The Infrasonic Impact:

Exploring the cognitive impact of frequencies below the hearing threshold during short term exposure

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Abstract

Infrasonic sound - or sound below the generally accepted audible threshold - is a persistent part of most modern environments and human beings have a near-constant exposure to it as it exists both naturally and from mechanical sources. While infrasonic sound frequencies are below the hearing threshold (20 to 20,000 Hz), studies show that they are still perceived by the human auditory system. Despite this evidence, studies determining the potential impact of infrasonic sound or the perception of the existence of infrasonic sound on cognition are scarce due to the challenges surrounding the delivery of infrasonic frequencies in a controlled environment such as replicating a non-audible sound, delivering this to participants and avoiding other overlap with other frequencies. There is rigorous discussion around what impact the placebo effect may have on infrasonic sound, with schools of thought vacillating between the placebo effect having no impact at all and it being the sole cause of any reported symptoms including changes to concentration abilities and diminished memory in subjects. As there remains no conclusive explanation for the relation between priming in the form of created expectation and the actual effect of infrasound, this leads to the question of whether infrasound may be able to affect cognitive functioning in any way. Determining the affect, and then studying the applications or mitigations needed to achieve a beneficial outcome to improve cognition by enhancing or inhibiting infrasonic sound are the focal point of this study.

This project explores the influence of infrasound on cognition by testing reaction time to stimuli and working memory in the presence and absence of exposure to infrasonic frequencies, using an advanced technical setup alongside tools like the Simon test and the n-back test. This approach creates a system to deliver infrasonic sound discreetly (without participant knowledge in all instance, unless briefed) and study the impact on short-term exposure patterns. In contrast, most research to date has investigated the possible effects that long-term exposure to infrasound (spanning months to years) may have on sleep

patterns and biological functions, with mixed findings. A number of studies have attempted to detect any correlation or investigate the relationship between reported symptoms (irritability, trouble with concentration/attention, dizziness, anxiousness, extreme fatigue and other self reported health concerns) in those exposed to constant infrasound generated by wind turbines, with some arguing a relationship between this exposure and perceived negative effects (the validity of which remains uncertain) and others unable to find evidence of a clear link between sound and symptomatology.

While exposure to infrasonic frequencies is a temperamental process due to the complexity of the technical set up needed and variation in exposure and delivery (and the reported effects are being debated), functional magnetic resonance imaging (fMRI) studies have been able to map the neural changes based on cerebral blood flow. Certain fMRI studies make note of brain stimulation on exposure to infrasonic sound, and are consistent with a potential effect on cognitive performance. This project aims to explore whether exposure to infrasonic sound can influence cognitive function using measures of accuracy, and reaction times as outcome measures in tests of reaction times and working memory intended to determine whether this could enhance or inhibit cognitive functioning. While long-term exposure could have a number of variables that may not be noticed, short term exposure limits any potential long lasting negative effects and allows us to take a closer look at immediate impact.

This project additionally intends to further explore the impact of positive and negative expectation on individuals exposed to infrasound, by creating positive/negative impressions prior to exposure using media created for the purpose of creating expectation. The concepts of placebo and nocebo, or the impact of positive and negative expectation, are argued to be contributory to the real and imagined impacts of infrasonic sound.

If infrasonic sound has a genuine impact on human cognitive performance, then the level to which this can be exploited or inhibited may have a proportional relationship with individual expectation of impact.

This research intends to further provide insight into the impact of infrasound on cognitive functioning and the relationship that awareness of infrasound (in the form of expectation) has on this outcome. The outcome of this study showed that accuracy when conducting cognitive tasks is not affected by the presence of infrasonic frequencies in a significant way. However, there was an observed negative impact on simple reaction times (time taken between the observation of a stimulus and the response to the stimulus as set out by the task) in the presence of infrasonic frequencies.

This suggests an impact on cognition due to the presence of infrasonic frequencies in an environment requiring computer-based information processing tasks. This outcome has practical implications for drug free methodology for cognitive enhancement, potentially creating a context within which we can purposefully prevent deterioration of memory recall and reaction time using the controlled absence of infrasonic sound.

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1. Introduction

1.1. Infrasonic Sound and the environment

The field of physics defines sound as a vibration that travels through a transmission medium such as solids, liquids, or gases in the form of a wave (Crawford, 1968). Sound can be divided into a scale based on perceptual properties (Klapuri & Davy, 2009). This is measured using the unit of frequency Hertz (Hz), defined in the International System of Units as one completed wave of alternating current or voltage (cycle) per second (International Bureau of Weights and Measures, 2019). The scale is divided into bands, ranging from extremely low frequencies (ELF) (3-30 Hz) to tremendously high frequency (THF) (300–3,000 GHz) (Booth, 1949). Human hearing can detect sounds in the frequency range spanning 20 Hz to 20,000 Hz, known as the audible spectrum (Purves & Williams, 2001). Infrasonic sound falls into the extremely low-frequency band and is generally understood to be below the threshold of human hearing, just under the audible spectrum (Yeowart & Evans, 1974). As noise is defined as any sound that is unwanted or does not serve a specific predetermined purpose, infrasonic frequencies can often be classified as noise (Garcia, 2001).

Environmental noise is defined as “unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road traffic, rail traffic, air traffic, and from sites of industrial activity” (EU, 2002, p. 4). Environmental noise includes infrasonic sound as most modern machinery has been found to emit infrasonic frequencies (Persinger, 2014). For example, infrasound frequencies have been detected originating from cars, aircraft, water vehicles and railway systems (Syracuse Research Corporation, 1980; Winiarski, 1983). In the automotive industry it was found that the levels of infrasonic sound were regularly created by most vehicles and were proportional to the number of openings in a vehicular structure, speed, and size of vehicles. (Haddad, 1989; Nowacki et al., 2007).

These frequencies are also present in agrarian settings where machinery like tractors, grain mixers and conveyor belts are used (Bilski,2017). Even household items like fridges and washing machines are responsible for the creation of infrasonic vibrations (Okada, 1990). These are often unknowingly perceived as they are obfuscated by the audible sounds made by these appliances through a process called auditory masking. This is where the overlap of other sounds can hide the presence of infrasonic sound (Gelfand, 2004).

Infrasonic frequencies can also be naturally occurring in the environment. Weather patterns including thunder, lightning, wind and precipitation, alongside the motion of bodies of water, tectonic shifts and glacial processes create large amounts of noise (Haak, 2006; Matoza et al., 2019). Nonlinear ocean wave patterns created by ocean movements, storms and water disturbance through human activity create infrasonic sounds (Garces & Willis, 2006; Garces et al., 2003). Many animals including elephants (Langbauer et al., 1991) and certain species of birds (Moss & Lockie,1979: Kreithen & Quine, 1979) also create and perceive infrasonic sound as a means of communication. Fish such as cod, sea bass and sharks have an acute sensitivity to low frequency sound generated by movement (Sand & Karlsen,1986; Kastelein et al., 2008). Marine mammals including seals, porpoises and whales also show sensitivity to these frequencies and use them for communication, orientation and location of prey (Kastelein et al., 2006; Mourlam & Maeva, 2017). This establishes an environmental presence of infrasound present both at land and sea using both air and water as a medium. The beating of the heart, respiration and internal functioning of most creatures including human beings also creates infrasonic noise (Colby et al., 2009).

This presence of infrasonic sound in the environment is not always easy to detect due to our auditory system based limited ability to notice low-frequency noise when compared to other noise or sound frequencies (Berglund et al., 1996). The effects of this noise have a large spread of influence due to the creation of large amounts of omnidirectional sound that can be easily propagated through the available medium (Ghadiali & Trivedi, 2015).

Without specialised equipment to capture, record and evaluate or measure infrasonic sound, we may be unaware of its presence (Lonzaga et al., 2015). The presence of infrasound permeates our surroundings and the probability of exposure to these frequencies is high.

In a year long evaluation of students in areas of higher traffic noise (including infrasonic frequencies) , it was found that exposure slowed down the development of working memory and attention (Foraster et al., 2022). Ascone et al. (2021), aimed to be the first-ever conducted randomized-controlled longitudinal exposure trial to study whether mental health, cognition and brain structure were affected by infrasonic sound. The study researched the long-term effect of infrasonic frequencies on the brain and behavioural patterns in human beings. Custom devices using 6Hz were used to expose participants to infrasonic sound over a period of 28 nights (n=38). The study aimed to measure the impact on sound-sensitivity to infrasonic sound, cognitive performance (Tests of Attentional Performance (TAP) 28, Simon task and Go/No-go), and changes to sleep quality most prominently. By the conclusion of the study, no differences to behavioural variables such as sensitivity to infrasonic sound, sleep disruption, reported psychiatric symptoms, elevated stress levels or cognitive functions (attention changes, flexibility, alertness or inhibition) were found and the study concluded that infrasonic sound did not affect healthy individuals after long term exposure. However, it is possible that the long duration of exposure created a diminishing response to the stimulus in the form of habituation (Uribe-Bahamonde et al., 2019). This further supports the need to study short term exposure of infrasonic frequencies and their impact on cognition.

1.2. Lack of understanding despite modern applications

Infrasonic sound frequencies have been observed during tectonic movement like earthquakes (Mutschlecner, 2005), landslides and volcanic eruptions (Walter et al., 2019) acting as an early warning system. Studies have shown that vibrations at an infrasonic sound frequency can be used as a measurement system by studying the relation between duration and magnitude of seismic activity (Mutschlecner, 2005). Nuclear detonation creates significant infrasonic sound vibrations (Che et al., 2014) and infrasonic sound is a key system used to identify if nuclear detonations have occurred. A 60-station seismic monitoring network set in place to track infrasonic sound makes up the International Monitoring System which serves as a watchdog to avoid violations of the Comprehensive Nuclear Test-Ban Treaty (CTBT) (Lay, 1998; United Nations, 1998). The Langley research centre wing of the National Aeronautics and Space Administration has developed an infrasonic sound-based system to measure and monitor atmospheric changes called the Extreme Low Frequency Acoustic Measurement System (Shams et al., 2013; National Aeronautics and Space Administration, 2014).

