-9) increased by ≈13% and ≈5%, respectively.

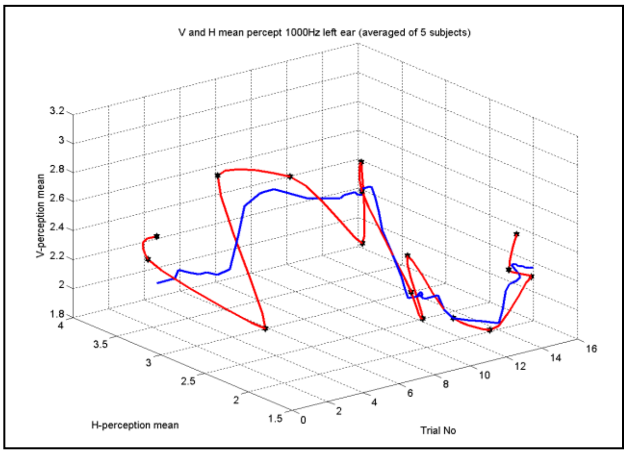

Figure 14: Comparing the development of V and H mean percepts against experiment trials for 1000Hz left ear

In Fig 14, the left ear was presented with 1000Hz and the results were averaged from a total of 5 subjects.

The perception of vertical and horizontal gratings during trials 8-9 decreased by ≈22% and ≈15%, respectively.

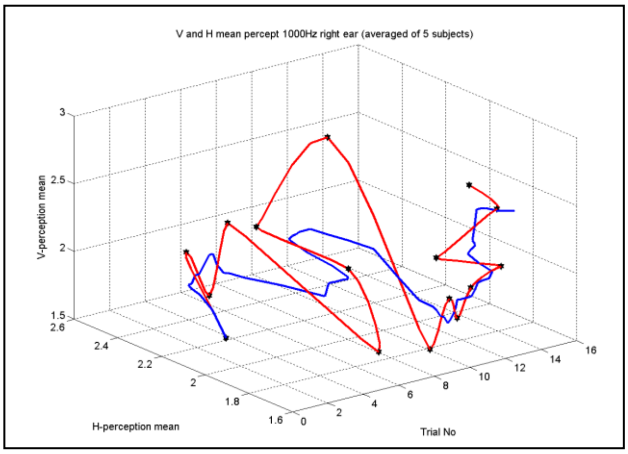

Figure 15: Comparing the development of V and H mean percepts against experiment trials for 1000Hz right ear

In Fig 15, the right ear was presented with 1000Hz and the results were averaged from a total of 5 subjects.

The perception of vertical and horizontal gratings between trials 8-9 decreased by ≈45.5% and ≈18.5%, respectively.

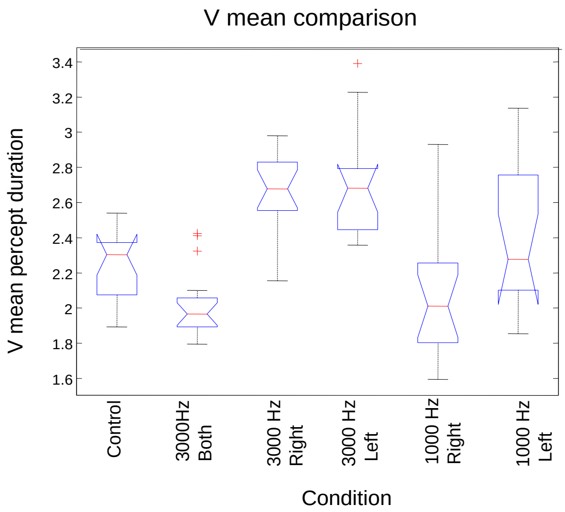

Figure 16: Boxplot for each experimental condition, comparing the V mean percept duration

Note: The red line in the middle of each box is the sample median

The top and bottom of each box are the 25th and 75th percentiles of the samples, respectively

The distances between the tops and bottoms are the interquartile ranges

The whiskers above and below the box indicate the highest and lowest value in the IQR, respectively, and values beyond the whiskers are outliers

The V mean refers to the mean value of time dedicating to vertical gratings throughout the four blocks.

In Fig 16, the median V mean values indicate that vertical perceptions were greatest when a tone of 3000Hz was presented to the left (2.697) and right (2.641) ear (P-value 0.56), followed by the control and both ears (P-value 0.0045). The V mean percept was least dominant for the 1000Hz left and right ear (P-value 0.0125). Outliers were evident for the 3000Hz left and both ear conditions.

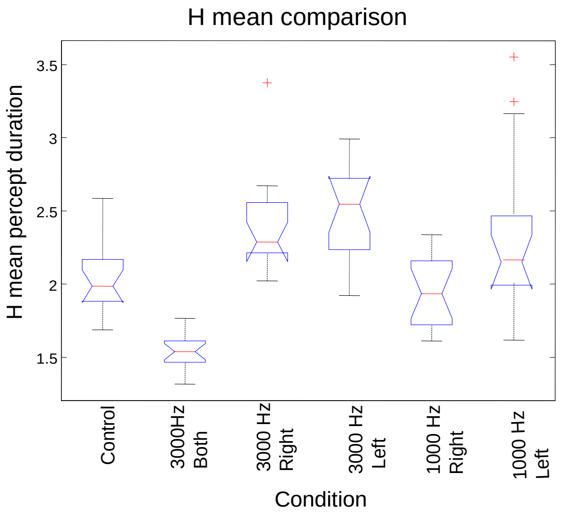

Figure 17: Boxplot for each experimental condition, comparing the H mean percept duration

The H mean refers to the mean value of time dedicating to horizontal gratings throughout the four blocks.

The median values indicate that horizontal perceptions were greatest when a tone of 3000Hz was presented to the left (2.486) and the right (2.403) ear, followed by the 1000Hz left and right ear condition. The H mean percept was least dominant when 3000Hz was presented to both ears and the control. Outliers were evident for the 3000Hz right and 1000Hz left ear conditions. The means of the control and both ears were at different levels (P-value 1.3032e-008). The 3000Hz left and right ear had a closer distribution (P-value 0.46) when compared to the 1000Hz left and right ear distributions (P-value 0.011).

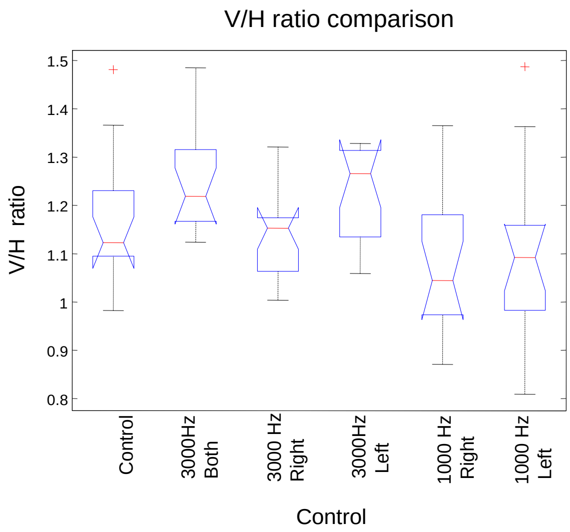

Figure 18: Boxplot for each experimental condition, comparing the V/H ratio

The V/H ratio comparison between six conditions is shown in Fig 18.

The median V/H ratios indicate that vertical gratings were the dominant percept under all conditions. The median V/H ratio was greatest for the 3000Hz left (1.23) and right (1.13) ear (P-value 0.005), followed by the 3000Hz both ears and the control condition (P-value 0.066). Vertical gratings were perceived least when 1000Hz was presented to the left and right ear (P-value 0.81).

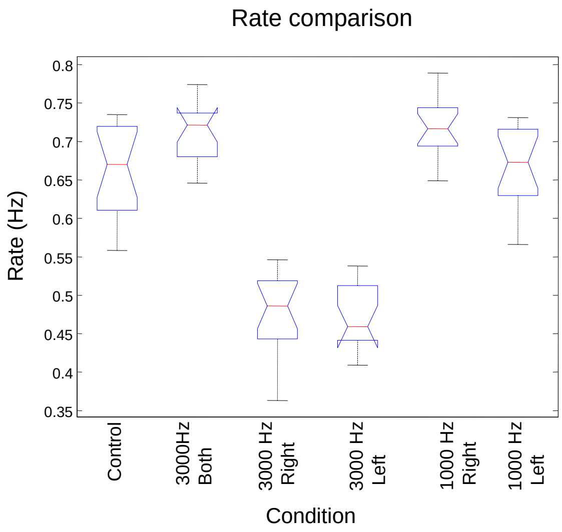

Figure 19: Boxplot for each experimental condition, comparing the rate

In Fig 19, the boxplot compares the BR rate amongst the six different conditions.

The median rate value was greatest for the 1000Hz right (0.718) and left (0.667) ear conditions (P-value 0.006), followed closely by the control and both ears (P-value 0.011). The 3000Hz right ear condition had a similar distribution to that of the 3000Hz left ear (P-value 0.8). The median rate appeared to be greatest when both ears were presented with 3000Hz (0.711) and when the right ear was presented with a tone of 1000Hz (0.718).

CHAPTER 4 – DISCUSSION

The aim of the project was to investigate the effects of auditory stimulation on BR, in particular to find the stimulation that produced the greatest effect on visual perception. The influence of sound on BR was tested on 15 subjects under six different experimental conditions, which included presenting the left, right and both ears with a tone of 3000Hz, followed by left and right ear 1000Hz stimulation. The two frequencies were tested on separate subjects and a control condition without any form of auditory stimulation was also included in the study. Therefore, the effects of auditory stimulation on the two defining features of BR, that is the rate and the predominance, were investigated.