There has been a lot of research dedicated to the possibility of using infrasonic sound for lethal and non-lethal military applications (Jauchem & Cook, 2007). Weapons have been developed and deployed as crowd control measures in Iraq in the form of a Long-Range Acoustic Device (LRAD) (Davidson & Lewer, 2004), Israel (Ben-Davidson, 2004) and the UK (Ministry of Defence, 1999). More innocuous use includes a device called “The Mosquito” using the frequencies at 8 Hz to allegedly dissuade loitering by creating discomfort (Stapleton, 2004). The 2018 attack on the American Embassy in Cuba was theorised to be using sound beneath the hearing threshold and in the infrasonic sound frequency range (Cohen, 2018).

The human rights advocacy NGO, Physicians for Human Rights have deemed infrasonic weapons to be of significant levels of concern and consider infrasonic sound-based acoustic weapons to have the potential to cause severe damage to the human body. In their 2020 report Long-Range Acoustic Devices, the Mosquito and infrasonic sound frequencies were specifically singled out (PHR, 2020).

In the field of medicine, new applications for infrasonic sound frequencies are increasingly seen as a viable complementary strategy, in addition to traditional and non-traditional methodologies (Persinger, 2014; Brooke-Wavell & Mansfield, 2008). Ballistocardiography, the monitoring of blood movements through the heart, is studied and measured in a non-invasive way using infrasonic sound (Gordon, 1877). This technique uses infrasound in the frequency range of 1-20 Hz to detect motions of the body created through the mechanical movements of the heart as blood is ejected and is able to detect heart defects or abnormalities by studying the infrasonic output (Pinheiro et al., 2010).

The developing military and medical use of infrasonic sound hints at expanded forms of use in the future, however the gaps in our knowledge regarding the potential side effects are large due to a lack of research. The impact on cognition when used offensively on civilian populations or during surgical/ therapeutic practices may have far reaching effects that have yet to be discovered. Furthermore the public perception of infrasound could be influenced by its prevalence in the media as a tool for warfare, further strengthening the argument of unknown cognitive influence by way of a placebo/nocebo effect. This study has looked at the effect of infrasonic sound on participants who have not been influenced positively or negatively to create an expectation prior to participation in the experiment. While a subsequent study to study the impact of placebo and nocebo effects on participants had begun, the study was forced to shut down due to the COVID-19 pandemic and mandatory restrictions on inter-personal contact, transportation and access to resources/locations by government decree.

1.3. Infrasonic frequency, perception and stress

Yeowart et al. (1967) demonstrated that, using earphones, frequencies in the range 5-100 Hz could be perceived. In an anechoic acoustic chamber, it has been shown that frequencies as low as 4-25 Hz could be perceived (Watanabe & Møller,1990). While we are near constantly exposed to these frequencies, the presence of external sound and environmental disturbances tend to mask the presence of infrasonic sound (Boretti et al.,2018). This occurs through the process of auditory masking, where the perception of sound is affected by the presence or interaction with other sounds (Gelfand, 2004). The outcome of this masking is that we are often not consciously aware of our exposure to infrasonic sound and the impact it may have on cognitive performance.

In fMRI studies, it was found that infrasonic sound led to activation of the auditory cortex (indicative of perception of infrasonic sound via acoustic pathways) in the Brodmann areas 41 and 42, and in the superior temporal gyrus within the cerebral cortex. As these regions are responsible for filtering and processing auditory stimuli, we can infer that infrasonic sound frequencies activating these cortical regions are processed in similar ways to audible frequencies, despite being considered inaudible (Dommes et al., 2009; Weichenberger et al., 2015). These findings would suggest that there may be a foundation for the influence of infrasound stimulation on cognitive task performance. Infrasonic frequencies have been shown to physiologically affect the human body by stimulating regions of the brain, interfering with vision as well as heart and lung function (Okai, 1986; Tandy, 1998; Dommes et al., 2009; Weichenberger et al., 2015).

Studies have shown that noise can trigger stress reactions and can be considered a cause of stress (Ising & Braun, 2000). Infrasonic sound specifically has been shown to be a ‘nonspecific biological stressor’ as an environmental noise product that causes the brain to release glucocorticoids (Du et al., 2010; Jiang et al., 2014). Glucocorticoid secretion by endocrine systems is seen as a stress response (Lupien et al., 2007; Vogel et al., 2016). Catecholamine-mediated stress responses can affect attention, working and long-term memory, while slower, cortisol effects are slower and longer-lasting, which may have implications for noise-induced stress responses (Vogel et al., 2016).Thus, we can see how infrasonic sound being present in multiple environmental forms has a stress-related impact. If we are to assume that infrasound has the potential to impact cognitive performance, human inability to hear it in most environments due to masking means a potentially important environmental factor influencing cognitive performance and mental wellbeing as a result.

1.4. Stress and its impact on cognitive functioning

Cognition is commonly accepted to be ‘all forms of knowing and awareness, such as perceiving, conceiving, remembering, reasoning, judging, imagining, and problem solving’ (American Psychological Association, 2021). In simple terms, cognitive functioning involves the mental processes relating to abilities like perception, memory, critical thinking, and mental imagery. Stress is characterised by the relationship between an individual’s cognitive capacity and the variables that create the environment surrounding the individual, and whether the environment is judged as exceeding available resources to cope (Lazarus, 1966,1993). Stress is an imbalanced relationship that can occur when the individual is forced to deal with environmental demands in a manner that challenges the available cognitive resources needed to meet these demands or conversely when there is excess cognitive resource (Lazarus & Folkman, 2013). Stress can be differentiated into separate and distinct categories, differing in process with positive or negative outcomes (O’Sullivan, 2010). Of these two outcomes, the positive psychological response to stress, when the available resources allow the individual to suitably deal with the environmental challenges, is called eustress. Distress is consequently the negative psychological response to limited resources in the face of environmental challenges (Simmons & Nelson, 2007).

Hans Selye (1976) termed stress as a “nonspecific response of the body to any demand” (p. 137) and eventually came to lay down the foundation that established the relation between stress and clinical conditions (Tan & Yip, 2018). Selye proposed that stress and stressors didn’t necessarily have to have a negative impact, but instead it was possible for a given stressor to elicit a positive or negative result. Rather than eustress and distress being two opposing sides, they are recognised as two related yet separate identifiable concepts. While they tend to have the same cause, they can have opposite or different outcomes. Studies show that the two forms of stress could occur together, and stress reaction can be considered comorbidities when occurring together. This means that the cause of stress could have both a positive effect on certain tasks and a negative outcome on others simultaneously (Simmons & Nelson, 2001, 2007).

Edwards and Cooper (1988) suggested that eustress enabled individuals to perform in a manner that would allow them to function efficiently, while able to mitigate the stress demands that they were exposed to. It was found that students who were experiencing higher levels of stress had better academic results whereas their counterparts who had experienced a lower level received poorer grades (Monk, 2004). Glass and Singer (1972) showed that sound can improve attentiveness on tasks that are repetitive or monotonous and might be considered under-arousing. In contrast, they also found that sound could potentially impair individual performance on tasks that required more complex responses or concentration. Stress as a stimulus has been shown to stimulate arousal, which is the stimulation of sense organs in a manner that affects perception (Cannon, 1932). The Yerkes–Dodson Law postulates that performance may increase or decrease depending on the level of arousal, as there is an empirically verified stress to performance relationship

(Yerkes, & Dodson, 1908). This supports the concept of cognitive resource being utilised to deal with environmental factors. Research suggests that tasks may require different levels of stress-related arousal to perform at an optimal level (Diamond et al., 2007). It can therefore be inferred that as stress has a strong impact on cognitive function, stress responses to infrasonic frequencies may demonstrably produce similar impacts creating sustained attentiveness or inhibiting attention;a significant factor in reaction time (Carlson et al., 1983).

The Simon test alongside the stroop test and flanker task, is one of the most widely used cognitive functioning tests used within the field of neuroscience and psychology to evaluate motor planning, cognitive control, and attention (Cespón et al., 2020). The Simon test uses the Stroop effect to determine the ability to inhibit cognitive interference when a second stimulus is present while the participant is required to process a given task related stimulus in the form of reaction times (Simon & Rudell, 1967). As reaction time testing during cognitive tasks is regarded as a valid measure of cognitive functioning (Jakobsen et al., 2010), measuring the impact of stress related change to individual reaction time will also enable us to study the relationship between cognitive functioning and the stimulus of infrasonic sound in a simple manner.

Working memory is a complex cognitive function based on sustained attention patterns, requiring the holding and processing of information despite external interference (Gajewski et al., 2018; Engle, 2002;1999). Complex cognitive tasks such as comprehension, reasoning, and learning are dependent on working memory functions. The concept of working memory developed from that of ‘short-term’ memory into one comprising three components. The central executive directs attention in a phonological loop with the visuo-spatial and verbal-acoustic systems and the episodic buffer, through which the components of working memory may integrate with long-term memories and perceptions (Baddeley, 1992, 2010).

Based on initial exploratory studies relating Auditory Cortex stimulation to the presence of infrasonic sound while conducting an n-back task (Weichenberger et al., 2015; Dommes et al., 2009), working memory could potentially be an area affected by infrasonic sound. This was supported by longitudinal studies that identified working memory as a good parameter for measuring the impact of infrasonic sound on cognitive capacity (Ascone et al., 2021).

A variety of tasks are used to measure working memory such as Dichotic-Listening tasks, stroop tasks, go/no-go task and the n-back task (Wilhelm et al., 2013). A commonly use effective test of working memory is the n-back test where participants are required to monitor a series of stimuli patterns and to respond whenever there is a repetition of stimulus presented after n number of previous trials. Here, participants are typically instructed to monitor a series of stimuli and to respond whenever a stimulus is presented that is the same as the one presented n trials previously (Owen et al., 2013). The increased attentional requirement (cognitive demands) for working memory in the n-back task may allow for unconscious sensory gating to suppress unwanted sound stimuli (such as infrasonic sound) which could demand additional cognitive resources and prevent completion of the task or allow the task to be successful depending on the cognitive demands of the unwanted sound stimulus (Nakajima et al., 2019; Miller & Cohen, 2001; Petersen & Posner, 2012). As the infrasonic stimulus represents an external stressor that creates interference, measuring any change in working memory in the presence of infrasonic sound may clarify whether it has a stress-related resource demanding impact on cognition that exceeds the suppression due to engagement in the task.