The BR rate is described as the total number of alternations in the perception of visual stimuli per unit time, with alternations in the dominant percept known to be irregular (or stochastic) over a viewing period (Fox & Herrmann 1967). In the investigation, the rate varied for each person despite the presence or absence of sound, which was expected as numerous studies have confirmed that the rate is relatively stable within individuals but significantly different between individuals (McDougall 1906; George 1936; Enoksson 1963; Aafjes, Hueting & Visser 1966; Pettigrew & Miller 1998; Miller et al. 2003; 2010). According to Hancock and colleagues (2012), interindividual rate variations during BR are due to eye movement rate differences and genetic factors (Miller et al. 2010). As opposed to the individual rate results, the mean rate for each condition provided a better representation of the changes in the BR rate and thus enabled the identification of any trends following auditory stimuli.

The averaged BR rate result for the control condition continuously increased by ≈4.5% after each trial. Numerous studies have claimed that rivalry rates vary as a function of the viewing time, increasing during interrupted viewing and remaining constant during continuous viewing periods

(Aafjes, Hueting & Visser 1966; Goldstein & Cofoid 1965). In this study, the viewing time was interrupted by rest periods in between each trial (30 second break) and block (110 second break), subsequently causing the steady increase in the rivalry rate. Washburn and Gillette (1933) and Cogan and Goldstein (1967), further suggest that the demanding nature of the BR task, due to sustained concentration and attention over a long period of time, can increase eye blink frequency and consequently increase the rate as well. Therefore, as expected the fastest rate in the control condition occurred in trial 15, which was during the last block and towards the end of the 40 minute session.

The remaining experimental conditions differed to the control as they included auditory stimulation. According to Alais and colleagues (2007), the presentation of a tone with intermittent intensity pulses slowed the BR rate. This effect was even more pronounced on Necker cube rivalry, a more complex form of BR, which further indicates that perceptual alternations are determined by attention. However, another study found auditory stimulation that was presented at the same rate as the visual stimuli increased the BR rate (van Ee et al. 2009). In this investigation both the tone and the visual stimuli presented were constant and unchanging, and as the tone did not involve intermittent intensity pulses, it was expected that the presence of sound would affect BR by increasing the rate (van Ee et al. 2009). Hence, conditions with auditory stimulation were expected to produce higher BR rates than the control condition.

The human ear can detect frequencies and intensities ranging from 20Hz to 20,000Hz and 0dB to 100dB, respectively (Forsythe 2007). The responses to different frequencies are located at certain points along the basilar membrane, within the cochlea of the inner ear. That is, lower frequencies (1000Hz) induce resonance at the middle of the basilar membrane and higher frequencies (3000Hz) at the position closer to the basal end of the membrane, where at these excited regions acoustic information undergoes mechanical to electrical transduction (Dallos 1992). The high frequency excites the basal part and the low frequency excites the apical end of basilar membrane.

Consequently, 3000Hz frequency was expected to produce a greater increase in the rate than the 1000Hz due to the higher level of sensitivity at this frequency (Alberti 2006). Alberti (2006) further explains that the ear canal functions as a resonating tube and amplifies sounds between 3000Hz and 4000Hz, thus increasing the sensitivity of the ear at these frequencies. The present results indicate that the greatest increase in perceptual alternations was during left and both ear stimulation with 1000Hz and 3000Hz, respectively. The next greatest acceleration in the rate occurred in the control condition, followed by right and left ear stimulation with 1000Hz and 3000Hz, respectively. Surprisingly, when 3000Hz was presented to the right ear, the rate decreased by ≈4.5%. A possible explanation for the surprising results could be due to the brain suppressing high frequencies in favour of low ones or according to Dallos (1992), due to the fact that low frequency noise is usually rated as more annoying than higher frequencies and thus, in this case, the 1000Hz stimulation influenced the viewing task and caused the faster switch rate.

Another possible explanation could be due to the sample number and the age of the tested individuals. That is, 3000Hz was tested on a total of 10 subjects (mean age 22.3); while 1000Hz was tested on 5 subjects (mean age 19.8). The group with the higher mean age could have produced a decrease in the rate due to the fact that hearing levels are known to deteriorate with age, as well as exposure to unsafe volume levels (Patterson et al. 1982). However, the possibility that hearing was a factor in influencing the rate results is unlikely as the age gap is insignificant and each subject had their hearing tested as part of the inclusion criteria. Thus, the smaller sample number is most probably the main reason for the surprising result, as it did not provide the best representation for the effects of the 1000Hz frequency. However, the rate alone is not a reliable indicator of the effects of auditory stimulation on BR; instead the predominance may provide a better interpretation of the results.

The predominance describes the amount of time that one image is perceived relative to the other image within a given viewing period. The V/H ratio is a realistic representation of the predominance, where ratios above one represent vertical gratings as the dominant percept, and ratios below one represent the perception of horizontal gratings during most of the viewing time. Nevertheless the changes in the V/H ratio in this study should reflect the presence or absence of sound. According to Conrad and colleagues (2010), predominance of visual stimuli is affected by audiovisual interactions, as a moving sound (motion sound) prolongs the time the image, moving in the same direction as the sound, is perceived. Additionally, Kang and Blake (2005) suggest that a strong stimulus enhances the predominance time by extending the perception of the dominant stimulus while suppressing it for shorter periods of time. The tone presented in this study was constant and unmodulated for each stage, and the two stages differed in the strength of the auditory stimuli presented.

It was expected that the presence of the sound would cause a decrease in the V/H ratio by increasing the perception of horizontal gratings and decreasing vertical perceptions. More specifically, the results would reflect the interhemispheric switch model, as each visual stimulus would be selected by one cerebral hemisphere. That is, horizontal gratings presented to the right eye would be adopted by the left hemisphere, and vertical gratings presented to the left eye would be adopted by the right hemisphere (Miller et al. 2000). According to Miller and colleagues (2000), horizontal gratings are selected by the left hemisphere due to a cultural bias for horizontal scripts and the left-lateralization of sentence reading.

In the investigation, the V/H ratio remained constant and above one under control conditions, which was expected as there was no auditory stimulation. The presentation of 3000Hz to the left and right ear during block 3 resulted in a ratio decrease of ≈5% and ≈9%, respectively. Similarly, tones of 1000Hz stimulating the right ear and 3000Hz stimulating both ears reduced the ratio by ≈22.5% and ≈2%, respectively (Figure 15 & 12B). Therefore, the decrease in the V/H ratio indicates the greater perception of horizontal gratings due to auditory stimulation. However, despite more horizontal perceptions in the presence of sound, the V/H ratio still remained above one, suggesting that vertical perceptions were dominant throughout the session and in each condition.

The predominance of vertical percepts across the majority of subjects indicates the dominant use of the right hemisphere. According to Gupta and colleagues (2011), the right brain hemisphere is the creative and emotional side, while the left hemisphere is the analytical and judgmental side. Furthermore, the right hemisphere is associated with new or unfamiliar situations, possibly explaining the dominant vertical perceptions throughout the session. However, this is unlikely as each subject attended a minimum of 3 sessions, and by the second session it would be expected that subjects had familiarized themselves with the task. Therefore, there are two possible explanations for the observed predominance of vertical percepts. Firstly, the right hemisphere is more specialized than the left hemisphere in perceptual tasks, such as in the analysis of space, geometrical shapes, and visuo-spatial tasks (Baron 2001). Secondly, the majority of the tested subjects were female (11/15), and, according to Baron (2001), females have demonstrated a greater right hemisphere superiority than males, particularly when making judgments on facial emotional expressions. Thus, the preference of the right hemisphere towards perceptual tasks and the gender of subjects could have affected the predominance, causing the greater perception of vertical gratings.

It is important to note that the auditory pathway is bilateral, as right and left primary auditory areas receive nerve impulses from both ears due to auditory axons travelling to either side of the brain. Andreassi (2007) further explains that despite the bilateral pathway of audition, each ear has more neuronal connections leading to the hemisphere on the contralateral side than on the ipsilateral side. Thus, auditory signals traveling to the central auditory nervous system would encounter two pathways, where due to hemispheric asymmetries, the contralateral auditory pathway would be stronger than the ipsilateral pathway (Andreassi 2007). Therefore, a tone presented to the right ear would transmit the signal to the ear on the opposite side (the left side) and in turn activate the left brain hemisphere, which would affect the horizontal perceptions. Similarly, tones presented to the left ear would stimulate the right ear and activate the right brain hemisphere, affecting vertical perceptions. The study produced the expected result as the largest decrease in vertical perceptions was observed following right ear 1000Hz and 3000Hz stimulation. Moreover, the 3000Hz tone presented to the right ear caused auditory information to be conveyed to the left ear, which activated the left hemisphere and ultimately increased horizontal perceptions, as indicated by the results. Additionally, when the left ear was presented with 1000Hz, the V/H ratio increased by ≈16.5% (Figure 14), further supporting the bilateral pathway of audition.

The perception of horizontal and vertical gratings following 3000Hz both ear stimulation decreased by ≈16.5% and ≈13%, respectively (Figure 12A). A possible explanation for this observation could be due to the brain’s ability to adjust the intensity differences and time of arrival of sounds (Alberti 2006). Therefore, instead of acoustic information travelling to the auditory cortex, sounds such as 3000Hz presented to both ears may have been uncomfortable to listen to and were consequently suppressed by feedback loops in audition, which may have caused the decrease in the perception of visual stimuli (Alberti 2006). It should be noted that brain cells, which allow the ear to respond to acoustic changes, have the ability to detect and respond to the onset and sudden absence of a sound. Thus, the initial tone of 3000Hz presented to both ears may have distracted subjects from the task, and upon becoming accustomed to the tone, the sudden absence of this tone during the rest period may have caused another brain cell response and distraction, ultimately affecting the predominance by decreasing both vertical and horizontal percepts.

However, as this study only involved observing the changes in visual perception following auditory stimulation, no direct conclusions on the mechanisms involved in multisensory integration can be made based on this study alone. Previous anatomical, electrophysiological and neuroimaging experiments have enabled the study of the brain regions and mechanisms involved in combining multisensory signals, as well as the neural basis of multisensory integration (Macaluso, Frith & Driver 2000; King & Calvert 2001). Therefore, the findings from the current study will be related to those from past imaging studies.