1.5. The influence of amplification by expectation

The exposure to environmental sound, which has been established to contain infrasonic frequencies (Persinger et al., 2014), has been reported to have a range of psychological and physiological effects on the human body (Kinsler et al., 2000). Exposure to everyday infrasonic sound frequencies has been found irritating and disturbing in workplace environment simulations, by participants aware of the sound being present in the work environment. A study of the impact of infrasonic on participants (n=52) exposed to naturally occurring office based infrasound stemming from workplace equipment such as airconditioners and computer equipment was contrasted with participants (n=60) who took part in continuous attention psychological tests while being exposed to low frequency sound in a laboratory setting. The findings concluded that efficiency and productivity decreased due to the annoyance caused by low frequency noise in the infrasonic range (Kaczmarska & Luczak, 2007). Behavioural alterations and cardiovascular diseases have also been attributed to infrasonic frequency exposure in several instances collectively termed vibroacoustic disease or VAD. This systemic pathology takes the form of symptoms like pulmonary instability, mood disorders and respiration difficulties (Ferreira et al., 2004; Huang et al., 2003; Pei et al., 2007).

As our understanding of infrasonic sound and ability to recognise its impact grows due to the emerging studies beginning to be published (and increasing media coverage), there has been an increase in the number of people coming forward to report symptoms attributed to infrasonic sound (Pierpont, 2009). Reported symptoms include changes to concentration abilities and diminished memory attributed to infrasound exposure in the long-term observation of participants (Punch & James, 2014). This trend has led to the coining of “Wind Turbine Syndrome” as a description of the collective symptomatology investigated by researchers exploring the impact of infrasonic frequencies on health. This condition is defined by health issues including irritability, trouble with concentration/attention, dizziness, anxiousness, extreme fatigue, and sleep disruption attributed to infrasonic exposure (Pierpont, 2009). A recent first of its kind longitudinal study of long term impact of infrasound argue that there is no impact on factors like sleep, attention, alertness, or any self-reported heath issues (Ascone et al., 2021). Based on the anecdotal and sensationalist nature of the studies(Roosth, 2018) put forward detailing ‘Wind Turbine Syndrome’ as a catch all term for infrasound attributed symptoms (Pierpont, 2009), attributing extreme reactions to infrasonic sound are reliant on confirmation bias and very likely pseudoscientific (Cover & Curd, 1998). In the report commissioned by the UK Department for Environment, Food and Rural Affairs the concept of ‘Wind Turbine Syndrome’ was pointed out as severely unscientific and unsupported by facts (Leventhall et al.,2003).

There are two distinct prevalent interpretations of the expectation based symptom phenomenon. Either, that there is a real and recognisable physiological impact of infrasonic sound, or alternatively, the effect is a psychogenic effect caused by expectation, where infrasonic frequencies play no causal physiological role (Tonin et al., 2016). A psychogenic illness is one where there are common symptoms spread through a population with no recognisable infectious agent or cause for contagion (Bartholomew & Wessely,2002; Kelly et al, 2014). During a trial, experiment or experience, a positive psychosocial context can create a positive outcome in the form of a placebo effect (Hróbjartsson & Gøtzsche, 2010). Similarly, a negative contextualisation (especially one that frames the possible adverse side effects) can create a contradictory or deleterious outcome, the nocebo effect (Häuser et al, 2011). Research in the field has proposed that several of the health concerns self-reported by individuals who have been exposed to infrasonic sound, are commonly seen in areas where wind turbine farms have had a large amount of negative publicity leading to the misattribution of symptoms to infrasonic sound aligned with the expectations of harm established in press media (Crichton et al., 2014; Tonin et al., 2016). Attempts to recreate symptoms of fatigue, irritation, depression, sleep deprivation, lack of attention (or similar) in a controlled environment showed that participants who were primed using material which increased their concerns about the effect of infrasonic sound were more likely to report symptomatic reactions to both infrasound and sham infrasound (Crichton et al., 2014). This supports the potential influence of the nocebo and/or placebo effect on the perception of infrasonic sound.

Whether this is an exacerbation of an existing cognitive response or responsible for the response itself is yet to be established. With the importance of priming or expectation being understood to potentially have an impact on any infrasonic study. This study looks into the effects of infrasonic sound without the presence of any external information regarding infrasonic sound that could influence the participant's cognitive performance during the course of the study.

1.6. Thesis rationale and hypothesis

Research to date has generally investigated the effect that exposure to infrasonic sound may have on sleep patterns and biological functions after or during long-term exposure (months to years) (Punch & James, 2014;Tonin et al.,2016;Ascone, 2021), leaving a gap in the literature regarding shorter-term exposure and the impact of acute exposure on cognitive functioning. This thesis aims to build on the small, but growing body of existing works of research investigating short exposure patterns and exploring the potential for these manipulations to influence cognitive functioning. Several fMRI studies investigated the areas of the brain stimulated by infrasonic sound. Stimulation of the Brodmann Areas 22,41,42 of the bilateral primary audio cortex, and the rAmygdala were activated when exposed to short term infrasonic sound bursts. There was found to be higher local connectivity of right superior temporal gyrus and similar areas of the aditory cortex. The studies also found a negligible trend supporting task improvement during infrasonic sound exposure (Dommes et al.,2009;Weichenberger et al., 2015, 2017).

- It is hypothesised that exposure to controlled short bursts of infrasonic sound, will affect cognitive functioning in a manner which is measurable through simple reaction time and accuracy (in the absence of priming or expectation).

It is hoped that this thesis will further our understanding of infrasonic sound in terms of potential influence on cognitive functioning, and the relationship between sound-based environmental factors and performance. It may also have practical implications, potentially creating a context with which we can enhance cognitive capability by using the presence or absence of infrasonic sound.

The second intended outcome was top evaluate the impact of expectation and priming on these tasks to understand the implications of a placebo / nocebo effect.

2. Methods

2.1. Participants, recruitment, and information

The study employed a within-subjects design, manipulating the presence or absence of infrasonic sound. Based on similar studies by Weichenberger et al. (2015, 2017) and Dommes et al. (2009), the smallest effect size of interest was determined as Cohen's d = 0.5. To detect an effect size of 0.5 with 80% power (alpha = .05, two tailed), using G*Power (Faul et al., 2007; 2009), a minimum of 34 participants would be required in a paired t-test.

43 adults aged 18-34 took part in this study (Mean age = 20.25 / Median age = 19, Standard deviation = 3.51, 14 males and 29 females). 3 participants from the total of 43 were excluded, and their data omitted from the study, as all 3 correctly identified the presence of infrasonic sound during the experiment as noted during the debrief.

Each test had a pilot stage to allow for testing errors and for gathering of initial data to ensure the smooth running of subsequent tests. During this pilot stage, 5 volunteers from outside the participant pool performed each test in its entirety. The data collected was too small a sample size to be indicative of the future outcome and was therefore not included in the study.

Participants were native English speakers, had no known learning difficulties, self-reported normal hearing and reported normal or corrected-to-normal vision with no colour blindness. Participants were a mix of students at the University of Leeds, who were reimbursed for their time with course credits, and volunteers who were reimbursed for their time with gift vouchers worth £3. These volunteers were recruited by poster and internal University participant pool systems. The experiment was approved by the School of Psychology Ethics Committee at the University of Leeds (PS-654) **(Appendix i).**

To conceal the research focus on infrasonic sound as the experiment was a blind study, participants were recruited using posters calling for an attention study **(Appendix ii**). An initial email was sent to students describing the study as a call for participation **(Appendix iii).** Participants were provided with a participant information sheet detailing a brief outline of the proposed attention span study, contact details of the researcher, withdrawal instructions and confidentiality explanations **(Appendix iv).** This was followed by a consent form **(Appendix v)** and an information sheet outlining task instructions for each experiment **(Appendix vi)**. At the end of the experiment, the participants were provided with a questionnaire **(Appendix vii)** followed by experiment debrief information **(Appendix viii)**.

The questionnaire consisted of three open-ended questions to determine whether participants could perceive the infrasonic sound during the experiments, and to seek further insights to inform future studies.

The debrief information informed the participants of the true nature of the study, and a reiteration of their ability to withdraw (as well as instructions on how to do so). Finally, the debrief information sheet also asked the participants not to disclose any information pertaining to the study to prevent any influence on other participants.

2.2. Procedure

To enable the exposure to infrasonic sound while concealing the true focus of this study, participants were instructed to wear headphones prior to the start of the experiments. This enabled the administration of the infrasonic frequencies during one block per test without detection. The use of headphones was explained as being a way to prevent external noise from interrupting the experiments.

The two tests of cognitive performance used for this study were the Simon test and the n-back test. Using a within-subjects design, the order of task completion and infrasonic sound exposure was counterbalanced using a Latin-square design. A Latin square is a table populated with different variables, so that each variable is present only once in each row and exactly once in each column. This means that the tasks were counterbalanced as the variables were rearranged to prevent nuisance variability (Vengadesan et al., 2004).

The Simon test was chosen as a simple test of reaction time and accuracy (Hommel, 2011). Reaction time is a simple form of the reflexive speed response of a nervous system and is a good indicator of reaction to stimulus perceived by the nervous system (Radak, 2018). Here, the participant is presented with a sequential stimulus set and is required to indicate options using the correct corresponding key. The speed of response time is then automatically tracked for comparison. The n-back test was chosen because it has a greater demand on working memory (Jaeggi, 2010). The participant is presented with a sequential stimulus set and is tasked with indicating when the current stimulus matches the one from ‘n’ (pre-defined) steps earlier in the sequence. This is expanded upon in section **2.2.3** and **2.2.4.**

Participants completed two blocks each of 120 randomised trials for the Simon test, and 109 trials (with 20 correct responses possible) for the n-back test. In order to vary the presentation order involved in the trials for the n-back test, three manual spreadsheets were created to be used in rotation with the same number of correct responses (but with different presentation orders).

No practice trials were used to prevent an attenuation effect that could influence results (Brown, 2008). The studies commenced with the provision of study information (for the first block of each set). This was followed by participant consent forms allowing for informed consent. As mentioned above, the true purpose of the study was initially concealed, to be then explained in detail during the debrief. Following the informed consent the participant was assigned a generated participant number. Before each task attempt, the participant was given clear written instructions that required them to acknowledge their understanding before proceeding **(Apendix vi).** These instructions were then repeated on the screen before each task. Each task block took 5 minutes to complete, with 2 blocks per task undertaken by each participant.

A brief break was taken after the first block of each test, where the participant would exit the room. This enabled the researcher to save the recorded information and prepare the second block. The task was repeated either with or without the presence of infrasonic sound, depending on the counterbalanced order. This is visually represented in **Figure A.**

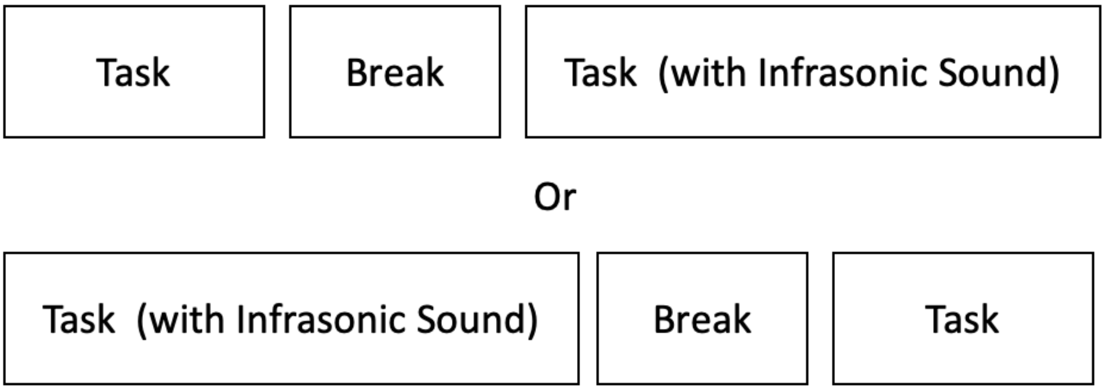


Figure A. Break up of blocks within each task.

2.2.1. Testing booth and physical layout

The physical testing space was consistently the same closed room with a computer, a desk, and a set of chairs. This room was based within the University of Leeds, School of

Psychology Building. This is seen visually represented in **Figure B,** where the researcher was seated at the location r and the participant at p.

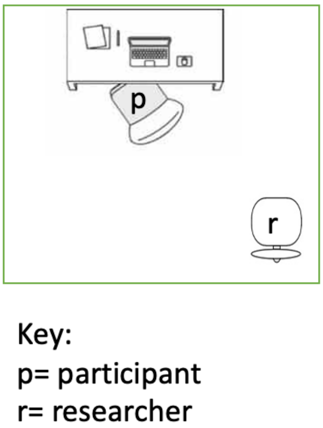


Figure B. Physical layout of testing booth.

2.2.2. Stimuli and equipment

A frequency at 17 Hz, similar to experiments previously conducted by Weichenberger et al. (2017) and Erfani et al. (2020) was used in the experiment. This was generated using a MAX/MSP patch (Battey & Amedlides, 2013). Weichenberger et al. (2015, 2017) conducted fMRI trials that found evidence suggesting near threshold (20 Hz) frequencies like 17 Hz showed stimulation of areas in the brain that were responsible for auditory processing, emotional control, and autonomic control (Weichenberger et al., 2017). 17 Hz was specifically chosen as it was the closest to the hearing threshold without affecting vision. The resonant frequency for the eyeball is generally accepted as between 18 Hz and 19 Hz. Presenting a frequency at or near 18.5 Hz could potentially affect vision (Tandy & Lawrence, 1998). A sound intensity level of 10 dB or decibels was used as this created a near hearing threshold sound that was comparable in loudness to normal breathing and was therefore suitable for an experiment where it was preferable for participants to not detect the presence of infrasonic frequencies (Centers for Disease Control and Prevention, 2019).

The frequency delivery mechanism was designed in the form of a sinusoidal oscillator primed to deliver a continuous sine wave with the use of a smooth periodic oscillation. The toggle options built into the application contained an on or off (I/O) setting. Audio Technica ATH M50x audio headphones possessing a frequency range of 15 Hz to 28 KHz were used to deliver the frequencies to the participant. An Asus Xonar U7 MK11 sound card was be used for hardware support (to process, deliver and maintain 17 Hz frequencies) and frequency output was consistently measured using an oscilloscope. This was done to ensure the correct and consistent frequency was present across participants during the experiments.

The open-source software package PsychoPy written in the Python programming language was used to create the tests and then capture participant responses (Pierce et al., 2007, 2009, 2018, 2019). These were made for the purpose of the experiment and did not use a template.

2.2.3. The Simon Test

The Simon test examines stimulus-response compatibility using the speed of reaction time to stimulus (Simon & Rudell,1967). The participant is presented with a sequential stimulus set and is required to indicate using the correct corresponding key(colour coded to match the stimulus) which option is displayed. The test has previously been shown as effective in determining the impact of interference on responses (Simon et al., 1973; Prinz & Hommel, 2002). It was chosen as a task as it would allow us to see if there was any change to the accuracy and reaction time responses when exposed to infrasonic sound.

For the Simon test, the infrasonic sound oscillator was turned on or off in accordance with counterbalancing before the start of the test. Doing so meant in an instance where the block required the infrasonic sound to be present it could be started and where the block required that the infrasonic sound to be absent it could be turned off prior to the start of the block. The initial screen asked the participant to fill in their age, gender, block number and participant number. Instructions regarding how to proceed (describing the actions needed to be performed) were given via the software itself. The appropriate response keys were stickered using a coloured sticker that corresponded to the two colours displayed. The option to continue if the instructions are clear remained on the computer screen until the spacebar key was pressed. The participant was also given the option to address any confusion by speaking to the researcher before the experiment began.

After pressing the spacebar, the participant was shown a randomly generated sequence of either red or green 5 cm x 5 cm opaque squares on a screen. Each square was present on the screen for 2 seconds, during which time participants were expected to press the corresponding stickered key on the keyboard in front of them. The on-screen instructions advised participants to keep both hands in a specifically directed position on the keyboard for the duration of the block. There was 1 second between the presentation of each subsequent square. There was a '+' symbol set at the centre of the screen and the generated squares would appear on either side of the + symbol at a set position. The purpose of this was to give participants a general idea of the centre of the screen near which the coloured squares would appear. This can be seen in **Figure C.**

The speed and accuracy of the participant in pressing the appropriate key was measured and recorded by the test through PsychoPy. Before beginning, the participant was informed that the test required accuracy and speed. As previously explained, there were no practice trials for these tasks.

The participant then began the first task for 5 minutes. At the 5 min mark, the software provided the participant with a break screen. At this time, the participant was asked to leave the room while the researcher saved the data and toggled the infrasonic sound oscillator on/off in accordance with counterbalancing before the start of the test. Once the participant returned for the second block, the participant then performed the same task for another 5 min. The data for block 2 was recorded during the activity. This created two data sets, one each for block 1 and 2 (one including and one without the presence of infra sonic sound).

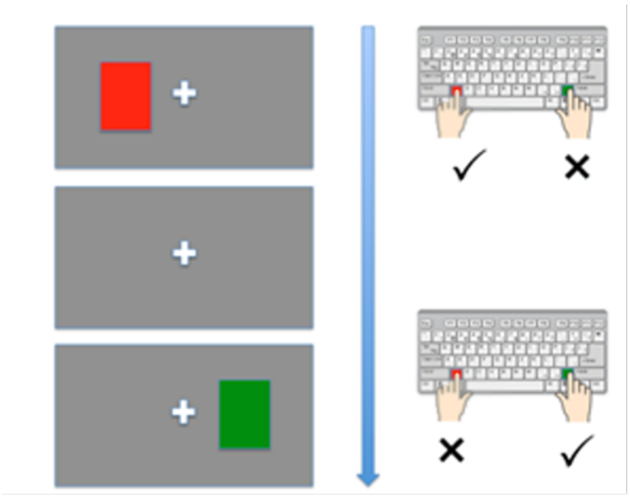


Figure C. The experimental paradigm used in the Simon Test.

2.2.4. The n-back test

The n-back task is a continuous performance task that measures working memory and working memory capacity (Kirchner, 1958;Gazzaniga et al., 2009). This test had similarly been used by Weichenberger et al. (2015) to study the impact of short term exposure to infrasonic sound to show difference in brain activity in the presence of infrasound (cerebral stimulation of the Brodmann areas 41,42). The participant is presented with a sequential stimulus set and the task consists of indicating when the current stimulus matches the one from ‘n’ (pre-defined) steps earlier in the sequence. It was chosen as a task as it would allow us to see if there was any disruption to the working memory responses when exposed to infrasonic sound. The n-back is a commonly used and established task and is a good indicator of working memory (Gajewski et al., 2018; Coulacoglou & Saklofske, 2017).

Similar to the other task, the infrasonic sound oscillator was turned on or off in accordance with counterbalancing before the start of the test. Doing so meant in an instance where the block required the infrasonic sound to be present it could be started and where the block required that the infrasonic sound to be absent it could be turned off prior to the start of the block. The initial screen then asked the participant to fill in their age, gender, experiment block number and participant number. The infrasonic sound oscillator was toggled on or off as required to counterbalance. Instructions regarding how to proceed were given via the software itself. The appropriate response keys were stickered.

The option to continue if the instructions were clear remained on the computer screen until the spacebar key was pressed. The participant was also given the option to address any confusion by speaking to the researcher before the task began. After pressing the spacebar, the participant was shown a pre-determined sequence of up to 7 colours (red, yellow, blue, cyan, magenta, white or green) and was expected to press the indicated stickered key when they saw the same colour repeated after 2 spaces (2 back test).

The colour stimulus was presented in the form of a 5 cm x 5 cm opaque square and participants were required to press the indicated stickered key. A sequence with repetition after 2 spaces was chosen (2-back test) as participants found a 3-back version difficult during the pilot phase. Each square was present on the screen for 2 seconds. There was 1 second between the presentation of each subsequent square. There was a central '+' symbol set at the centre of the screen and the generated squares would appear overlapping the + symbol at a set position in the centre of the screen. This can be seen in **Figure D.**

The participant performed the task for 5 min before reaching a break screen. During this time, the data sets were collated for block one. Since this was a pre-determined sequence, at this point the researcher swapped out the sequence for a second prepared sequence to prevent habituation. While there were two predetermined sequences used, this was counterbalanced across the block order.