The influence of auditory stimulation on BR was explained by Kang and Blake (2005), who claim that sound impacts rivalry only when the visual stimulus is consciously perceived and not suppressed from awareness. This view further suggests that rivalry is not influenced at early (low) levels of processing, as this stage registers the suppressed stimulus, and instead is influenced at high levels of processing. Brain-imaging studies have confirmed that rivalry involves neurons in higher levels of visual processing and that higher brain areas are associated with multisensory integration in humans (Bushara et al. 2003). Thus, interactions of sound with other parts of the brain exist, where auditory stimulation influences visual perception at higher brain areas.

According to King and Calvert (2001), animal studies have shown that neurons in the brain receive converging input from multiple sensory systems, and that different brain regions are responsible for different crossmodal and integration tasks. However, a brain stimulation study using

TMS investigated the two defining features of BR, and found that predominance of visual stimuli was associated with greater activity in brain regions that are functionally specialised, and that perceptual alternations were associated with increased transient activity in focal regions of the parietal cortex and lateral prefrontal cortex (Kleinschmidt, Sterzer & Rees 2012). Briefly, the prefrontal cortex functions in crossmodal integration as it receives information from visual, auditory and multisensory cortical regions, which are processed separately through different functional streams that end in the dorsal and ventral prefrontal regions (Kleinschmidt, Sterzer & Rees 2012). Thus, the prefrontal cortex is multisensory as it is known to combine auditory and visual information. Therefore, in the present study it can be assumed that alternations in horizontal and vertical perceptions during rivalry resulted from increased activity in the frontoparietal region of the cortex. The results also reveal the involvement of supra-modal brain regions in perceptual inference and in generating perceptual alternations (Kleinschmidt, Sterzer & Rees 2012).

Furtherstill, Kleinschmidt, Sterzer and Rees (2012) state that neural activity is associated with perceptual multistability, and that there appears to be a link between perceptual rivalry and perceptual decision-making, which indicates the involvement of higher order brain areas in processing multiple sensory stimuli. This finding can be related to the current study as subjects' experienced perceptual rivalry and following auditory stimulation, relied on perceptual decision-making to indicate their visual perceptions. Therefore, brain stimulating studies provide more concrete evidence on the mechanisms involved in rivalry, particularly on the brain areas responsible for perception and processing of visual and auditory information. It can be concluded that higher brain areas are responsible for sensory integration and cognitive interpretation to form coherent perceptions.

4.1 Significance of Results

The observed changes in the predominance (V/H ratio) are associated with the presentation of auditory stimulation. The results are significant as they support the interhemispheric switch model, whereby competition of visual stimuli during BR occurs between each hemisphere. That is, when the left hemisphere was stimulated by a 3000Hz tone, there was an increase in horizontal perceptions, whereas right hemisphere stimulation resulted in greater vertical perceptions. Therefore, the predominance result is a reliable indicator of the effect of auditory stimulation on visual perception, and further confirms the brain mechanisms involved in audiovisual interactions.

Furthermore, the predominance results provide additional information on the patterns involved in rivalry. Hence, predominance of the right hemisphere is associated with negative emotions such as fear, depression and grief, while predominance of the left hemisphere is associated with confidence, well-being and euphoria (Pettigrew 2001). For example, it can be assumed that negative emotions would be associated with greater vertical perceptions due to activity of the right hemisphere, and possibly suggest the mood of the individual (Pettigrew 2001). Therefore, the predominance and rate may be used as potential diagnostic tools for psychiatric illnesses as predominance indicates the mood/emotional state of the individual (Pettigrew 2001), while slower BR rates have been linked to bipolar disorder (Miller et al. 2010).

Furthermore, this multimodal study is significant as it provides a better understanding of perceptual systems and how the brain receives signals from multiple senses. This is further confirmed by Joassin and colleagues (2004), who claim that multimodal studies can provide a better understanding of the neural correlates of crossmodal interactions. In this study, the constant and unmodulating frequency of 3000Hz to the right ear impacted the perception of visual stimuli and therefore supports the amalgam view of both high and low processing involved in rivalry.

4.2 Improvements and Future Experiments

The BR task is a highly variable psycho-physiological test where many external factors can impact the results. Factors that cannot be controlled such as mood and the emotional state of subjects can affect the results, e.g. anxious personalities have been found to have accelerated perceptual alternation rates due to some common serotonergic neural substrates between BR and anxiety (Nagamine et al. 2007). However, the factors that can be controlled include engaging in strenuous exercise and drinking caffeine, which increase the rate, while alcohol and certain meditation have been found to decrease the BR rate (Carter et al. 2005b). Additionally, triggers such as external noise can distract individuals from the task and cause unreliable results. The study aimed to minimize the mentioned external factors; however, during some testing sessions, distractions in the form of external noise (construction site use of drills and machinery) were audible. Therefore, one way to minimize such distractions would be to isolate the testing room and ensure the absence of any surrounding noise. In order to avoid further irregularities and discrepancies in the collected results, individuals were scheduled to attend each session during the same time of day, conditions were counter balanced between subjects, and the first block was treated as a pilot block to familiarise subjects with the task. During the task several subjects had eye strain issues, therefore, a possible improvement could be to reduce the total length of the task by reducing the number of trials or the total duration of each block.

The future directions for this field of research could involve testing a wider range of frequencies and intensities on a diverse group of subjects. For example, subjects could be divided in groups based on age and gender, as it has been suggested that BR alternation rate declines with age (Ukai, Ando & Kuze 2003) and that responses to emotional stimuli are gender-related, which according to Hofer and colleagues (2006) can further our understanding on the causes of gender-related vulnerability to neuropsychiatric disorders. Another possibility is to present each ear with a different frequency, known as binaural beats, which may further assist in understanding the auditory pathway and neuronal connections in the brain, specifically the contralateral and ipsilateral pathway of auditory exons. Moreover, a similar design to the olfactory study by Zhou et al. (2010) could be applied, e.g. an image of a bird presented to one eye and an image of a house to the other, with a bird's chirp presented as auditory stimuli. This design would enable the study of the degree auditory stimuli affects visual perception.

Away from audiovisual interactions, further research on rivalry may investigate the potential use of BR as a diagnostic tool for psychiatric illnesses. Already, bipolar disorder has been associated with slower than normal BR rates (Miller et al. 2010), however future studies may focus on other conditions such as depression and schizophrenia and there effect on rivalry rates. Along with the BR rate, the predominance ratio may provide further links to understanding the processes involved in psychiatric conditions. According to Pettigrew (2001), the predominance ratio is based on a circadian rhythm as an increase in REM episodes just before waking has been found to increase the dominance of vertical gratings due to right hemisphere bias. The circadian variation of predominance ratio is known to continue throughout the day and is associated with mood changes, which would further help to clarify the brain mechanisms involved in perception and possibly psychiatric illnesses. According to Kimura (1996), fluctuations in sex hormones, due to diurnal, menstrual and seasonal variations, continue to affect cognitive pattern in adulthood. A possible explanation for these changes was suggested to arise from brain sex differences in left-right, anterior-posterior, and interhemispheric functional organization (Kimura 1996). Therefore, future studies could investigate the affects of reproductive hormones and seasonal changes on predominance.

CHAPTER 5 - CONCLUSIONS

The conclusion drawn from the results in this multimodal study is that auditory stimuli influences visual perception. That is, the higher unmodulated frequency within the hearing range (3000Hz) increased visual temporal rate perception and influenced the predominance of the visual stimulus to a greater extent than the lower frequency (1000Hz). Generally, there was an increase in the rate and in the perception of horizontal gratings in the presence of auditory stimulation. Therefore, audiovisual interactions during rivalry involve both high and low level processing of stimuli, supporting the amalgam view of rivalry as occurring at different stages of visual processing.

REFERENCES

Aafjes, M., Hueting, J. E. & Visser, P. 1966. Individual and interindividual differences in binocular retinal rivalry in man. *Psychophysiology,* vol. 3**,** pp. 18-22.

Abadi, R. V. 1976. Induction masking--a study of some inhibitory interactions during dichoptic viewing. *Vision Res,* vol. 16**,** pp. 269-75.

Alais, D. 2012. Binocular rivalry: competition and inhibition in visual perception. *Cognitive Science*, vol. 3, pp. 87-103.

Alais, D. & Blake, R. 2005. *Binocular rivalry,* Cambridge, Mass., MIT Press.

Alais, D., O'Shea, R. P., Mesana-Alais, C. & Wilson, I. G. 2000. On binocular alternation. *Perception,* vol. 29**,** pp. 1437-45.

Alais, D., Parker, A., Boxtel, J., Paffen, C. & van Ee, R. 2007. Attending to auditory signals slows binocular rivalry. *Perception,* vol. 36, ECVP Abstract Supplement.

Alais, D., van Boxtel, J. J., Parker, A. & van Ee, R. 2010. Attending to auditory signals slows visual alternations in binocular rivalry. *Vision Res,* vol. 50**,** pp. 929-35.

Alberti, P.W. 2006. The Anatomy and Physiology of the Ear and Hearing, retrieved from http://www.who.int/occupational_health/publications/noise2.pdf

Alpers, G. W., Ruhleder, M., Walz, N., Muhlberger, A. & Pauli, P. 2005. Binocular rivalry between emotional and neutral stimuli: A validation using fear conditioning and eeg. *Int J Psychophysiol,* vol. 57**,** pp. 25-32.

Andreassi, J. L. 2007. *Psychophysiology: Human Behavior and Physiological Response*, Lawrence Erlbaum Associates.

Asher, H. 1953. Suppression theory of binocular vision. *Br J Ophthalmol,* vol. 37**,** pp. 37-49.

Banks, M. I., Uhlrich, D. J., Smith, P. H., Krause, B. M. & Manning, K. A. 2011. Descending projections from extrastriate visual cortex modulate responses of cells in primary auditory cortex. *Cereb Cortex,* vol. 21**,** pp. 2620-38.