The infrasonic sound oscillator was toggled on or off with relation to counterbalancing. The participant then performed the same task for another 5 min (with a different sequence). The data for block 2 was recorded during the activity. This creates two data sets, one each for block 1 and 2 (one including and one without the presence of infrasonic sound).

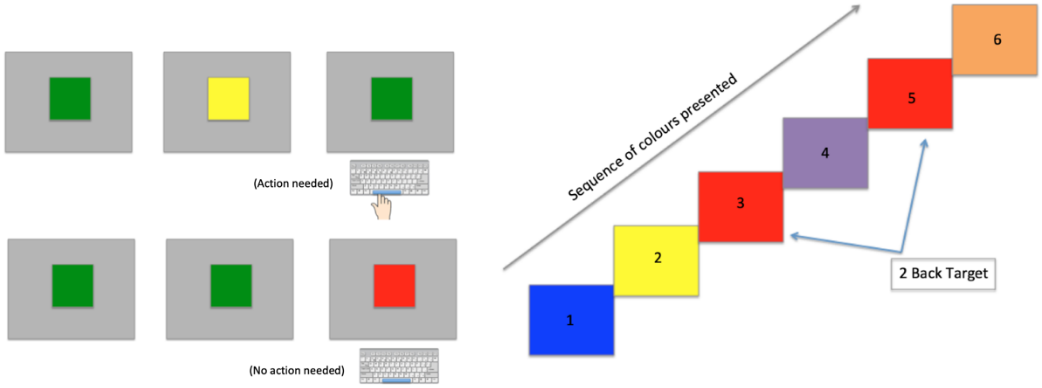


Figure D. The experimental paradigm used in the n-back test. Figure not to scale.

At the end of this participants were provided with a brief questionnaire **(Appendix viii)** that asked if they had identified any sound during the experiment, what they believed the purpose of the experiment to be and any further open-ended comments they may have. This allowed the researcher to determine whether there was a conscious rejection of the external sounds, whether the participants had considered that this was infrasonic sound (if so whether their pre-conceived expectations had affected the outcomes of the test), whether their awareness of the sound or deception influenced the way they performed the tasks.

A debrief explaining the nature of the infrasonic frequency presence during the experiment took place at the end of the experiment. Post debrief, participants were asked not to reveal the use of infrasonic sound to others who might take part. This was done to avoid demand characteristics.

2.3. Data analysis

The first dependent variable was accuracy, determined by proportion correct. Here the number of trials responded to correctly when divided by the number of total trials, gave us an accuracy level. This was measured in percentage (%). The second dependent variable was response time, determined by the arithmetic mean of all correct response times of the trials (within the block). This was measured in milliseconds (ms). Data outliers for reaction time were discarded by the removal of 2.5 standard deviations above and below to prevent gross deviation or experimental error from impacting the study (Grubbs, 1969; Maddala,1992).

A Bayesian hypothesis test in the form of Bayes factor was calculated using the software JASP. The Bayes factor is described as a likelihood ratio of the marginal likelihood of two hypotheses. This is normally the null and an alternative hypothesis (Good & Hardin, 2012). For a data set such as the one present for this experiment, the Bayes factor was useful as it quantifies the support of one model over another without needing models to be correct (Ly et al., 2016).

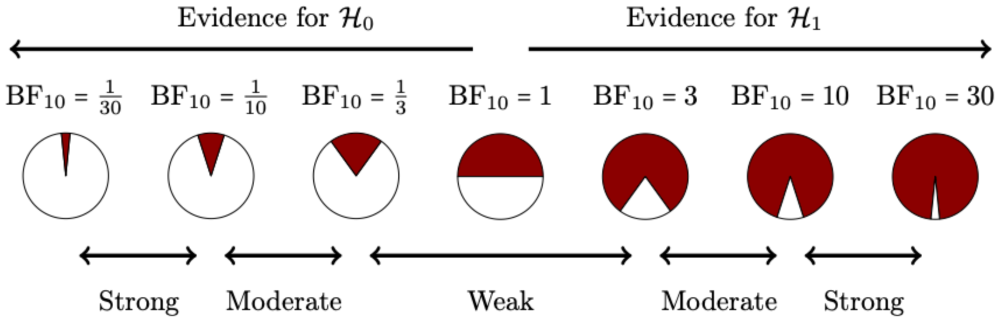


Figure E: The bayes factor classification graphical representation as probability wheels

In **Figure E**, the JASP guidelines for conducting and reporting a Bayesian analysis (van Doorn et al., 2020) shows us the evidence represented in the form of probability wheels.

Here the ratio of red (hypothesis affirmation) to white (null hypothesis) shows the corresponding level of support for each hypothesis.

We see that as the Bayes factor moves away from 1 (which is an equal indicator of the hypothesis being 1 or 0) it gains a degree of strength either for or against the hypothesis. Bayes factors from 1-3 are seen as weak, Bayes factors from 3-10 are seen as moderate, and Bayes factors above 10 are seen as strong evidence (van Doorn et al., 2020).
The resulting likelihood ratio or Bayes factor thus tells us whether the observed finding is most likely to have occurred under either the null or alternative hypothesis (Leppink et al., 2017).

As detailed in the introduction, the amount of supporting literature on this topic was quite limited when this study was first conceived, and the potential for either a positive or negative effect was equally likely. The Bayes factor analysis was used to support the originally chosen frequentist inference. There was a high chance that while the effect would be statistically significant, it would only be present under specific circumstances, for example in parts of the test or showing dual effects over different tests. The Bayes factor was therefore useful to see how strong the support for either side of a two tailed hypothesis would be.

3. Results

3.1. Response times

Data outliers for reaction time were discarded by the removal of 2.5 standard deviations above and below. 3 participants from the Simon test were excluded due to being data outliers.

Table 1. Reaction time data set from Simon and n-back tests with and without infrasonic sound (ms).

	Mean	N	Std. deviation
Simon test (no infrasonic sound)	**466.78**	**37**	**46.63**
Simon test (infrasonic sound)	**481.64**	**37**	**67.68**
n-back test (no infrasonic sound)	**576.29**	**40**	**102.82**
n-back test (infrasonic sound)	**590.14**	**40**	**98.72**

A statistically significant increase in response time was shown in the presence of infrasonic sound in comparison to response time without infrasonic sound, during the Simon Test, *t*(36) = -2.306, *p* = .027, *d* = -.379, BF_{10} = 1.82. No statistically reliable difference between the response time with infrasonic sound and response time without infrasonic sound, during the n-back Test, *t*(39) = -1.166, *p* = .251, *d* = -.184, BF01 = 3.122, BF_{10} = 0.32. On average participants exposed to infrasound during the Simon test showed an increase in response time to the stimuli. However, this was not seen during the n-back test. There was no difference in response time in particpants performing the n- back test in either group.

3.2. Accuracy

Data outliers for reaction time were discarded by the removal of 2.5 standard deviations above and below. 1 participant was excluded from the Simon test and 1 from the n-back due to being data outliers.

Table 2. Accuracy data from Simon and n-back tests with and without infrasound (%).

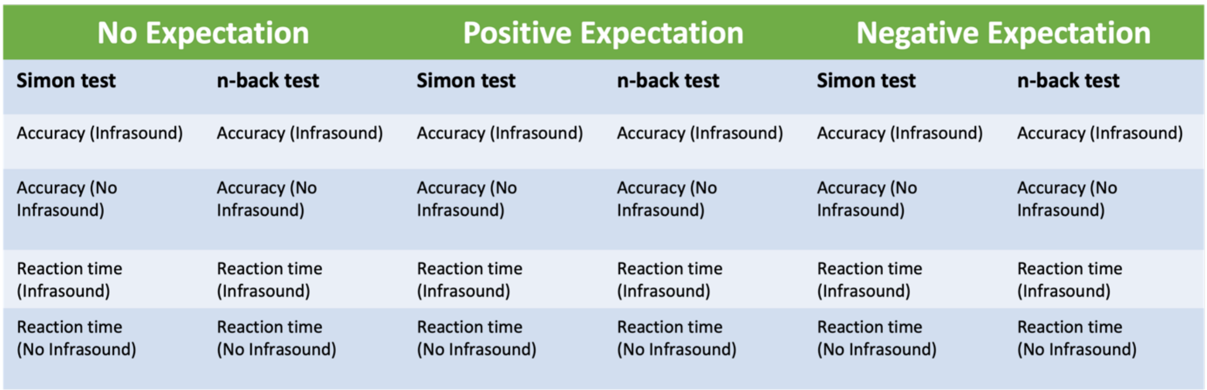
	Mean	N	Std. Deviation
Simon test (no infrasonic sound)	**96.30**	**39**	**2.33**
Simon test (infrasonic sound)	**96.08**	**39**	**2.43**
n-back test (no infrasonic sound)	**91.01**	**39**	**15.43**
n-back test (infrasonic sound)	**91.06**	**39**	**15.48**

No statistically reliable difference between the accuracy levels with the presence and without of infrasonic sound during the Simon Test, $t(38) = .559$, $p = .580$, $d = .089$, BF01 = 5.006, $BF_{10} = 0.19$. No statistically reliable difference between the accuracy levels with the presence and without of infrasonic sound was indicated during the n-back Test, $t(38) = -.068$, $p = .946$, $d = -.011$, BF01 = 5.781, $BF_{10} = 0.17$. Participants of the Simon test showed no change to their accuracy in either group. This was consistent with accuracy during the n-back test, as there was no difference in accuracy between either group here too.

Notes:

It is interesting to note that of 43 participants, 3 (6.9%) were able to detect the presence of a sound (none identified this as infrasonic sound). This is despite being unaware of the infrasonic sound exposure, owing to the pre-task study briefing informing them that it was to gather data on attention spans. The participants broadly described this as a barely audible uncomfortable hum. They were unable to describe any specifics, nor were there any details that were common across all three participants. This information was meant to inform a subsequent study involving the placebo and nocebo effect.

While this subsequent study expanding on the first set of experiments was begun **(Figure F),** it was forced to shut down due to the legislation surrounding the COVID-19 pandemic for the greater part of the following two years. The overall number of participants (n=5) was too few to draw any meaningful conclusion from their results as to what impact their awareness or priming had on performance. The experiment was approved by the School of Psychology Ethics Committee at the University of Leeds (PS-668) **(Appendix ix).** The priming information and debrief for this study are included in the Appendix **(Appendix x and Appendix xi).** Due to prevention of travel, inter-personal meetings, access to labs and national level shutdowns, it was not possible to recruit further participants and continue. The precise nature of the technical setup required to deliver infrasonic sound and other technical aspects meant that the study was unable to pivot to an online model. This was initially attempted using the online experimentation tool GORILLA for experimentation, but was found to be not feasible.



No Expectation		Positive Expectation		Negative Expectation	
Simon test	**n-back test**	**Simon test**	**n-back test**	**Simon test**	**n-back test**
Accuracy (Infrasound)	Accuracy (Infrasound)	Accuracy (Infrasound)	Accuracy (Infrasound)	Accuracy (Infrasound)	Accuracy (Infrasound)
Accuracy (No Infrasound)	Accuracy (No Infrasound)	Accuracy (No Infrasound)	Accuracy (No Infrasound)	Accuracy (No Infrasound)	Accuracy (No Infrasound)
Reaction time (Infrasound)	Reaction time (Infrasound)	Reaction time (Infrasound)	Reaction time (Infrasound)	Reaction time (Infrasound)	Reaction time (Infrasound)
Reaction time (No Infrasound)	Reaction time (No Infrasound)	Reaction time (No Infrasound)	Reaction time (No Infrasound)	Reaction time (No Infrasound)	Reaction time (No Infrasound)

Figure F. Planned expansion of study to include positive and negative expectation (priming) arms.

A larger sample size would have allowed an analysis on this presumed population who are able to detect very low frequency sound, and it may be relevant to determine how prevalent the ability to detect infrasonic sound is in a general population. There is no reliable research to inform this at the time of study.

4. Discussion

This study is to the best of my knowledge the first non fMRI study to look at the direct impact of infrasonic sound on cognition during short term exposure, picking up from exploratory studies using fMRI (Wiechenberger et al., 2015,2017;Dommes et al., 2009) that established the potential for infrasonic sound to have an impact. This study set out to prove that exposure to controlled short bursts of infrasonic sound would have an effect on cognitive functioning in a manner which is measurable through simple reaction time and accuracy (in the absence of priming or expectation). To this end while there was found to be no impact on working memory, there was a statistically signification disruption of attention which was reflected in the form of impaired reaction time in the presence of infrasound.

The increased attentional requirement (cognitive demands) for working memory in the n-back task may have allowed for unconscious sensory gating to suppress the unwanted infrasonic sound as it demanded additional cognitive resources and prevent completion of the task (Nakajima et al., 2019; Miller & Cohen, 2001; Petersen & Posner, 2012). This is potentially why we see that the n-back which had greater demands on working memory (Jaeggi, 2010) was unaffected, whereas the Simon test which was a simple reaction time test was negatively impacted. It is known that auditory stimulus irrelevant to the task can disrupt visual decisions in a Simon task (Simon & Craft, 1970). The task traditionally showing faster reaction times to visual stimuli when compared to auditory stimuli during cross modal stimulus exposure (Donohue et al., 2013). This suggests that the Simon test is more sensitive to auditory interference. Response to the presence of infrasonic sound may vary when faced with differing cognitive demands and the observable stimulation of the central nervous system (Weichenberger et al., 2015; Dommes et al., 2009) does not always correlate directly with behavioural responses.

The Bayes factor finding showing a statistically significant but weak effect, supports the understanding that the effect of infrasonic sound may often be overlooked despite being nearly omnipresent (Ghadiali & Trivedi, 2015). This is because it is largely inaudible to the human auditory system (Berglund et al., 1996) and is easily masked by other sound (Gelfand, 2004). Which means that a non-prominent or subtle impact on cognition would not always be noticeable and subsequently not be attributed to infrasonic sound.

The project initially set out to find out the results of short-term exposure to infrasonic frequencies to better understand how this could be used positively to provide cognitive enhancement by enhancing or inhibiting the presence of infrasonic sound in an environment. The findings of this study could help create a better study or work environment by noting that the infrasonic sound emitted by equipment, machinery, traffic or ambient noise could have a negative impact on attention. Studies in players of esports show that response time may be crucial in skill level (Toth et al., 2019; Hagiwara et al., 2022), and masking or accounting for a detrimental impact to this could therefore be beneficial to performance. This would also be true for driving reaction times, where split section reactions could mean the difference between a fatal crash in non-automated vehicles (Nordhoff et al., 2019). Perhaps most importantly the findings of this study will contribute to the literature on verifiable known attributes of infrasonic sound, to help dispel the unsupported information commonly found in the media (Roosth, 2018).

4.1. Limitations and future directions

While previous studies using fMRI (Weichenberger et al., 2015,2017;Dommes et al., 2009) were able to establish the potential for infrasonic sound to have an effect, but a challenge to this study remained the large amount of sensationalised and unattributed information (Roosth, 2018), not based in scientific research, leading some studies to take negative assumptions as fact (Pierpont, 2009).

The pool of participants could only be used for sets of experiments prior to debrief, as they would then be aware of the presence of the infrasonic sound during experiments. This would have been a useful carryover into the second planned study where participants would be primed (created expectation) using positive or negative information before completing tasks **(Appendix x and Appendix xii)**.

A potential future study would examine the placebo/nocebo effect which the research literature identified as having a potential impact on participants.
Previous studies suggested that positive or negative expectations can have an effect on physiological responses, enhancing, counteracting or even negating the effects of stimuli in alignment with expectation (Crichton, 2014). Tonin et al. (2016) were able to show that

infrasound had no effect reported without priming or expectation during long term exposure, while pre-conceived notions about the potential effects created a sharp rise in reported symptoms.

Infrasonic sound frequencies by nature are quite difficult to effectively create and disseminate due to their being inaudible, the issue of auditory masking and the differing hearing ability of the human population. Individuals may have varying hearing upper and lower limits based on the condition of the auditory and nervous system, these systems begin to change with age (Rogriguez et al., 2014) and as a result being able to perceive infrasonic sound varies. There seems to be a gender and age based disparity regarding frequency perception as well (Moller, 2014;Gelfand, 2004). A thorough testing of how prevalent the ability to detect infrasonic sound (auditory threshold) is in a general population is, would be beneficial to future studies.

Sound has been shown to have an effect on heart rate, pupil dilation and galvanic skin-response when the participant is aware of the sound (Sim et al., 2015;Liao et al., 2016;Engelien et al., 2000). By measuring these individual aspects, we can potentially support the argument of unconscious perception of infrasonic sound and use this data along with hearing threshold to create a baseline of conscious and unconscious perception of infrasonic sound.

4.2. Concluding Remarks

In summary, the experiment was able to provide a conclusion to the proposed effect potential of short term exposure to infrasonic sound (Weichenberger et al., 2015, 2017; Dommes et al., 2009), by showing an increase in average reaction time to stimuli while in the presence of infrasonic sound for some cognitive tasks but not others. A controlled investigation of the effects hypothesised by these studies was carried out as well as an examination of related effects and phenomena. It was determined that accuracy when conducting cognitive tasks like the n-back or Simon test may not affected by the presence of infrasonic frequencies in a significant way. While no change to reaction time was observed in the working memory task, the simple reaction time task showed an increase in average reaction time to stimuli when in the presence of infrasonic sound in an environment requiring computer-based information processing tasks.

As outlined in the introduction and general discussion, the aim of this project was to explore the possibility of a short term impact on cognition, with the added aspect of priming or lack of being involved. Research exploring variations of tasks relating to other forms of cognitive engagement, the impact of priming and the placebo/nocebo effect would be able to create a stronger profile of the potential to impact cognitive capability. Since there is a measurable impact under certain circumstances, the impact of infrasonic sound in other non-controlled environments should be further explored. Regardless of the outcomes of future research, the current study suggests support for the hypothesis that the presence of infrasonic frequencies has a detectable effect on cognition.

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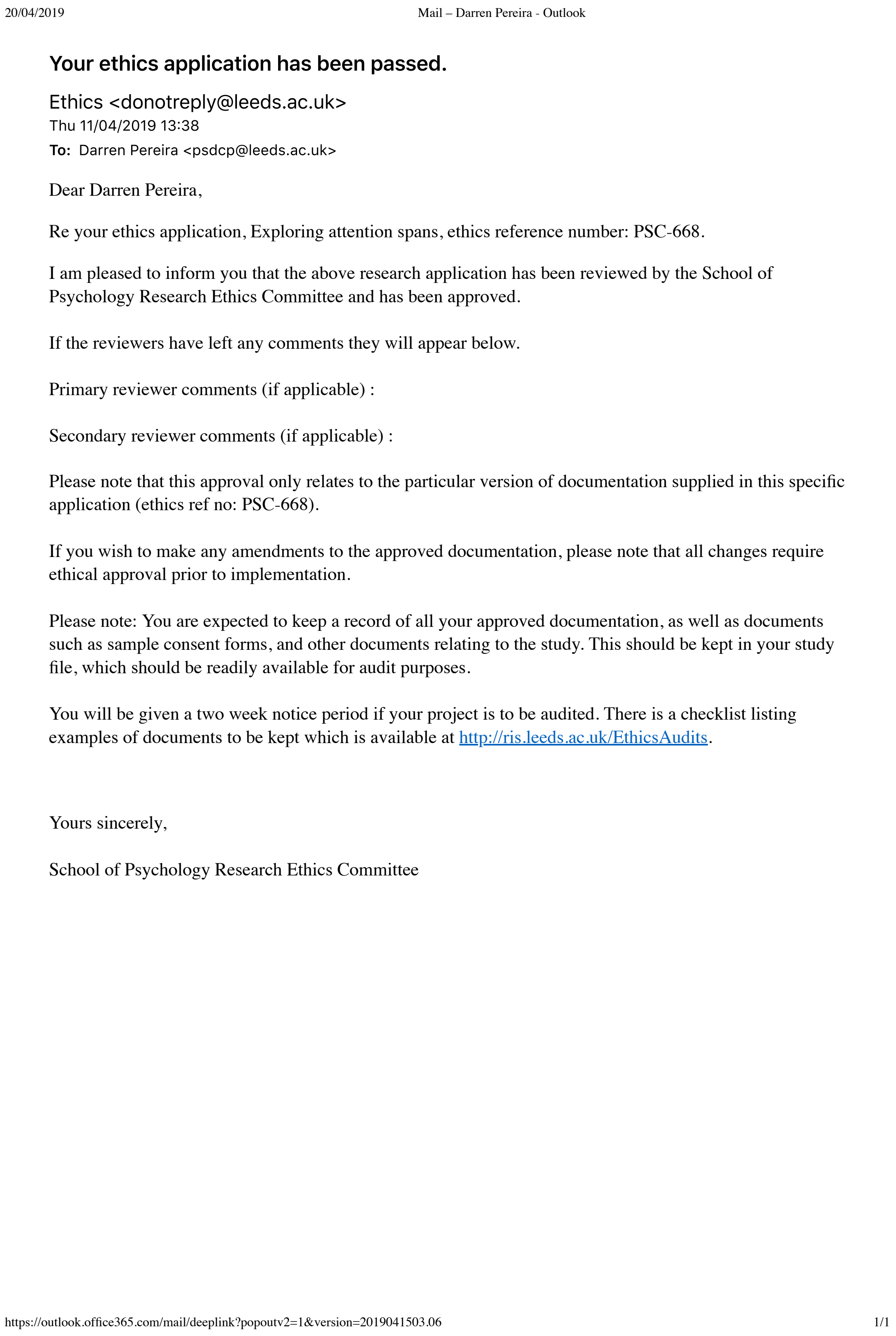
6. Appendices

I. Ethics approval



20/04/2019 Mail – Darren Pereira - Outlook

Your ethics application has been passed.