Baron, R. A. 2001. *Psychology (5th ed.).* Needham Heights: Allyn & Bacon.

Blake, R. 1989. A neural theory of binocular rivalry. *Psychol Rev,* vol. 96**,** pp. 145-67.

Blake, R. & Logothetis, N. K. 2002. Visual competition. *Nat Rev Neurosci,* vol. 3**,** pp. 13-21.

Brancucci, A., Babiloni, C., Babiloni, F., Galderisi, S., Mucci, A., Tecchio, F., Zappasodi, F., Pizzella, V., Romani, G. L. & Rossini, P. M. 2004. Inhibition of auditory cortical responses to ipsilateral stimuli during dichotic listening: Evidence from magnetoencephalography. *Eur J Neurosci,* vol. 19**,** pp. 2329-36.

Brancucci, A. & Tommasi, L. 2011. "Binaural rivalry": Dichotic listening as a tool for the investigation of the neural correlate of consciousness. *Brain Cogn,* vol. 76**,** pp. 218-24.

Bushara, K. O., Hanakawa, T., Immisch, I., Toma, K., Kansaku, K. & Hallet, M. 2003. Neural correlates of crossmodal Binding. *Nature Neuroscience*, vol. 6, pp. 190-195.

Cappe, C., Rouiller, E. M. & Barone, P. 2012. Cortical and thalamic pathways for multisensory and sensorimotor interplay. *In:* Murray, M. M. & Wallace, M. T. (eds.) *The neural bases of multisensory processes.* Boca Raton (FL).

Carter, O. L., Pettigrew, J. D., Hasler, F., Wallis, G. M., Liu, G. B., Hell, D. & Vollenweider, F. X. 2005a. Modulating the rate and rhythmicity of perceptual rivalry alternations with the mixed 5-ht2a and 5-ht1a agonist psilocybin. *Neuropsychopharmacology,* vol. 30**,** pp. 1154-62.

Carter, O. L., Presti, D. E., Callistemon, C., Ungerer, Y., Liu, G. B. & Pettigrew, J. D. 2005b. Meditation alters perceptual rivalry in tibetan buddhist monks. *Curr Biol,* vol. 15**,** pp. R412-3.

Chen, Y. C., Yeh, S. L. & Spence, C. 2011. Crossmodal constraints on human perceptual awareness: Auditory semantic modulation of binocular rivalry. *Front Psychol,* vol. 2**,** pp. 212.

Cogan, A. I. 1987. Human binocular interaction: Towards a neural model. *Vision Res,* vol. 27**,** pp. 2125-39.

Cogan, R. & Goldstein, A. G. 1967. The stability of binocular rivalry during spaced and massed viewing. *Percept. & Psychophys,* vol. 2, pp. 171-174.

Conrad, V., Bartels, A., Kleiner, M. & Noppeney, U. 2010. Audiovisual interactions in binocular rivalry. *J Vis,* vol. 10**,** pp. 27.

Crick, F. & Koch, C. 1998. Consciousness and neuroscience. *Cereb Cortex,* vol. 8**,** pp. 97-107.

Dallos, J. 1992. The active cochlea. *The Journal of Neuroscience*, vol. 12, pp. 45-77.

Della Penna, S., Brancucci, A., Babiloni, C., Franciotti, R., Pizzella, V., Rossi, D., Torquati, K., Rossini, P. M. & Romani, G. L. 2007. Lateralization of dichotic speech stimuli is based on specific auditory pathway interactions: Neuromagnetic evidence. *Cereb Cortex,* vol. 17**,** pp. 2303-11.

Eimer, M. 2004. Multisensory integration: How visual experience shapes spatial perception. *Curr Biol,* vol. 14**,** pp. R115-7.

Einhauser, W., Stout, J., Koch, C. & Carter, O. 2008. Pupil dilation reflects perceptual selection and predicts subsequent stability in perceptual rivalry. *Proc Natl Acad Sci U S A,* vol. 105**,** pp. 1704-9.

Enoksson, P. 1963. Binocular rivalry and monocular dominance studied with optokinetic nystagmus. *Acta Ophthalmol (Copenh),* vol. 41**,** pp. 544-63.

Evans, K. K. & Treisman, A. 2010. Natural cross-modal mappings between visual and auditory features. *J Vis,* vol. 10**,** pp. 1-12.

Forsythe, I. D. 2007. Hearing: A fantasia on Kolliker's organ. *Nature*, vol. 450, pp. 43-44.

Fox, R. & Check, R. 1966. Binocular fusion: A test of the suppression theory. *Attention, Perception & Psychophysics*, vol. 1, pp. 331-334.

Fox, R. & Herrmann, J. 1967. Stochastic properties of binocular rivalry alternations. *Percept Psychophysics,* vol. 2, pp. 432-436.

George, R. W. 1936. The significance of the fluctuations experienced in observing ambiguous figures and in binocular rivalry, *J. Neurophysiol*, vol. 94, pp. 4412-4420.

Goldstein, A. G. & Cofoid, D. 1965. A developmental study of retinal rivalry. *Percept Mot Skills,* vol. 20**,** pp. 235-8.

Gupta, G., Dubey, A., Saxena, P. & Pandey, R. 2011. Individual differences in hemispheric preference and emotion regulation difficulties. *Ind Psychiatry J,* vol. 20**,** pp. 32-8.

Hancock, S., Gareze, L., Findlay, J. M., Andrews, T. J. 2012. Temporal patterns of saccadic eye movements predict individual variation in alternation rate during binocular rivalry. *i-Perception*, vol. 3, pp. 88-96.

Helmholtz, H. V. & Southall, J. P. C. 1924. *Helmholtz's treatise on physiological optics,* Rochester, N.Y., The Optical Society of America.

Hidaka, S., Teramoto, W., Sugita, Y., Manaka, Y., Sakamoto, S. & Suzuki, Y. 2011. Auditory motion information drives visual motion perception. *PLoS One,* vol. 6**,** pp. e17499.

Hofer, A., Siedentopf, C. M., Ischebeck, A., Rettenbacher, M. A., Verius, M., Felber, S. & Fleischhacker, W. W. 2006. Gender differences in regional cerebral activity during the perception of emotion: A functional mri study. *Neuroimage,* vol. 32**,** pp. 854-62.

Howard, I. P. & Rogers, B. J. 2012. *Perceiving in depth,* New York, Oxford University Press.

Hubel, D. H. 1963. Integrative processes in central visual pathways of the cat. *J Opt Soc Am,* vol. 53**,** pp. 58-66.

Hugdahl, K., Bronnick, K., Kyllingsbaek, S., Law, I., Gade, A. & Paulson, O. B. 1999. Brain activation during dichotic presentations of consonant-vowel and musical instrument stimuli: A 15o-pet study. *Neuropsychologia,* vol. 37**,** pp. 431-40.
Hupe, J. M., Joffo, L. M. & Pressnitzer, D. 2008. Bistability for audiovisual stimuli: Perceptual decision is modality specific. *J Vis,* vol. 8**,** pp. 1 1-15.
Hupe, J. M., Lamirel, C. & Lorenceau, J. 2009. Pupil dynamics during bistable motion perception. *J Vis,* vol. 9**,** pp. 10.
Joassin, F., Maurage, P., Bruyer, R., Crommelinck, M. & Campanella, S. 2004. When audition alters vision: An event-related potential study of the cross-modal interactions between faces and voices. *Neurosci Lett,* vol. 369**,** pp. 132-7.
Joseph, R. 2000. Superior and inferior colliculi. *Neuropsychiatry, Neuropsychology, Clinical Neuroscience,* vol. 3, pp. 1-6.
Kandel, E. R. 2001. Psychotherapy and the single synapse: The impact of psychiatric thought on neurobiological research. 1979. *J Neuropsychiatry Clin Neurosci,* vol. 13**,** pp. 290-300; dscussion 289.
Kang, M. S. & Blake, R. 2005. Perceptual synergy between seeing and hearing revealed during binocular rivalry. *Psichologija*, vol. 32, pp. 7-15.
Kelso, J. A. 2012. Multistability and metastability: Understanding dynamic coordination in the brain. *Philos Trans R Soc Lond B Biol Sci,* vol. 367**,** pp. 906-18.
Kimura, D. 1996. Sex, sexual orientation and sex hormones influence human cognitive function. *Curr Opin Neurobiol,* vol. 6**,** pp. 259-63.
King, A. J. & Calvert, G. A. 2001. Multisensory integration: Perceptual grouping by eye and ear. *Curr Biol,* vol. 11**,** pp. R322-5.
Kleinschmidt, A., Sterzer, P. & Rees, G. 2012. Variability of perceptual multistability: From brain state to individual trait. *Philos Trans R Soc Lond B Biol Sci,* vol. 367**,** pp. 988-1000.
Kovács, I., Papathomas, T. V., Yang, M. & Feher, A. 1996. When the brain changes its mind: Interocular grouping during binocular rivalry. *Proc Natl Acad Sci U S A,* vol. 93**,** pp. 15508-11.
Kubovy, M. & Yu, M. 2012. Multistability, cross-modal binding and the additivity of conjoined grouping principles. *Philos Trans R Soc Lond B Biol Sci,* vol. 367**,** pp. 954-64.
Lack, L. C. 1978. *Selective attention and the control of binocular rivalry,* The Hague (Noordeinde 41), Mouton.
Leopold, D. A. & Logothetis, N. K. 1996. Activity changes in early visual cortex reflect monkeys' percepts during binocular rivalry. *Nature,* vol. 379**,** pp. 549-53.
Lewis, J. W., Beauchamp, M. S. & DeYoe, E. A. 2000. A comparison of visual and auditory motion processing in human cerebral cortex. *Cereb Cortex,* vol. 10**,** pp. 873-88.
Lund, R. D. 1972. Anatomic studies on the superior colliculus. *Invest Ophthalmol,* vol. 11**,** pp. 434-41.
Lunghi, C., Binda, P. & Morrone, M. C. 2010. Touch disambiguates rivalrous perception at early stages of visual analysis. *Curr Biol,* vol. 20**,** pp. R143-4.
Macaluso, E., Frith, C. D. & Driver, J. 2000. Modulation of human visual cortex by crossmodal spatial attention. *Science,* vol. 289**,** pp. 1206-8.
McDougall, W. 1906. Physiological factors of the attention-process. *Mind,* vol. 15, pp. 329-359.
Miller, S. M., Gynther, B. D., Heslop, K. R., Liu, G. B., Mitchell, P. B., Ngo, T. T., Pettigrew, J. D. & Geffen, L. B. 2003. Slow binocular rivalry in bipolar disorder. *Psychol Med,* vol. 33**,** pp. 683-92.

Miller, S. M., Hansell, N. K., Ngo, T. T., Liu, G. B., Pettigrew, J. D., Martin, N. G. & Wright, M. J. 2010. Genetic contribution to individual variation in binocular rivalry rate. *Proc Natl Acad Sci U S A,* vol. 107**,** pp. 2664-8.

Miller, S. M., Liu, G. B., Ngo, T. T., Hooper, G., Riek, S., Carson, R. G. & Pettigrew, J. D. 2000. Interhemispheric switching mediates perceptual rivalry. *Curr Biol,* vol. 10**,** pp. 383-92.

Miller, S. M., Ngo, T. T. & van Swinderen, B. 2011. Attentional switching in humans and flies: Rivalry in large and miniature brains. *Front Hum Neurosci,* vol. 5**,** pp. 188.

Mittmann, D. H. & Wenstrup, J. J. 1995. Combination-sensitive neurons in the inferior colliculus. *Hear Res,* vol. 90**,** pp. 185-91.

Nagamine, M., Yoshino, A., Yamazaki, M., Obara, M., Sato, S., Takahashi, Y. & Nomura, S. 2007. Accelerated binocular rivalry with anxious personality. *Physiol Behav,* vol. 91**,** pp. 161-5.

Ngo, T. T., Liu, G. B., Tilley, A. J., Pettigrew, J. D. & Miller, S. M. 2007. Caloric vestibular stimulation reveals discrete neural mechanisms for coherence rivalry and eye rivalry: A meta-rivalry model. *Vision Res,* vol. 47**,** pp. 2685-99.

Ngo, T. T., Liu, G. B., Tilley, A. J., Pettigrew, J. D. & Miller, S. M. 2008. The changing face of perceptual rivalry. *Brain Res Bull,* vol. 75**,** pp. 610-8.

Ngo, T. T., Mitchell, P. B., Martin, N. G. & Miller, S. M. 2011. Psychiatric and genetic studies of binocular rivalry: An endophenotype for bipolar disorder? *Acta Neuropsychiatrica,* vol. 23, pp. 37-42.

Ooi, T. L. & He, Z. J. 2003. A distributed intercortical processing of binocular rivalry: Psychophysical evidence. *Perception,* vol. 32**,** pp. 155-66.

Paffen, C. L., Alais, D. & Verstraten, F. A. 2006. Attention speeds binocular rivalry. *Psychol Sci,* vol. 17**,** pp. 752-6.

Patel, A. D. 2011. Why would musical training benefit the neural encoding of speech? The OPERA hypothesis. *Front. Psychology,* vol. 2, pp. 1-14.

Patterson, R. D., Nimmo-Smith, I., Weber, D. L. & Milroy, R. 1982. The deterioration of hearing with age: Frequency selectivity, the critical ratio, the audiogram, and speech threshold. *J Acoust Soc Am,* vol. 72**,** pp. 1788-803.

Pearson, J. & Clifford, C. W. 2005. Suppressed patterns alter vision during binocular rivalry. *Curr Biol,* vol. 15**,** pp. 2142-8.

Pettigrew, J.D. 2001. Searching for the Switch: Neural Bases for Perceptual Rivalry Alternations. *Brain and Mind*, vol. 2, pp. 85-118.

Pettigrew, J. D. & Miller, S. M. 1998. A 'sticky' interhemispheric switch in bipolar disorder? *Proc Biol Sci,* vol. 265**,** pp. 2141-8.

Purves, D. & Williams, S. M. 2001. *Neuroscience,* Sunderland, Mass., Sinauer Associates.

Ravey, J. 1969. A Study of Sensory Interactions. *Papers in Psychology,* vol. 3, pp.67-68.

Recanzone, G. H. 2003. Auditory influences on visual temporal rate perception. *J Neurophysiol,* vol. 89**,** pp. 1078-93.

Romani, G. L., Williamson, S. J. & Kaufman, L. 1982. Tonotopic organization of the human auditory cortex. *Science,* vol. 216**,** pp. 1339-40.

Schwartz, J. L., Grimault, N., Hupe, J. M., Moore, B. C. & Pressnitzer, D. 2012. Multistability in perception: Binding sensory modalities, an overview. *Philos Trans R Soc Lond B Biol Sci,* vol. 367**,** pp. 896-905.

Shams, L., Iwaki, S., Chawla, A. & Bhattacharya, J. 2005. Early modulation of visual cortex by sound: An meg study. *Neurosci Lett,* vol. 378**,** pp. 76-81.

Sheinberg, D. L. & Logothetis, N. K. 1997. The role of temporal cortical areas in perceptual organization. *Proc Natl Acad Sci U S A,* vol. 94**,** pp. 3408-13.

Shimojo, S., Scheier, C., Nijhawan, R., Shams, L., Kamitani, Y. & Wantanabe, K. 2001. Beyond

perceptual modality: Auditory effects on visual perception, vol. 22, pp. 61-67.
Shneiderman, A. & Henkel, C. K. 1987. Banding of lateral superior olivary nucleus afferents in the inferior colliculus: A possible substrate for sensory integration. *J Comp Neurol,* vol. 266**,** pp. 519-34.
Sloane, M. E. 1985. *Binocular rivalry: A psychophysics in search of a Physiology*, In D. Rose & V. A. Dobson.
Stein, B. E. & Meredith, M. A. 1990. Multisensory integration. Neural and behavioral solutions for dealing with stimuli from different sensory modalities. *Ann N Y Acad Sci,* vol. 608**,** pp. 51-65; discussion 65-70.
Stepp-Gilbert, E. 1988. Sensory integration dysfunction. *Issues Compr Pediatr Nurs,* vol. 11**,** pp. 313-8.
Sugie, N. 1982. Neural models of brightness perception and retinal rivalry in binocular vision. *Biol Cybern,* vol. 43**,** pp. 13-21.
Tong, F., Meng, M. & Blake, R. 2006. Neural bases of binocular rivalry. *Trends Cogn Sci,* vol. 10**,** pp. 502-11.
Ukai, K., Ando, H. & Kuze, J. 2003. Binocular rivalry alternation rate declines with age. *Percept Mot Skills,* vol. 97**,** pp. 393-7.
van Ee, R., van Boxtel, J. J., Parker, A. L. & Alais, D. 2009. Multisensory congruency as a mechanism for attentional control over perceptual selection. *J Neurosci,* vol. 29**,** pp. 11641-9.
Vroomen, J. & de Gelder, B. 2000. Sound enhances visual perception: Cross-modal effects of auditory organization on vision. *J Exp Psychol Hum Percept Perform,* vol. 26**,** pp. 1583-90.
Wade, N. J. 1998. *A natural history of vision,* Cambridge, Mass., MIT Press.
Washburn, M. F. & Gillette, A. 1933. Studies from the Psych. Lab. of Vassar College: LXH. Motor factors in voluntary control of cube perspective fluctuations and retinal rivalry fluctuations. *Amer. J. Psychol*, vol. 45, pp. 315-319.
Watanabe, K. & Shimojo, S. 2001. When sound affects vision: Effects of auditory grouping on visual motion perception. *Psychol Sci,* vol. 12**,** pp. 109-16.
Welch, R. B., DuttonHurt, L. D. & Warren, D. H. 1986. Contributions of audition and vision to temporal rate perception. *Percept Psychophys,* vol. 39**,** pp. 294-300.
Welch, R. B. & Warren, D. H. 1980. Immediate perceptual response to intersensory discrepancy. *Psychol Bull,* vol. 88**,** pp. 638-67.
Wheatstone, C. 1962. On some remarkable and hitherto unobserved phenomena of binocular vision. *Optom Wkly,* vol. 53**,** pp. 2311-5.
Zhou, W., Jiang, Y., He, S. & Chen, D. 2010. Olfaction modulates visual perception in binocular rivalry. *Curr Biol,* vol. 20**,** pp. 1356-8.

APPENDIX I
Raw Data and Results

The rate and predominance results for the individual subjects in the control, 3000Hz left/right/both ears and 1000Hz left/right ear conditions are provided below.