Ethics <donotreply@leeds.ac.uk>
Thu 11/04/2019 13:38
To: Darren Pereira <psdcp@leeds.ac.uk>

Dear Darren Pereira,

Re your ethics application, Exploring attention spans, ethics reference number: PSC-668.

I am pleased to inform you that the above research application has been reviewed by the School of Psychology Research Ethics Committee and has been approved.

If the reviewers have left any comments they will appear below.

Primary reviewer comments (if applicable) :

Secondary reviewer comments (if applicable) :

Please note that this approval only relates to the particular version of documentation supplied in this specific application (ethics ref no: PSC-668).

If you wish to make any amendments to the approved documentation, please note that all changes require ethical approval prior to implementation.

Please note: You are expected to keep a record of all your approved documentation, as well as documents such as sample consent forms, and other documents relating to the study. This should be kept in your study file, which should be readily available for audit purposes.

You will be given a two week notice period if your project is to be audited. There is a checklist listing examples of documents to be kept which is available at http://ris.leeds.ac.uk/EthicsAudits.

Yours sincerely,

School of Psychology Research Ethics Committee

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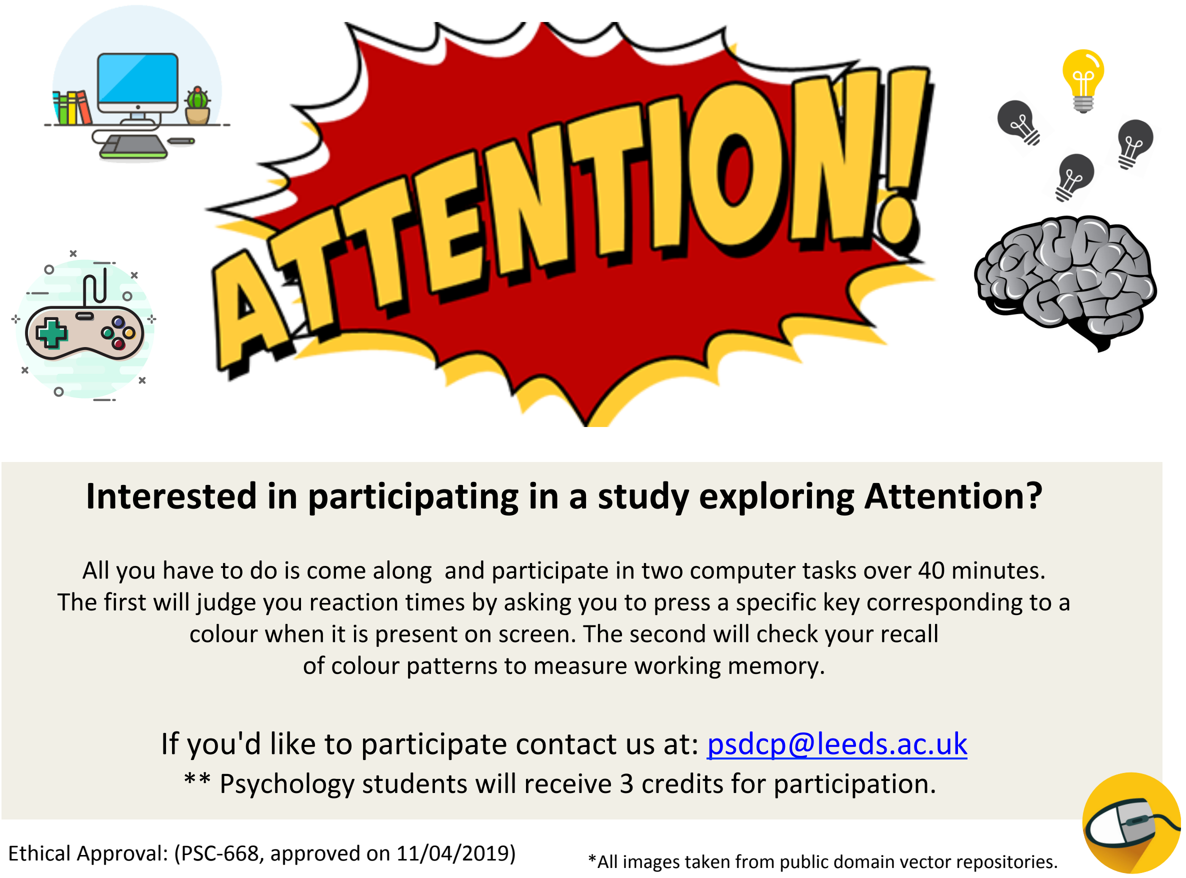
II. Recruitment poster



Interested in participating in a study exploring Attention?

All you have to do is come along and participate in two computer tasks over 40 minutes.
The first will judge you reaction times by asking you to press a specific key corresponding to a colour when it is present on screen. The second will check your recall of colour patterns to measure working memory.

If you'd like to participate contact us at: psdcp@leeds.ac.uk
** Psychology students will receive 3 credits for participation.

Ethical Approval: (PSC-668, approved on 11/04/2019)

*All images taken from public domain vector repositories.

III. Email sent to participant pool

E-mail to be sent using the University of Leeds database:

Subject: £5 or 3 credits for a 40-minute attention study Dear

all,

This experiment aims to investigate attention span. The whole process from start to finish will take 40 minutes and take place in the Psychology labs at the University of Leeds.

You will be asked to attempt tasks on a computer screen for a period no longer that 30 minutes as well as 10 minutes to be allowed for additional questions. The tasks are as follows:

1) A Simon Test which will judge a participants reaction time by asking you to press a specific key corresponding to a colour when it is present on screen.

2) An N-back Test, which will check your recall of colour patterns to measure working memory.

(You will be asked to wear headphones for the duration of the experiment to minimise noise and distraction).

Due to the requirements of the task, all participants must be between the age of 18-40, possess normal hearing, must have normal colour vision and have normal/corrected to normal vision.

If you would like to take part, please email Darren Pereira (psdcp@leeds.ac.uk) to arrange a suitable time.

On the day of the session, please arrive at the main foyer of the Psychology building 5 minutes before the start of your session. You will be met there by a researcher working on the project.

Participants will receive £5 for participating or 3 credits for psychology students.

If you have any questions, please contact Darren Pereira (psdcp@leeds.ac.uk) or Dr Jelena Havelka (0113 343 6695 / J.Havelka@leeds.ac.uk).

The study is organised within the School of Psychology and approved by the School of Psychology Research Ethics Committee

Ethics reference: XXX   Date of approval: XXX

IV. Participant Information Sheet

Ethics Code: xxx
Ethics Approval Date: xx

UNIVERSITY OF LEEDS

Participant Information Sheet

Exploring Attention Spans

I would like to invite you to take part in the above-named study but before you decide it is important for you to understand why the research is being carried out and what it will involve. Please ask if there is anything that is not clear or if you would like more information before deciding whether to take part, contact details are shown at the end of this document. Please read the following information carefully.

Purpose of this study

This study is part of a project working towards my PhD qualification in Psychology. It aims to explore the nature of attention spans possessed by individuals. By doing this we will be able to map the types of attention spans and perhaps uncover patterns.

Who is doing the study?

This study is being undertaken by Mr Darren C Pereira as part of a PhD in the School of Psychology at the University of Leeds, UK. Dr. Jelena Havelka, Dr. Freya Bailes and Dr. Richard Allen from the University of Leeds are supervising this research.

Why have I been asked to participate?

As part of this project, we are seeking to include a wide range of participants that meet the criteria of being between the age of 18-40, possess normal hearing, normal colour vision and possessing normal or corrected to normal vision. You have been invited to participate in this study because you have been identified as belonging to this groups.

What will be involved if I take part in this study?

Your participation in this study is entirely voluntary.

You will be asked to attempt tasks on a computer screen for a period no longer than 30 minutes. There will be an additional 10 minutes for additional questions. The tasks are as follows:

1) A Simon Test which will judge your reaction times by asking you to press a specific key corresponding to a colour when it is present on screen.

2) An n-back Test, which will check your recall of colour patterns to measure working memory.

You will be asked to wear headphones for the duration of the experiment to minimise noise and distraction.

The whole process from start to finish will take 40 minutes and take place in the Psychology laboratory at the University of Leeds.

What are the advantages and disadvantages of taking part?

Your participation in this study will inform the design of future research addressing individual attention spans.

Can I withdraw from the study at any time?

You are under no obligation to take part in the study and you may withdraw at any point. This will mean that your responses will not be used for analysis or any other purpose. You do not need to give a reason for discontinuing. Participants may withdraw from the process at any point during the experiment and can withdraw data up to 30 days after testing. To do so participants will be assigned a participant number which they would quote when requesting the withdrawal of data.

Will the information I give be kept confidential?

The data gathered from the task will be used and kept in a manner that is fully compliant with all current UK and EU data protection laws. All information obtained from you will be anonymised. No personal data will be stored other than your gender and age. None of the data gathered will be passed onto third parties.