Table 5: Individual rate results for 3000Hz

Subject	Control				Left				Right				Both			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Test	0.6	0.56	0.67	0.71	0.4	0.43	0.38	0.51	0.41	0.63	0.55	0.61	0.59	0.62	0.64	0.58
1	0.28	0.32	0.34	0.27	0.18	0.17	0.18	0.2	0.25	0.25	0.22	0.25				
2	0.48	0.57	0.62	0.62	0.36	0.34	0.45	0.45	0.38	0.38	0.41	0.48	0.29	0.2	0.27	0.28
3	0.29	0.2	0.27	0.28	0.47	0.38	0.45	0.41	0.34	0.27	0.39	0.32	0.4	0.48	0.53	0.48
4	0.58	0.68	0.71	0.70	0.48	0.49	0.52	0.48	0.28	0.41	0.42	0.45	0.57	0.49	0.52	0.64
5	0.55	0.98	1.14	1.46	0.33	0.35	0.30	0.26	0.32	0.45	0.59	0.5				
6	1.18	1.15	1.17	1.18	0.79	0.9	1.00	1.04	0.49	0.65	0.72	0.74	1.03	1.07	1.13	1.17
7					0.51	0.55	0.61	0.64	0.44	0.52	0.58	0.49	0.58	0.54	0.59	0.57
8	1.69	1.71	1.82	1.79	0.21	0.3	0.4	0.47	0.73	0.85	0.85	1.09	1.37	1.49	1.52	1.61
9	0.28	0.3	0.28	0.26												
10	0.64	0.71	0.8	0.86	0.52	0.64	0.65	0.58	0.97	0.98	0.97	0.94				
11													0.66	0.67	0.72	0.72
12					0.6	0.72	0.7	0.67	0.54	0.58	0.55	0.58	0.6	0.6	0.72	0.65
13	0.49	0.42	0.62	0.55												
14	0.26	0.32	0.38	0.29												
15	0.24	0.26	0.29	0.37												

Note: The numbers (1-4) below each condition are the experimental blocks

Control conditions were tested for subjects 1, 2, 3, 4, 5, 6, 8, 9, 10, 13, 14, 15

Both ears were tested for subjects 2, 3, 4, 6, 7, 8, 11, 12

Left and right ear presented with 1000Hz were tested for subjects 8, 9, 13, 14, 15

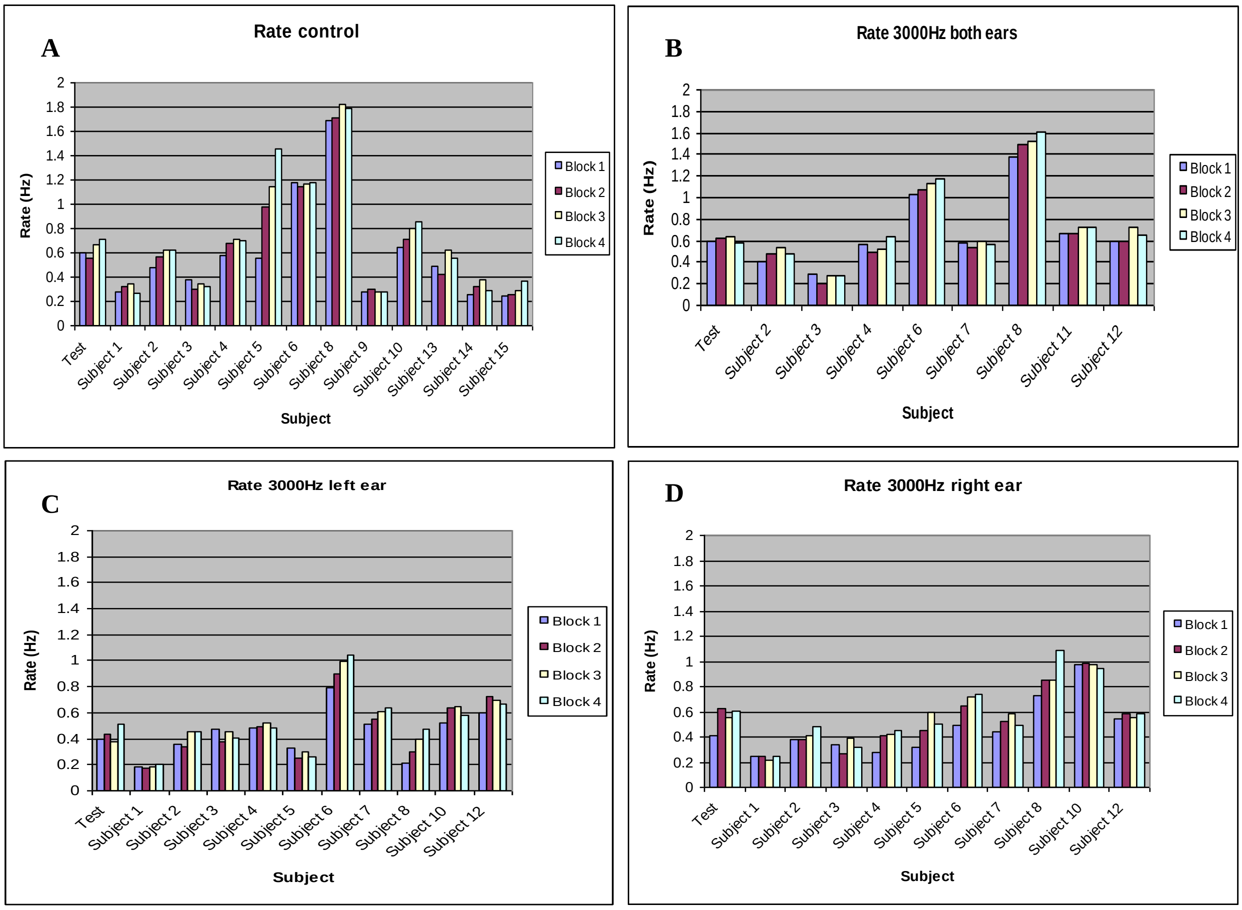

Figure 20 (A, B, C & D): Comparing the individual rate against experiment blocks for control (A), 3000Hz both ears (B), 3000Hz left ear (C) and 3000Hz right ear (D)

Fig 20 represents the individual BR rate during the four different conditions.

The rate indicates the total number of switches per second (Hz), which occurred due to alternations in the perception of vertical and horizontal gratings. Block 3 was the only block with auditory stimulation (3000Hz), excluding the control condition, where all four blocks remained without auditory stimuli. A general trend can be observed by comparing the rate between subjects. That is, in control conditions and when auditory stimulation was presented to both ears **(A & B)**, the rate continued to increase throughout the four blocks. However, when sound was presented to the left and right ear **(C & D)**, then the rate remained fairly constant without any significant changes.

Table 6: Individual rate results for 1000Hz

Subject	Left				Right			
	1	2	3	4	1	2	3	4
Test	0.41	0.56	0.45	0.6	0.57	0.63	0.55	0.54
8	1.66	1.64	1.78	1.77	0.73	0.85	0.85	1.09
9	0.09	0.26	0.05	0.17	0.15	0.18	0.18	0.23
13	0.44	0.52	0.61	0.43	0.32	0.32	0.42	0.31
14	0.27	0.25	0.34	0.34	0.42	0.42	0.41	0.34
15	0.23	0.31	0.32	0.39	0.43	0.47	0.68	0.66

Note: Subject 9 results were excluded from analysis due to significant discrepancies between individual and group collected data

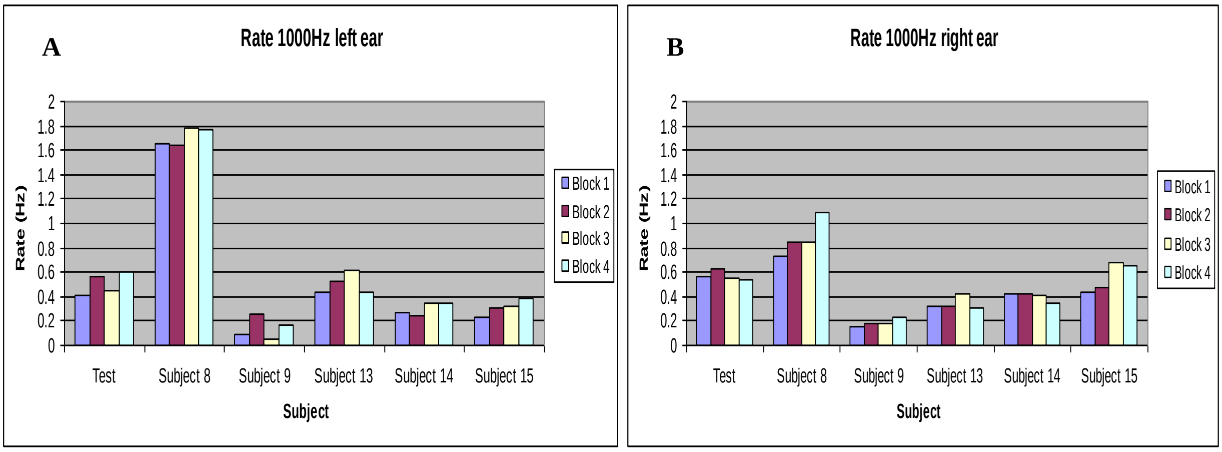

Figure 21 (A & B): Comparing the individual rate against experiment blocks for 1000Hz left ear (A) and 1000Hz right ear (B)

Fig 21 represents the individual BR rate during 1000Hz left and right ear stimulation.

The rate remained fairly constant across the 4 blocks when 1000Hz was presented to the left **(A)** and right **(B)** ear. The rate appears to vary across subjects in both conditions and is highly variable from person to person.

Table 7: Individual predominance (V/H ratio) results for 3000Hz

Subject	Control				Left				Right				Both			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Test	0.97	0.88	0.81	0.81	1.05	0.83	0.81	0.96	0.84	0.86	0.9	0.88	1	1.01	0.94	1.16
1	0.68	1.04	0.85	1.15	0.52	0.75	0.58	0.74	0.81	0.86	0.86	0.91				
2	1.18	1.15	1.25	1.36	1.33	0.98	1.3	1.1	1	1.12	0.89	0.8	1.24	1.21	1.06	1.09
3	1.43	1.63	1.76	1.99	1.5	2.15	2.1	2.24	1.77	2.27	1.71	1.78	1.52	2.47	1.9	1.61
4	1.11	1.12	1.16	0.97	0.9	1.01	0.95	0.9	1.04	0.9	0.83	1.06	1.07	1.01	1.04	1.07
5	0.55	0.98	1.14	1.46	1.44	1.62	1.43	1.72	0.8	0.77	0.6	0.99				
6	1.07	1.07	1.06	1.08	1.16	1.2	1.23	1.4	1.49	1.21	1.09	1.15	1.44	1.35	1.14	1.14
7					1.8	1.45	1.2	1.25	1.32	1.64	1.35	1.69	1.58	1.61	1.63	1.61
8	0.98	0.96	0.96	0.96	1.44	1.27	1.26	1.33	1	1.1	1.14	1.04	0.85	0.9	0.99	0.98
9	1.38	0.8	1.26	0.98												
10	0.77	0.68	0.71	0.77	0.76	1.25	0.96	0.92	0.72	0.78	0.68	0.68				
11													0.82	1.08	1.12	1.21
12					0.98	1.02	1.14	1.16	1.23	1.34	1.11	1	1.02	1.06	1.08	1.26
13	1.61	1.73	1.34	1.62												
14	0.79	0.79	0.73	0.89	0.59											
15	0.97	0.95	0.97	0.97	0.8											

Note: Left and right ear presented with 1000Hz were tested for subjects 8, 9, 13, 14, 15

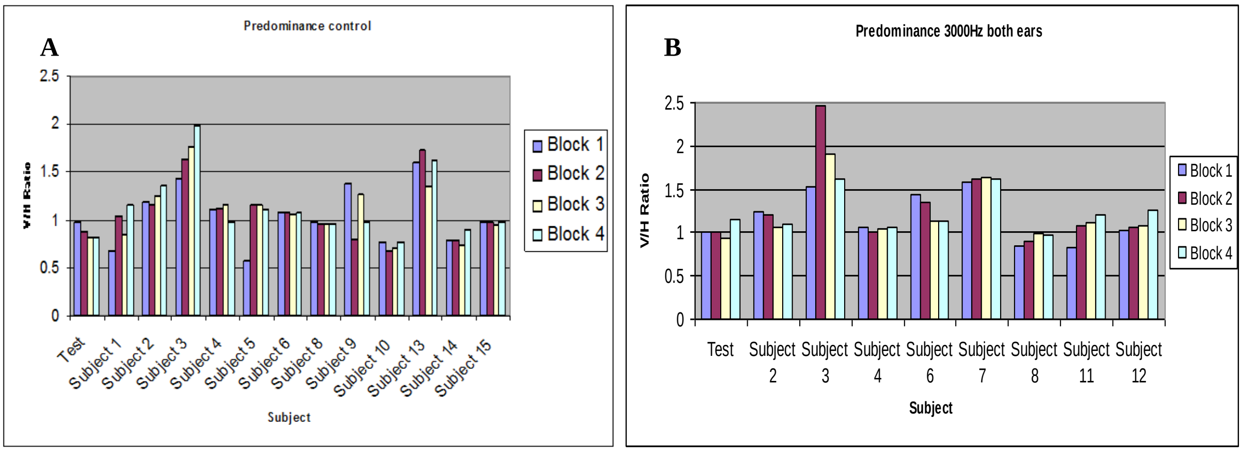

Figure 22 (A & B): Comparing the individual development of V/H ratio against experiment blocks for control (A) and 3000Hz both ears (B)

Fig 22 shows the individual predominance, where in control conditions **(A)**, vertical gratings were the dominant percept throughout the 4 blocks. When the tone was presented to both ears, the ratio remained constant for most subjects **(B)**.

Table 8: Individual predominance (V/H ratio) results for 1000Hz

Subject	Left				Right			
	1	2	3	4	1	2	3	4
Test	0.71	0.98	1.01	0.76	0.76	0.74	0.82	0.8
8	1.01	1.01	0.96	1.02	1	1.1	1.14	1.04
9	2.92	1.17	0.75	1.77	1.96	0.69	0.95	2.82
13	1.42	1.44	1.63	2.12	1.03	2.1	1.52	2.27
14	0.59	1.23	0.75	1.02	0.97	0.7	0.98	0.75
15	0.8	0.95	0.91	1	0.96	0.95	0.9	0.87

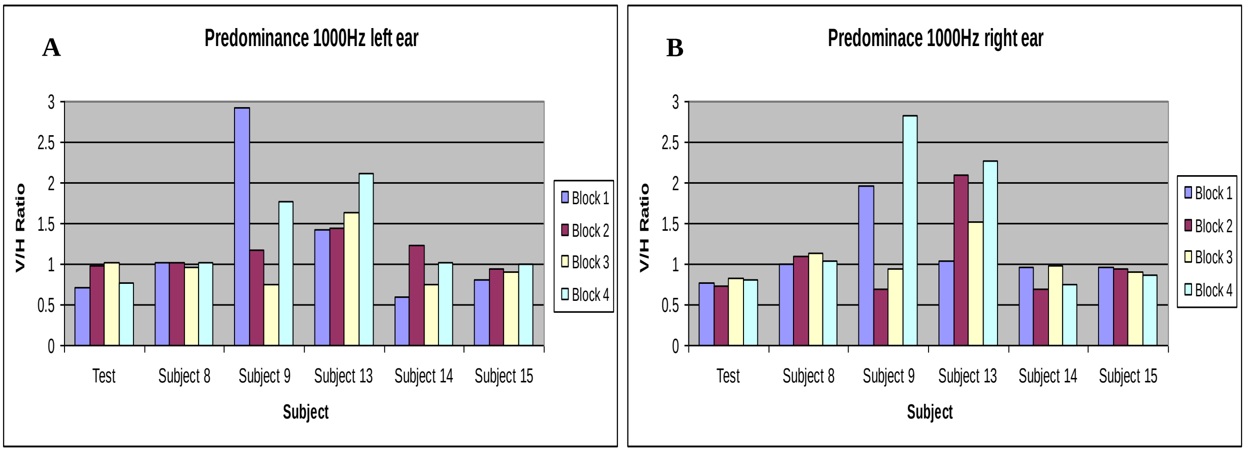

Figure 23 (A & B): Comparing the individual development of V/H ratio against experiment blocks for 1000Hz left ear (A) and 1000Hz right ear (B)

Fig 23 shows the individual predominance results when 1000Hz was presented to the left and right ear.

The tone of 1000Hz presented to the left **(A)** ear during block 3 resulted in slight decreases in the V/H ratio, with vertical gratings remaining the dominant percept. Stimulating the right ear caused a slight shift in the predominance **(B)**, where there appeared to be discrepancies between subjects as the V/H ratio increased for some and decreased for others.

APPENDIX II
Screening and Observation

USQ
AUSTRALIA

University of Southern Queensland

The University of Southern Queensland

Participant Information Sheet

HREC Approval Number:

Full Project Title: Auditory Influence on Binocular Rivalry

Principal Researcher: Dr Guang Bin Liu

Other Researcher(s): Natasa Borojevic

I would like to invite you to take part in this research project.

1. <u>Procedures</u>

This project will involve voluntary participants viewing dissimilar images on a computer monitor via a pair of polarized glasses and being exposed to different sounds via headphones. Participants will be required to respond to image perceptions by clicking on the appropriate keys (left-B, right-V, or space bar). The personal binocular rivalry rate and the influence of sounds on it will be determined through off-line analysis. There are no risks in this procedure and it will take up 30 minutes of your time.

2. <u>Voluntary Participation</u>

Participation is entirely voluntary. **If you do not wish to take part in you are not obliged to.** If you decide to take part in and later change your mind, you are free to withdraw from the project at any stage. Any information already obtained from you will be destroyed.

Your decision whether to take part in or not to take part, or to take part in and then withdraw, will not affect your relationship with the University of Southern Queensland.

Please notify the researcher if you decide to withdraw from this project.

Should you have any queries regarding the progress or conduct of this research, you can contact the principal researcher:

Dr Guang Bin Liu
Senior Lecturer in Human Physiology
Centre of Systems Biology
Faculty of Science
The University of Southern Queensland
617 4631 2275
guangbin.liu@usq.edu.au

If you have any ethical concerns with how the research is being conducted or any queries about your rights as a participant please feel free to contact the University of Southern Queensland Ethics Officer on the following details.

Ethics and Research Integrity Officer, Office of Research and Higher Degrees
University of Southern Queensland, West Street, Toowoomba 4350
Ph: +61 7 4631 2690, Email: ethics@usq.edu.au

University of Southern Queensland

USQ AUSTRALIA

The University of Southern Queensland

Consent Form

Ph: +61 7 4631 2690
Email: *ethics@usq.edu.au*

HREC Approval Number:

TO: Participants

Full Project Title: Auditory Influence on Binocular Rivalry

Principal Researcher: Dr Guang Bin Liu

Student Researcher: Natasa Borojevic

Associate Researcher(s):

• I have read the Participant Information Sheet and the nature and purpose of the research project has been explained to me. I understand and agree to take part in.

• I understand the purpose of the research project and my involvement in it.

• I understand that I may withdraw from the research project at any stage and that this will not affect my status now or in the future.

• I confirm that I am over 18 years of age.

• I understand that while information gained during the study may be published, I will not be identified and my personal results will remain confidential. *If other arrangements have been agreed in relation to identification of research participants this point will require amendment to accurately reflect those arrangements.*

Participants under the age of 18 normally require parental or guardian consent to be involved in research. The consent form should allow for those under the age of 18 to agree to their involvement and for a parent to give consent. Copy and paste another signature field if necessary.

Name of participant……………………………………………………………......

Signed……………………………………………………**Date**………………………

If you have any ethical concerns with how the research is being conducted or any queries about your rights as a participant please feel free to contact the University of Southern Queensland Ethics Officer on the following details.

Ethics and Research Integrity Officer, Office of Research and Higher Degrees
University of Southern Queensland, West Street, Toowoomba 4350
Ph: +61 7 4631 2690, Email: *ethics@usq.edu.au*

Researcher (initials): Date:

Time of screening: Start time of rivalry task:

Subject ID: ____________________

Sex: M F *Date of birth*: _____________ *Age*: ______ *Country of birth*: _____________

Native language: _____________ *Other spoken languages*: _____________

Screening items (Personal)

1. Does subject wear prescription glasses or contact lenses?
   e.g., "Before we start, I would like to ask you some questions about your vision. Do you wear any prescription glasses or contact lenses?"