All data will be password protected and kept on the password protected secure network of the University of Leeds or encrypted University of Leeds Laptops. Other members of the project that may have access to this data are Dr. Jelena Havelka, Dr. Freya Bailes and Dr. Richard Allen from the University of Leeds.

What will happen to the results of the study?

Your responses will be analysed, along with other participant’s responses. This data will then be analysed and used in conjunction with other data sets to help work towards a final PhD thesis.

Who has reviewed this study?

Ethical approval has been granted by the University of Leeds School of Psychology.

If you would like more information or have any questions or concerns about the study please contact:

Darren Pereira, School of Psychology, Psychology Building, University of Leeds, Leeds, LS2 9JT
Email: psdcp@leeds.ac.uk

Dr Jelena Havelka (PhD supervisor),
Room G. 19, School of Psychology, Psychology Building, University of Leeds,
Leeds, LS2 9JT Email: J.Havelka@leeds.ac.uk
Telephone: +44(0113 343 6695

Thank you for taking the time to read this information sheet

V. Participant Consent Form

UNIVERSITY OF LEEDS

Participant Consent Form

Title of Research Project: Exploring attention spans.

Name of Researcher: Darren Christopher Pereira

Please Initial Box :

1. I confirm that I have read and understand the information sheet dated *[insert date]* explaining the above research project and I have had the opportunity to ask questions about the project. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline. *[insert contact number].* ☐
3. I understand that my responses will be kept strictly confidential. I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research. ☐
4. I agree for the data collected from me to be used in future research ☐
5. I agree to take part in the above research project. ☐

________________________	________________	____________________
Name of Participant (*or legal representative*)	Date	Signature
________________________	________________	____________________
Name of person taking consent (*if different from lead researcher*) *To be signed and dated in presence of the participant*	Date	Signature
________________________	________________	____________________
Lead Researcher	Date	Signature

Date:

Name of Applicant:

VI. Task Instruction Sheet

Task Instruction Sheet

You will be asked to attempt a set of tasks on a computer screen for a period no longer than 30 minutes. There will be an additional 10 minutes for additional questions at the end alongside a debrief.

Each task will be performed twice under the supervision of the researcher, you will leave the room after each attempt so that the task can be reset. The researcher will call you in when the setup is ready for the next attempt.

The Simon Test will judge your reaction times by asking you to press the **green** stickered key or the **red** stickered key corresponding to the colour when it is present on screen.

Speed and accuracy are encouraged.

The n-back Test will check your recall of colour patterns. Press the **blue** stickered key when you see the same colour 2 times after you initially see it (n+2).

Please Note:

This instruction will be explained verbally and will be present in detail on the screen before the start of the attempt. If you do not understand the instructions, please clarify this with the researcher before starting an attempt.

You will be asked to wear headphones for the duration of the experiment to minimise noise and distraction.

The whole process from start to finish will take 40 minutes and take place in the Psychology laboratory at the University of Leeds.

VII. Debrief Information

Exploring Attention Spans

EXPERIMENT DEBRIEF INFORMATION

The impact of infrasonic frequencies on cognition

Environmental noise is universally present in some form in all areas of human, animal, or environmental activity. The effects of exposure to this environmental noise on humans, covers a spectrum, from emotional to physiological**.** Infrasound, sometimes referred to as low-frequency sound, is sound that is lower in frequency than 20 Hz (Hertz) or cycles per second, the "normal" limit of human hearing. However, under certain conditions we may be able to perceive sound at a much lower frequency. While the actual studies related to infrasound are few, they do not often have a conclusive finding on the effect of infrasound on human cognition.

Using the current understanding of the presence of this sound in an environment, our interest was in being able to we may be able to analyse and understand its effect on cognition. For the duration of this study you were either given a positive or negative piece of manufactured (fake) literature. The purpose of this was to create a positive or negative expectation of infrasonic sound. By collecting data pertaining to the changes in accuracy and response times between groups influenced by either positive expectation literature or negative expectation literature, we hope to be able to study the impact that expectation or priming plays on the effect of infrasonic frequencies on cognitive functioning. This is conventionally known as placebo or nocebo.

Thank you for taking the time to read this information sheet.

If you have any further questions, please contact Darren Pereira (psdcp@leeds.ac.uk) or Dr. Jelena Havelka (J.Havelka@leeds.ac.uk).

VIII. Debrief Questionnaire

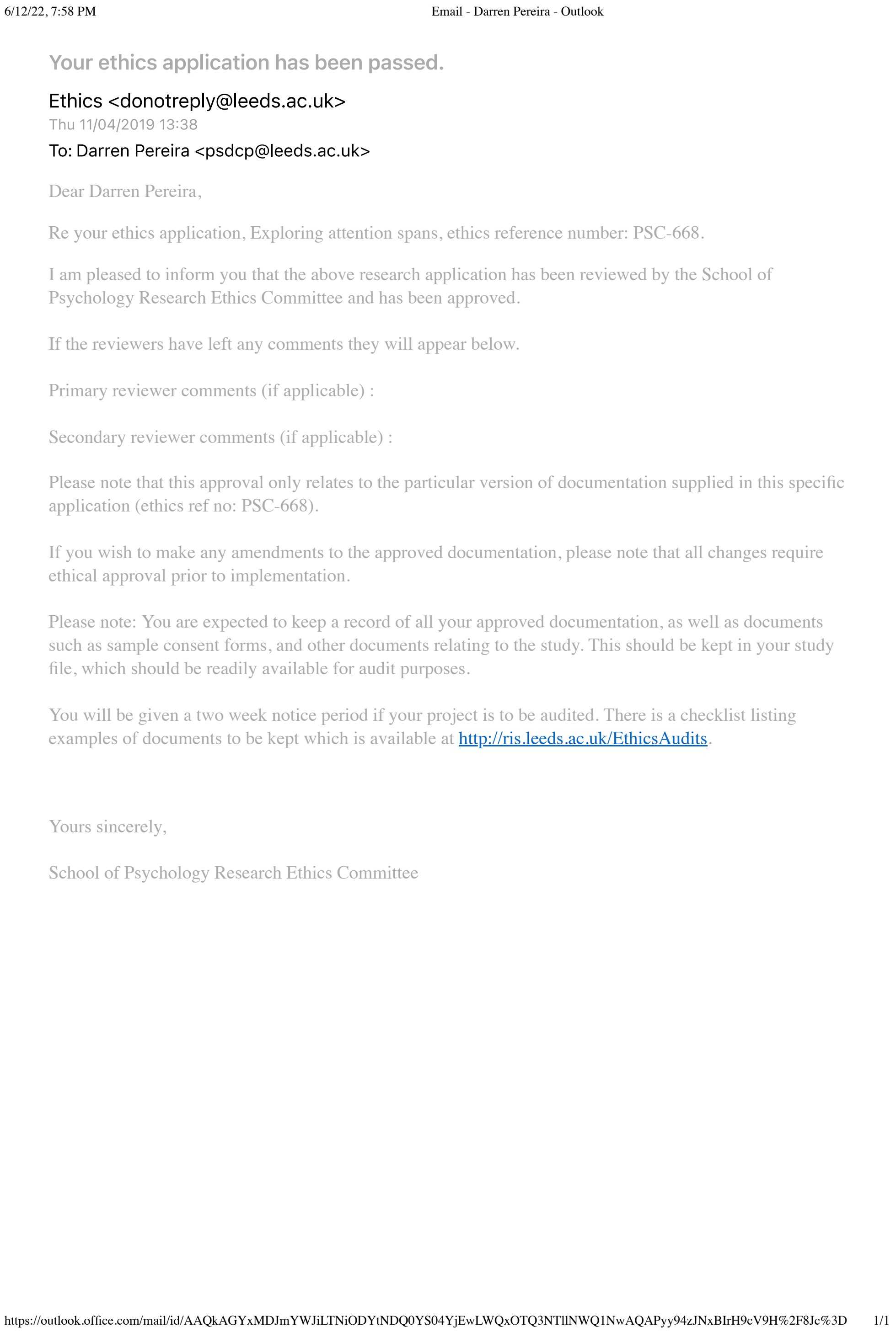
Volunteer Participant xxxx

What did you think the experiment was about?

Did you detect any sound during the experiments?

Other Comments:

IX. Ethics Approval (Placebo /Nocebo)



6/12/22, 7:58 PM Email - Darren Pereira - Outlook

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Yours sincerely,

School of Psychology Research Ethics Committee

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X. Placebo / Nocebo Expectation Text

Additional Material: Placebo / Nocebo text

Positive Expectation

An infrasonic frequency is a low-frequency sound that is below the normal limit of human hearing. Infrasonic frequencies are naturally occurring in nature and studies have shown that they have many positive effects on the human body. Studies have shown that infrasonic sound has a positive impact on cognition by improveing memory, attention and general alertness.

Negative Expectation

An infrasonic frequency is a low-frequency sound that is below the normal limit of human hearing. Infrasonic frequencies are naturally occurring in nature and studies have shown that they have many negative effects on the human body. Studies have shown that infrasonic sound has a negative impact on cognition by impairing memory, attention and general alertness.

XI. Debrief Information (Placebo / Nocebo)

Exploring Attention Spans

EXPERIMENT DEBRIEF INFORMATION

The Impact of Infrasonic Frequencies on Cognition

Infrasound, sometimes referred to as low-frequency sound, is sound that is lower in frequency than 20 Hz (Hertz) or cycles per second, the "normal" limit of human hearing. Using the current understanding of the presence of this sound in an environment, our interest was in being able to we may be able to analyse and understand its effect on cognition. For the duration of this study you were either given a positive or negative piece of manufactured (fake) literature. The purpose of this was to create a positive or negative expectation of infrasonic sound. By collecting data pertaining to the changes in accuracy and response times between groups influenced by either positive expectation literature or negative expectation literature, we hope to be able to study the impact that expectation or priming plays on the effect of infrasonic frequencies on cognitive functioning. This is conventionally known as a placebo or nocebo effect.

Kindly refrain from disclosing any part of this study as this information is highly confidential and disclosing this may influence the outcome of future studies. I am happy to send you the final results of this study for your perusal if you would like me to do so.

Thank you for taking the time to read this information sheet.

If you have any further questions, please contact:
Darren Pereira (psdcp@leeds.ac.uk) or
Dr Jelena Havelka (J.Havelka@leeds.ac.uk)