No (skip section ☐ Yes ☐
If yes, intended purpose *(e.g., "what do you usually use them for?")*:
History *(e.g., "when did you first get them?"; "how often do you wear them?")*:

2. Does the subject have eye health problems?
   e.g., "have you had any problems with your eye health in the past or more recently…such as injuries to your eyes, strabismus (where the two eyes are not aligned with each other), double-vision, colour-blindness, glaucoma, and/or cataracts?"

No (skip section ☐ Yes ☐
If yes, list condition(s)? *(e.g., "could you please name them?")*:
If yes, history of condition(s)? *(e.g., "when was it first diagnosed?")*:

3. Psychiatric history
e.g., "have you ever been diagnosed with a psychiatric condition …such as schizophrenia, bipolar disorder, depression, borderline personality disorder, substance/alcohol abuse?"

No (skip section☐ Yes☐
If yes, nature of condition(s)? *(e.g., "could you please name them?")*:
If yes, history of condition(s)? *(e.g., "when did this first occur?; when was it first diagnosed?")*:

4. Neurological history
e.g., "have you had any neurological problems in the past or more recently…such as a brain injury, brain tumour, epilepsy, stroke, migraines, movement disorders?"

No (skip section☐ Yes☐
If yes, nature of condition(s)? *(e.g., "could you please name them?")*:
If yes, history of condition(s)? *(e.g., "when did this first occur?; when was it first diagnosed?")*:

5. Other medical conditions
e.g., "do you have any other medical conditions…such as diabetes, heart problems, respiratory conditions, metabolic conditions?"

No (skip section☐ Yes☐
If yes, list condition(s)? *(e.g., "could you please name them?")*:
If yes, history of condition(s)? *(e.g., "when was it first diagnosed?")*:

6. History of medical intervention(s)
e.g., "have you had or are currently undergoing any major or minor treatments?...such as surgery and/or chemotherapy?"

No (skip section☐ Yes☐
If yes, list intervention(s)? *(e.g., "could you please name them?")*:
If yes, history of treatment(s)? *(e.g., "when did the treatment(s) occur?")*:

7. Has the subject altered their state today?
e.g., "have you had caffeinated drinks, tobacco, alcohol, and/or engaged in strenuous exercise before this session?"

No (skip section☐ Yes☐
If yes, what are they? When did this occur (check if it was within the past 3 hours)? If a smoker, for how long?

8. Is the subject currently taking any prescribed medication(s)?
e.g., "are you taking any prescribed medications?"

No (skip section☐ Yes☐
If yes, what was taken? *(e.g., "can you list them? "what are they for?"*) / When was it taken? *(e.g., "when did you last take them?")* / Dose *(e.g., "how much was taken?")*?

9. Did the subject take any non-prescription medication(s) today?
e.g. "did you take anything else today, such as herbal supplements or vitamins?"

No (skip section☐ Yes☐
If yes, what was taken? *(e.g., "can you list them? "what are they for?"*) / When was it taken? *(e.g., "when did you last take them?")* / Dose *(e.g., "how much was taken?")*?

Screening item (Familial)

10. Family psychiatric history
e.g. *"Do you have relatives who are diagnosed with a psychiatric illness?"*

No (skip section ☐	Yes ☐
If yes, who? *(e.g., "without naming, how are you related?")* / Nature of condition(s)? *(e.g., "what is/was their diagnosis?")*:	

***11.* Visual acuity testing (Snellen chart)**
"…because some degree of visual ability is needed to do the experiment…"
"…I would like to test the accuracy of your eyesight …"

6/9 or better in both eyes is required. If visual acuity is worse than 6/9 in either eye, then exclude subject.

a. If subject wears glasses/contacts, test their visual acuity with glasses/contacts on.

b. Stand the subject at the marker that is 3 metres away from the Snellen chart.

c. Ask subject to cover one eye with hand by cupping the hand (and not pressing on the eye with their fingers).

d. Ask subject to verbalise from left to right each letter starting at 6/18 (e.g., U H Z N D V).

e. If the subject correctly verbalises letters that correspond to those on the Snellen chart, repeat steps (d) and (e) for the next row below.

f. However, if subject gets one or more incorrect. Repeat steps (c) to (e) in the opposite direction while covering the other eye with a cupped hand.
NB. If this is the first time the subject made an incorrect response, begin on the 6/18 row. If not, resume on the row that the subject last made an incorrect response for that eye.

g. The subject's visual acuity corresponds to the row in which they correctly verbalised all letters.
NB. For example, if the subject incorrectly makes a mistake on the same row a 2nd time, their visual acuity corresponds to the row above it. However, it is acceptable to include a subject if they get no more than one letter wrong on the 6/9 line with one or both eyes.

Left eye	**Right eye**
/	/

20/20 (foot) = 6/6 (metre) = 1.00 (dec) = 0.00 (LogMAR)

12. Eye dominance testing (hole-in-the-card test or Dolman method using the USAEyes.org card)
"…I would now like to test your eye dominance…"

a) Identify a small target object in the room

b) Ask subject to hold the card with both hands at arm's length and centred in front of them
e.g. "…hold this card at arm's length and centred in front of you. Move the card closer so that the card is directly over the [target object] and that you are viewing the [target object] through the hole."

c) Ask subject to view target object with both eyes through the hole in the card.
e.g. "…with both eyes open, focus on [target object] viewed through the hole in the card."

d) Ask subject to maintain focus on the target object and move the card closer until it touches their face.
e.g. "…while keeping focus on the [target object], keep it centred in the hole, and with both eyes open, slowly bring the card toward you until you touch your face."

e) When the card touches the subject's face, indicate the dominant eye.
e.g. "…you will find that the hole in the card is now over one of your eyes, this is your dominant eye, you may close one eye to check which eye this is."

f) Repeat test to verify
e.g. "…lets do it one more time to double-check."

Dominant eye in 1st run (please circle one): LEFT RIGHT

Dominant eye in 2nd run (please circle one): LEFT RIGHT
N.B. If 1st and 2nd run are inconsistent,
Repeat test a 3rd time to verify.

Dominant eye

Dominant eye in 3rd run (please circle one): LEFT RIGHT

13. Edinburgh Handedness Inventory and Subjective Mood Rating

Edinburgh Handedness Inventory

Please indicate your preferences in the use of your hands in the following activities. If you are really indifferent, select "**EITHER HAND**". Where the preference is so strong that you would never try to use the other hand, select "**NO**".

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.

Try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

When…		**Which limb do you prefer to use?**			**Do you ever use the other limb?**
1.	Writing	☐ LEFT HAND	☐ RIGHT HAND	☐ EITHER HAND	☐ YES ☐ NO
2.	Drawing	☐ LEFT HAND	☐ RIGHT HAND	☐ EITHER HAND	☐ YES ☐ NO
3.	Throwing	☐ LEFT HAND	☐ RIGHT HAND	☐ EITHER HAND	☐ YES ☐ NO
4.	Using scissors	☐ LEFT HAND	☐ RIGHT HAND	☐ EITHER HAND	☐ YES ☐ NO
5.	Using a toothbrush	☐ LEFT HAND	☐ RIGHT HAND	☐ EITHER HAND	☐ YES ☐ NO
6.	Using a knife (without a fork)	☐ LEFT HAND	☐ RIGHT HAND	☐ EITHER HAND	☐ YES ☐ NO
7.	Using a spoon	☐ LEFT HAND	☐ RIGHT HAND	☐ EITHER HAND	☐ YES ☐ NO
8.	Using a broom (upper hand)	☐ LEFT HAND	☐ RIGHT HAND	☐ EITHER HAND	☐ YES ☐ NO
9.	Striking a match	☐ LEFT HAND	☐ RIGHT HAND	☐ EITHER HAND	☐ YES ☐ NO
10.	Opening a box (lid)	☐ LEFT HAND	☐ RIGHT HAND	☐ EITHER HAND	☐ YES ☐ NO

i.	Which foot do you prefer to kick with?	☐ LEFT FOOT	☐ RIGHT FOOT	☐ EITHER FOOT	☐ YES ☐ NO
ii.	Which eye do you use when using only one?	☐ LEFT EYE	☐ RIGHT EYE	☐ EITHER EYE	☐ YES ☐ NO

Subjective Mood Rating

BEFORE TESTING SESSION

Circle one number on the scale to rate the mood you are feeling right now:

0 1 2 3 4 5 6 7 8 9 10

THE WORST YOU HAVE EVER FELT — *THE BEST YOU HAVE EVER FELT*

AFTER TESTING SESSION

0 1 2 3 4 5 6 7 8 9 10

THE WORST YOU HAVE EVER FELT — *THE BEST YOU HAVE EVER FELT*

***14.* Inclusion criteria**

Subjects will be included on the basis of:

(i) aged 18 to 80 years

(ii) capacity to give consent (esp. older subjects)

***15.* Exclusion criteria**

Subjects will be excluded on the basis of:

(i) visual acuity worse than 6/9 in either eye and unable to hear frequencies ranging from 200Hz to 10,000Hz

(ii) uncorrected strabismus

(iii) personal history of neurological disorder

(iv) optical or retinal pathology

(v) colour-blindness

(vi) over the age of 80 years old and under the age of 18 years old

(vii) unable to perceive alternating percepts

(viii) exclusive clinical diagnosis of bipolar I disorder, schizophrenia, schizoaffective disorder, major depressive disorder, anxiety disorder, obsessive compulsive disorder, ADHD

(ix) prospective control subjects who are first-degree relatives of individuals with bipolar disorder, schizophrenia, or major depressive disorder

16. Reschedule criteria

All subjects are rescheduled for testing on the basis:

(i) consumption of stimulant drugs (e.g. caffeinated drinks, amphetamines)

(ii) consumption of depressant drugs (e.g. SSRI, barbiturates, minor tranquilizers, alcohol, tobacco)

(iii) consumption of SSRI anti-depressant drugs

(iv) strenuous exercise

N.B. Exclusion criteria and reschedule criteria are to ensure that recorded binocular rivalry rates (BRRs) are not confounded.